Building Skills in Python

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A Programmer's Introduction to Python

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Part I

Front Matter

CHAPTER

ONE

PREFACE

The Zen Of Python – Tim Peters

> Beautiful is better than ugly.
> Explicit is better than implicit.
> Simple is better than complex.
> Complex is better than complicated.
> Flat is better than nested.
> Sparse is better than dense.
> Readability counts.
> Special cases aren't special enough to break the rules.
> Although practicality beats purity.
> Errors should never pass silently.
> Unless explicitly silenced.
> In the face of ambiguity, refuse the temptation to guess.
> There should be one– and preferably only one –obvious way to do it.
> Although that way may not be obvious at first unless you're Dutch.
> Now is better than never.
> Although never is often better than *right* now.
> If the implementation is hard to explain, it's a bad idea.
> If the implementation is easy to explain, it may be a good idea.
> Namespaces are one honking great idea – let's do more of those!

1.1 Why Read This Book?

You need this book because you need to learn Python. Here are a few reasons why you might need to learn Python

- You need a programming language which is easy to read and has a vast library of modules focused on solving the problems you're faced with.
- You saw an article about Python specifically, or dynamic languages in general, and want to learn more.
- You're starting a project where Python will be used or is in use.
- A colleague has suggested that you look into Python.
- You've run across a Python code sample on the web and need to learn more.

Python reflects a number of growing trends in software development, putting it at or near the leading edge of good programming languages. It is a very simple language surrounded by a vast library of add-on modules. It is an open source project, supported by many individuals. It is an object-oriented language, binding data and processing into class definitions. It is a platform-independent, scripted language, with complete access

to operating system API's. It supports integration of complex solutions from pre-built components. It is a dynamic language, which avoids many of the complexities and overheads of compiled languages.

This book is a close-to-complete presentation of the Python language. It is oriented toward learning, which involves accumulating many closely intertwined concepts. In our experience teaching, coaching and doing programming, there is an upper limit on the "clue absorption rate". In order to keep within this limit, we've found that it helps to present a language as ever-expanding layers. We'll lead you from a very tiny, easy to understand subset of statements to the entire Python language and all of the built-in data structures. We've also found that doing a number of exercises helps internalize each language concept.

Three Faces of a Language. There are three facets to a programming language: how you write it, what it means, and the additional practical considerations that make a program useful. While many books cover the syntax and semantics of Python, in this book we'll also cover the pragmatic considerations. Our core objective is to build enough language skills that good object-oriented design will be an easy next step.

The *syntax* of a language is covered in the language reference manual available online. In the case of relatively simple languages, like Python, the syntax is simple. We'll provide additional examples of language syntax.

The *semantics* of the language can be a bit more slippery than the syntax. Some languages involve obscure or unique concepts that make it difficult to see what a statement really means. In the case of languages like Python, which have extensive additional *libraries*, the burden is doubled. First, one has to learn the language, then one has to learn the libraries. The number of open source packages made available by the Python community can increase the effort required to understand an entire architecture. The reward, however, is high-quality software based on high-quality components, with a minimum of development and integration effort.

Many languages offer a number of tools that can accomplish the same basic task. Python is no exception. It is often difficult to know which of many alternatives performs better or is easier to adapt. We'll try to focus on showing the most helpful approach, emphasizing techniques that apply for larger development efforts. We'll try to avoid "quick and dirty" solutions that are only appropriate when learning the language.

1.2 Audience

Professional programmers who need to learn Python are our primary audience. We provide specific help for you in a number of ways.

- Since Python is simple, we can address *newbie* programmers who don't have deep experience in a number of other languages. We will call out some details in specific newbie sections. Experienced programmers can skip these sections.
- Since Python has a large number of sophisticated built-in data structures, we address these separately and fully. An understanding of these structures can simplify complex programs.
- The object-orientation of Python provides tremendous flexibility and power. This is a deep subject, and we will provide an introduction to object-oriented programming in this book. More advanced design techniques are addressed in *Building Skills in Object-Oriented Design*, [Lott05].
- The accompanying libraries make it inexpensive to develop complex and complete solutions with minimal effort. This, however, requires some time to understand the packaged components that are available, and how they can be integrated to create useful software. We cover some of the most important modules to specifically prevent programmers from reinventing the wheel with each project.

Instructors are a secondary audience. If you are looking for classroom projects that are engaging, comprehensible, and focus on perfecting language skills, this book can help. Each chapter in this book contains exercises that help students master the concepts presented in the chapter.

This book assumes an basic level of skill with any of the commonly-available computer systems. The following skills will be required.

- Download and install open-source application software. Principally, this is the Python distribution kit from http://www.python.org. However, we will provide references to additional software components.
- Create text files. We will address doing this in **IDLE**, the Python Integrated Development Environment (IDE). We will also talk about doing this with a garden-variety text editor like Komodo, **VIM**, **EMACS**, **TEXTPAD** and **BBEDIT**.
- Run programs from the command-line. This includes the DOS command shell in Microsoft **Windows**, or the **Terminal** tool in **Linux** or Apple's **Macintosh OS X**.
- Be familiar with high-school algebra and some trigonometry. Some of the exercises make heavy use of basic algebra and trigonometry.

When you've finished with this book you should be able to do the following.

- Use of the core procedural programming constructs: variables, statements, exceptions, functions. We will not, for example, spend any time on design of loops that terminate properly.
- Create class definitions and subclasses. This includes managing the basic features of inheritance, as well as overloaded method names.
- Use the Python collection classes appropriately, this includes the various kinds of sequences, and the dictionary.

1.3 Organization of This Book

This book falls into five distinct parts. To manage the clue absorption rate, the first three parts are organized in a way that builds up the language in layers from central concepts to more advanced features. Each layer introduces a few new concepts, and is presented in some depth. Programming exercises are provided to encourage further exploration of each layer. The last two parts cover the extension modules and provide specifications for some complex exercises that will help solidify programming skills.

Some of the chapters include digressions on more advanced topics. These can be skipped, as they cover topics related to programming in general, or notes about the implementation of the Python language. These are reference material to help advanced students build skills above and beyond the basic language.

The first part, *Language Basics* introduces the basic feartures of the Python language, covering most of the statements but sticking with basic numeric data types.

Background and History provides some history and background on Python. *Getting Started* covers installation of Python, using the interpreter interactively and creating simple program files.

Simple Numeric Expressions and Output covers the basic expressions and core numeric types. *Variables, Assignment and Input* introduces variables, assignment and some simple input constructs. *Truth, Comparison and Conditional Processing* adds truth and conditions to the language. *Loops and Iterative Processing*.

In *Functions* we'll add basic function definition and function call constructs; *Additional Notes On Functions* introduces some advanced function call features.

The second part, *Data Structures* adds a number of data structures to enhance the expressive power of the language.

In this part we will use a number of different kinds of objects, prior to designing our own objects. *Sequences: Strings, Tuples and Lists* extends the data types to include various kinds of sequences. These include *Strings* , *Tuples* and *Lists*. *Mappings and Dictionaries* describes mappings and dictionaries. *Exceptions* covers exception objects, and exception creation and handling.

Files covers files and several closely related operating system (OS) services. *Functional Programming with Collections* describes more advanced sequence techniques, including multi-dimensional matrix processing. This part attempts to describe a reasonably complete set of built-in data types.

The third part, *Data + Processing = Objects*, unifies data and processing to define the object-oriented programming features of Python.

Classes introduces basics of class definitions and introduces simple inheritance. *Advanced Class Definition* adds some features to basic class definitions. *Some Design Patterns* extend this discussion further to include several common design patterns that use polymorphism. *Creating or Extending Data Types* describes the mechanism for adding types to Python that behave like the built-in types.

Part four, *Components, Modules and Packages*, describes modules, which provide a higher-level grouping of class and function definitions. It also summarizes selected extension modules provided with the Python environment.

Modules provides basic semantics and syntax for creating modules. We cover the organization of packages of modules in *Packages*. An overview of the Python library is the subject of *The Python Library*. *Complex Strings: the re Module* covers string pattern matching and processing with the `re` module. *Dates and Times: the time and datetime Modules* covers the `time` and `datetime` module. *Programs: Standing Alone* covers the creation of main programs. We touch just the tip of the client-server iceberg in *Architecture: Clients, Servers, the Internet and the World Wide Web*.

Some of the commonly-used modules are covered during earlier chapters. In particular the `math` and `random` modules are covered in *The math Module* and the `string` module is covered in *Strings*. *Files* touches on `fileinput`, `os`, `os.path`, `glob`, and `fnmatch`.

Finally, part five, *Projects*, presents several larger and more complex programming problems. These are ranked from relatively simple to quite complex.

Areas of the Flag covers computing the area of the symbols on the American flag. *Bowling Scores* covers scoring in a game of bowling. *Musical Pitches* has several algorithms for the exact frequencies of musical pitches. *What Can be Computed?* has several exercises related to computability and the basics of finite state machines. *Mah Jongg Hands* describes algorithms for evaluating hands in the game of Maj Jongg. *Chess Game Notation* deals with interpreting the log from a game of chess.

1.4 Limitations

This book can't cover everything Python. There are a number of things which we will not cover in depth, and some things which we can't even touch on lightly. This list will provide you directions for further study.

- The rest of the Python library. The library is a large, sophisticated, rapidly-evolving collection of software components. We selected a few modules that are widely-used. There are many books which cover the library in general, and books which cover specific modules in depth.
- The subject of Object-Oriented (OO) design is the logical next step in learning Python. That topic is covered in *Building Skills in Object-Oriented Design* [Lott05].
- Database design and programming requires a knowledge of Python and a grip on OO design. It requires a digression into the relational model and the SQL language.
- Graphical User Interface (GUI) development requires a knowledge of Python, OO design and database design. There are two commonly-used toolkits: `Tkinter` and `pyGTK`.
- Web application development, likewise, requires a knowledge of Python, OO design and database design. This topic requires digressions into internetworking protocols, specifically HTTP and SOAP, plus HTML, XML and CSS languages. There are numerous web development frameworks for Python.

1.5 Programming Style

We have to adopt a *style* for presenting Python. We won't present a complete set of *coding standards*, instead we'll present examples. This section has some justification of the style we use for the examples in this book.

Just to continune this rant, we find that actual examples speak louder than any of the gratuitously detailed coding standards which are so popular in IT shops. We find that many IT organizations waste considerable time trying to write descriptions of a preferred style. A good example, however, trumps any description. As consultants, we are often asked to provide standards to an inexperienced team of programmers. The programmers only look at the examples (often cutting and pasting them). Why spend money on empty verbiage that is peripheral to the useful example?

One important note: we specifically reject using complex prefixes for variable names. Prefixes are little more than "visual clutter". In many places, for example, an integer parameter with the amount of a bet might be called `pi_amount` where the prefix indicates the scope (*p* for a parameter) and type (*i* for an integer). We reject the '`pi_`' as potentially misleading and therefore uninformative.

This style of name is only appropriate for primitive types, and doesn't address complex data structures well at all. How does one name a parameter that is a list of dictionaries of class instances? '`pldc_`'?

In some cases, prefixes are used to denote the scope of an instance variables. Variable names might include a cryptic one-letter prefix like '`f`' to denote an instance variable; sometimes programmers will use '`my`' or '`the`' as an English-like prefix. We prefer to reduce clutter. In Python, instance variables are always qualified by `self.`, making the scope crystal clear.

All of the code samples were tested on Python 2.6 for MacOS, using an iMac running MacOS 10.5. Additional testing of all code was done with Windows 2000 on a Dell Latitude laptop as well as a VMWare implementation of Fedora 11.

1.6 Conventions Used in This Book

Here is a typical Code sample.

Typical Python Example

```
combo = { }
for i in range(1,7):
    for j in range(1,7):
        roll= i+j
        combo.setdefault( roll, 0 )
        combo[roll] += 1
for n in range(2,13):
    print "%d %.2f%%" % ( n, combo[n]/36.0 )
```

1. This creates a Python dictionary, a map from key to value. If we initialize it with something like the following: '`combo = dict( [ (n,0) for n in range(2,13) ] )`' , we don't need the `setdefault()` function call below.
2. This assures that the rolled number exists in the dictionary with a default frequency count of 0.
3. Print each member of the resulting dictionary. Something more obscure like '`[ (n,combo[n]/36.0) for n in range(2,13)]`' is certainly possible.

The output from the above program will be shown as follows:

```
2 0.03%
3 0.06%
4 0.08%
5 0.11%
6 0.14%
7 0.17%
8 0.14%
9 0.11%
10 0.08%
11 0.06%
12 0.03%
Tool completed successfully
```

We will use the following type styles for references to a specific `Class`, `method()`, `attribute`, which includes both class variables or instance variables.

Sidebars

When we do have a significant digression, it will appear in a sidebar, like this.

Tip: tip

There will be design tips, and warnings, in the material for each exercise. These reflect considerations and lessons learned that aren't typically clear to starting OO designers.

1.7 Acknowledgements

I'd like to thank Carl Frederick for asking me if I was using Python to develop complex applications. At the time, I said I'd have to look into it. This is the result of that investigation.

I am indebted to Thomas Pautler, Jim Bullock, Michaël Van Dorpe, Matthew Curry, Igor Sakovich, Drew, John Larsen, Robert Lucente, Lex Hider, John Nowlan and Tom Elliott for supplying much-needed corrections to errors in previous editions.

John Hayes provided particular complete and meticulous copy-editing.

Part II

Language Basics

The Processing View

A programming language involves two closely interleaved topics. On one hand, there are the *procedural* constructs that process information inside the computer, with visible effects on the various external devices. On the other hand are the various types of data structures and relationships for organizing the information manipulated by the program.

This part describes the most commonly-used Python statements, sticking with basic numeric data types. *Data Structures* will present a reasonably complete set of built-in data types and features for Python. While the two are tightly interwoven, we pick the statements as more fundamental because we can (and will) add new data types. Indeed, the essential thrust of object-oriented programming (covered in *Data + Processing = Objects*) is the creation of new data types.

Some of the examples in this part refer to the rules of various common casino games. Knowledge of casino gambling is not essential to understanding the language or this part of the book. We don't endorse casino gambling. Indeed, many of the exercises reveal the magnitude of the house edge in most casino games. However, casino games have just the right level of algorithmic complexity to make for excellent programming exercises.

We'll provide a little background on Python in *Background and History*. From there, we'll move on to installing Python in *Python Installation*.

In *Simple Numeric Expressions and Output* we'll introduce the **print** statement (and `print()` function); we'll use this to see the results of arithmetic expressions including the numeric data types, operators, conversions, and some built-in functions. We'll expand on this in *Advanced Expressions*.

We'll introduce variables, the assignment statement, and input in *Variables, Assignment and Input*, allowing us to create simple input-process-output programs. When we add truth, comparisons, conditional processing in *Truth, Comparison and Conditional Processing*, and iteration in *Loops and Iterative Processing*, we'll have all the tools necessary for programming. In *Functions* and *Additional Notes On Functions*, we'll show how to define and use functions, the first of many tools for organizing programs to make them understandable.

CHAPTER

TWO

BACKGROUND AND HISTORY

History of Python and Comparison with Other Languages

This chapter describes the history of Python in *History*. The *Features of Python* is an overview of the features of Python. After that, *Comparisons* is a subjective comparison between Python and a few other other languages, using some quality criteria harvested from two sources: the *Java Language Environment White Paper* and *On the Design of Programming Languages*. This material can be skipped by newbies: it doesn't help explain Python, it puts it into a context among other programming languages.

2.1 History

Python is a relatively simple programming language that includes a rich set of supporting libraries. This approach keeps the language simple and reliable, while providing specialized feature sets as separate extensions.

Python has an easy-to-use syntax, focused on the programmer who must type in the program, read what was typed, and provide formal documentation for the program. Many languages have syntax focused on developing a simple, fast compiler; but those languages may sacrifice readability and writability. Python strikes a good balance between fast compilation, readability and writability.

Python is implemented in C, and relies on the extensive, well understood, portable C libraries. It fits seamlessly with Unix, Linux and POSIX environments. Since these standard C libraries are widely available for the various MS-Windows variants, and other non-POSIX operating systems, Python runs similarly in all environments.

The Python programming language was created in 1991 by Guido van Rossum based on lessons learned doing language and operating system support. Python is built from concepts in the ABC language and Modula-3. For information ABC, see *The ABC Programmer's Handbook* [Geurts91], as well as http://www.cwi.nl/~steven/abc/. For information on Modula-3, see *Modula-3* [Harbison92], as well as http://www.research.compaq.com/SRC/modula-3/html/home.html.

The current Python development is centralized at http://www.python.org.

2.2 Features of Python

Python reflects a number of growing trends in software development. It is a very simple language surrounded by a vast library of add-on modules. It is an open source project, supported by dozens of individuals. It is an object-oriented language. It is a platform-independent, scripted language, with complete access to operating

system API 's. It supports integration of complex solutions from pre-built components. It is a dynamic language, allowing more run-time flexibility than statically compiled languages.

Additionally, Python is a scripting language with full access to Operating System (OS) services. Consequently, Python can create high level solutions built up from other complete programs. This allows someone to integrate applications seamlessly, creating high-powered, highly-focused meta-applications. This kind of very-high-level programming (*programming in the large*) is often attempted with shell scripting tools. However, the programming power in most shell script languages is severely limited. Python is a complete programming language in its own right, allowing a powerful mixture of existing application programs and unique processing to be combined.

Python includes the basic text manipulation facilities of Awk or Perl. It extends these with extensive OS services and other useful packages. It also includes some additional data types and an easier-to-read syntax than either of these languages.

Python has several layers of program organization. The Python package is the broadest organizational unit; it is collection of modules. The Python module, analogous to the Java package, is the next level of grouping. A module may have one or more classes and free functions. A class has a number of static (class-level) variables, instance variables and methods. We'll lookl at these layers in detail in appropriate sections.

Some languages (like COBOL) have features that are folded into the language itself, leading to a complicated mixture of core features, optional extensions, operating-system features and special-purpose data structures or algorithms. These poorly designed languages may have problems with portability. This complexity makes these languages hard to learn. One hint that a language has too many features is that a language subset is available. Python suffers from none of these defects: the language has only about 24 statements (of which five are declaratory in nature), the compiler is simple and portable. This makes the the language is easy to learn, with no need to create a simplified language subset.

2.3 Comparisons

We'll measure Python with two yardsticks. First, we'll look at a yardstick originally used for Java. Then we'll look at yardstick based on experience designing Modula-2.

2.3.1 The Java Yardstick

The *Java Language Environment White Paper* [Gosling96] lists a number of desirable features of a programming language:

- Simple and Familiar
- Object-Oriented
- Secure
- Interpreted
- Dynamic
- Architecture Neutral
- Portable
- Robust
- Multithreaded
- Garbage Collection
- Exceptions

- High Performance

Python meets and exceeds most of these expectations. We'll look closely at each of these twelve desireable attributes.

Simple and Familiar. By simple, we mean that there is no GOTO statement, we don't need to explicitly manage memory and pointers, there is no confusing preprocessor, we don't have the aliasing problems associated with unions. We note that this list summarizes the most confusing and bug-inducing features of the C programming language.

Python is simple. It relies on a few core data structures and statements. The rich set of features is introduced by explicit import of extension modules. Python lacks the problem-plagued GOTO statement, and includes the more reliable **break**, **continue** and exception **raise** statements. Python conceals the mechanics of object references from the programmer, making it impossible to corrupt a pointer. There is no language preprocessor to obscure the syntax of the language. There is no C-style union (or COBOL-style REDEFINES) to create problematic aliases for data in memory.

Python uses an English-like syntax, making it reasonably familiar to people who read and write English or related languages. There are few syntax rules, and ordinary, obvious indentation is used to make the structure of the software very clear.

Object-Oriented. Python is object oriented. Almost all language features are first class objects, and can be used in a variety of contexts. This is distinct from Java and C++ which create confusion by having objects as well as primitive data types that are not objects. The built-in `type()` function can interrogate the types of all objects. The language permits creation of new object classes. It supports single and multiple inheritance. Polymorphism is supported via run-time interpretation, leading to some additional implementation freedoms not permitted in Java or C++.

Secure. The Python language environment is reasonably secure from tampering. Pre-compiled python modules can be distributed to prevent altering the source code. Additional security checks can be added by supplementing the built-in `__import__()` function.

Many security flaws are problems with operating systems or framework software (for example, database servers or web servers). There is, however, one prominent language-related security problem: the "buffer overflow" problem, where an input buffer, of finite size, is overwritten by input data which is larger than the available buffer. Python doesn't suffer from this problem.

Python is a dynamic language, and abuse of features like the **exec** statement or the `eval()` function can introduce security problems. These mechanisms are easy to identify and audit in a large program.

Interpreted. An interpreted language, like Python allows for rapid, flexible, exploratory software development. Compiled languages require a sometimes lengthy edit-compile-link-execute cycle. Interpreted languages permit a simpler edit-execute cycle. Interpreted languages can support a complete debugging and diagnostic environment. The Python interpreter can be run interactively; which can help with program development and testing.

The Python interpreter can be extended with additional high-performance modules. Also, the Python interpreter can be embedded into another application to provide a handy scripting extension to that application.

Dynamic. Python executes dynamically. Python modules can be distributed as source; they are compiled (if necessary) at import time. Object messages are interpreted, and problems are reported at run time, allowing for flexible development of applications.

In C++, any change to centrally used class headers will lead to lengthy recompilation of dependent modules. In Java, a change to the public interface of a class can invalidate a number of other modules, leading to recompilation in the best case, or runtime errors in the worst case.

Portable. Since Python rests squarely on a portable C source, Python programs behave the same on a variety of platforms. Subtle issues like memory management are completely hidden. Operating system

inconsistency makes it impossible to provide perfect portability of every feature. Portable GUI's are built using the widely-ported Tk GUI tools `Tkinter`, or the GTK+ tools and the the `pyGTK` bindings.

Robust. Programmers do not directly manipulate memory or pointers, making the language run-time environment very robust. Errors are raised as exceptions, allowing programs to catch and handle a variety of conditions. All Python language mistakes lead to simple, easy-to-interpret error messages from exceptions.

Multithreaded. The Python `threading` module is a Posix-compliant threading library. This is not completely supported on all platforms, but does provide the necessary interfaces. Beyond thread management, OS process management is also available, as are execution of shell scripts and other programs from within a Python program.

Additionally, many of the web frameworks include thread management. In products like TurboGears, individual web requests implicitly spawn new threads.

Garbage Collection. Memory-management can be done with explicit deletes or automated garbage collection. Since Python uses garbage collection, the programmer doesn't have to worry about memory leaks (failure to delete) or dangling references (deleting too early).

The Python run-time environment handles garbage collection of all Python objects. Reference counters are used to assure that no live objects are removed. When objects go out of scope, they are eligible for garbage collection.

Exceptions. Python has exceptions, and a sophisticated **try** statement that handles exceptions. Unlike the standard C library where status codes are returned from some functions, invalid pointers returned from others and a global error number variable used for determining error conditions, Python signals almost all errors with an exception. Even common, generic OS services are *wrapped* so that exceptions are raised in a uniform way.

High Performance. The Python interpreter is quite fast. However, where necessary, a class or module that is a bottleneck can be rewritten in C or C++, creating an extension to the runtime environment that improves performance.

2.3.2 The Modula-2 Yardstick

One of the languages which strongly influenced the design of Python was Modula-2. In 1974, N. Wirth (creator of Pascal and its successor, Modula-2) wrote an article *On the Design of Programming Languages* [Wirth74], which defined some timeless considerations in designing a programming language. He suggests the following:

- a language be easy to learn and easy to use;
- safe from misinterpretation;
- extensible without changing existing features;
- machine [*platform*] independent;
- the compiler [*interpreter*] must be fast and compact;
- there must be ready access to system services, libraries and extensions written in other languages;
- the whole package must be portable.

Python syntax is designed for readability; the language is quite simple, making it easy to learn and use. The Python community is always alert to ways to simplify Python. The Python 3.0 project is actively working to remove a few poorly-concieved features of Python. This will mean that Python 3.0 will be simpler and easier to use, but incompatible with Python 2.x in a few areas.

Most Python features are brought in via modules, assuring that extensions do not change or break existing features. This allows tremendous flexibility and permits rapid growth in the language libraries.

The Python interpreter is very small. Typically, it is smaller than the Java Virtual Machine. Since Python is (ultimately) written in C, it has the same kind of broad access to external libraries and extensions. Also, this makes Python completely portable.

2.4 Some Jargon

For folks new to developing software, it might help to understand a few distinctions made above.

- Interperted
- Not Interpreted (i.e., Compiled)

Python is a *byte-code interpreter*. A Python `code` object is a sequence of bytes that represent various operations and values. The Python interpreter steps through the bytes, performing the operations.

A compiled language (e.g., C, C++, etc.) is translated from source form to executable binary specific to operating system and hardware platform.

Java is similar to Python: it's compiled and the Java Virtual Machine is a byte-code interpreter.

- Dynamic
- Not Dynamic (i.e., Static)

Python is a dynamic language. Variables and functions do not have defined data types. Instead, a variable is simply a label attached to an object. A function is a callable object with parameters, but no declared result type. Each object has a strongly-defined permanent class.

There is no sophisticated compile-time type checking. Instead, any type mismatches will be detected at run-time. Since many types are nearly interchangeable, there isn't a need for a lot of type checking. For examples of interchangeable ("polymorphic") types, see *Simple Numeric Expressions and Output*.

Languages like C, C++ and Java have statically-declared variables and functions.

- Scripting
- Non-Scripting

The "scripting" distinction is an operational feature of POSIX-compliant operating systems. Files which begin with the '`#!/path/to/interpreter`' will be used as scripts by the OS. They can be executed from the command-line because the interpreter is named in the first line of the file.

Languages like Java, C and C++ do not have this feature; these files must be compiled before they can be executed.

CHAPTER

THREE

PYTHON INSTALLATION

Downloading, Installing and Upgrading Python

This chapter is becoming less and less relevant as Python comes pre-installed with most Linux-based operating systems. Consequently, the most interesting part of this chapter is the *Windows Installation*, where we describe downloading and installing Python on Windows.

Python runs on a wide, wide variety of platforms. If your particular operating system isn't described here, refer to http://www.python.org/community/ to locate an implementation.

Mac OS developers will find it simplest to upgrade to Leopard (Max OS 10.5) or Snow Leopard (Mac OS 10.6), since it has Python included. The Mac OS installation includes the complete suite of tools. We'll look at upgrading in *Macintosh Installation*.

For other GNU/Linux developers, you'll find that Python is generally included in most distributions. Further, many Linux distributions automatically upgrade their Python installation. For example, Fedora Core 11 includes Python 2.6 and installs upgrades as they become available. You can find installation guidelines in *GNU/Linux and UNIX Overview*.

The Goal. The goal of installation is to get the Python interpreter and associated libraries. Windows users will get a program called `python.exe`. Linux and MacOS users will get the Python interpreter, a program named `python`.

In addition to the libraries and the interpreter, your Python installation comes with a tutorial document (also available at http://docs.python.org/tutorial/) on Python that will step you through a number of quick examples. For newbies, this provides an additional point of view that you may find helpful. You may also want to refer to the Beginner's Guide Wiki at http://wiki.python.org/moin/BeginnersGuide.

3.1 Windows Installation

In some circumstances, your Windows environment may require administrator privilege. The details are beyond the scope of this book. If you can install software on your PC, then you have administrator privileges. In a corporate or academic environment, someone else may be the administrator for your PC.

The Windows installation of Python has three broad steps.

1. Pre-installation: make backups and download the installation kit.
2. Installation: install Python.
3. Post-installation: check to be sure everything worked.

We'll go through each of these in detail.

3.1.1 Windows Pre-Installation

Backup. Before installing software, back up your computer. I strongly recommend that you get a tool like Norton's **Ghost** (http://www.symantec.com/norton/ghost) or **clonezilla** (http://clonezilla.org/).

Products like these will create a CD that you can use to reconstruct the operating system on your PC in case something goes wrong. It is difficult to undo an installation in Windows, and get your computer back the way it was before you started.

I've never had a single problem installing Python. I've worked with a number of people, however, who either have bad luck or don't read carefully and have managed to corrupt their Windows installation by downloading and installing software. While Python is safe, stable, reliable, virus-free, and well-respected, you may be someone with bad luck who has a problem. Often the problem already existed on your PC and installing Python was the straw that broke the camel's back. A backup is cheap insurance.

You should also have a folder for saving your downloads. You can create a folder in `My Documents` called `downloads`. I suggest that you keep all of your various downloaded tools and utilities in this folder for two reasons. If you need to reinstall your software, you know exactly what you downloaded. When you get a new computer (or an additional computer), you know what needs to be installed on that computer.

Download. After making a backup, go to the http://www.python.org web site and look for the Download area. In here, you're looking for the pre-built Windows installer. This book will emphasize Python 2.6. In that case, the kit will have a filename like `python-2.6.x.msi`. When you click on the filename, your browser should start downloading the file. Save it in your `downloads` folder.

Backup. Now is a good time to make a second backup. Seriously. This backup will have your untouched Windows system, plus the Python installation kit. It is still cheap insurance.

If you have anti-virus software [*you do, don't you?*] you may need to disable this until you are done installing Python.

At this point, you have everything you need to install Python:

- A backup
- The Python installer

3.1.2 Windows Installation

You'll need two things to install Python. If you don't have both, see the previous section on pre-installation.

- A backup
- The Python installer

Double-click the Python installer (`python-2.6.x.msi`).

The first step is to select a destination directory. The default destination should be `C:\Python26` . Note that Python does not expect to live in the `C:\My Programs` folder. Because the `My Programs` folder has a space in the middle of the name – something that is atypical for all operating systems other than Windows – subtle problems can arise. Consequently, Python folks prefer to put Python into `C:\Python26` on Windows machines. Click **Next** to continue.

If you have a previous installation, then the next step is to confirm that you want to backup replaced files. The option to make backups is already selected and the folder is usually `C:\Python26\BACKUP`. This is the way it should be. Click **Next** to continue.

The next step is the list of components to install. You have a list of five components.

- Python interpreter and libraries. You want this.

- Tcl/Tk (Tkinter, IDLE, pydoc). You want this, so that you can use IDLE to build programs.
- Python HTML Help file. This is some reference material that you'll probably want to have.
- Python utility scripts (Tools/). We won't be making any use of this in this book. In the long run, you'll want it.
- Python test suite (Lib/test/). We won't make any use of this, either. It won't hurt anything if you install it.

There is an **Advanced Options...** button that is necessary if you are using a company-supplied computer for which you are not the administrator. If you are not the administrator, and you have permission to install additional software, you can click on this button to get the Advanced Options panel. There's a button labeled **Non-Admin install** that you'll need to click in order to install Python on a PC where you don't have administrator privileges.

Click **Next** to continue.

You can pick a Start Menu Group for the Python program, IDLE and the help files. Usually, it is placed in a menu named `Python 2.6`. I can't see any reason for changing this, since it only seems to make things harder to find. Click **Next** to continue.

The installer puts files in the selected places. This takes less than a minute.

Click **Finish** ; you have just installed **Python** on your computer.

Tip: Debugging Windows Installation

The only problem you are likely to encounter doing a Windows installation is a lack of administrative privileges on your computer. In this case, you will need help from your support department to either do the installation for you, or give you administrative privileges.

3.1.3 Windows Post-Installation

In your **Start...** menu, under **All Programs** , you will now have a **Python 2.6** group that lists five things:

- IDLE (Python GUI)
- Module Docs
- Python (command line)
- Python Manuals
- Uninstall Python

Important: Testing

If you select the **Python (command line)** menu item, you'll see the '`Python (command line)`' window. This will contain something like the following.

```
Python 2.6.2 (r262:71605, Apr 14 2009, 22:40:02) [MSC v.1500 32 bit (Intel)] on
win32
Type "help", "copyright", "credits" or "license" for more information.
>>> ^Z
```

If you hit `Ctrl-Z` and then `Enter` , Python will exit. The basic **Python** program works. You can skip to *Getting Started* to start using Python.

If you select the **Python Manuals** menu item, this will open a Microsoft Help reader that will show the complete Python documentation library.

3.2 Macintosh Installation

Python is part of the MacOS environment. Tiger (Mac OS 10.4) includes Python 2.3.5 and IDLE. Leopard (Mac OS 10.5) includes Python 2.5.1. Snow Leopard (Mac OS 10.6) includes Python 2.6.

Generally, you don't need to do much to get started. You'll just need to locate the various Python files. Look in `/System/Library/Frameworks/Python.Framework/Versions` for the relevant files.

In order to upgrade software in the Macintosh OS, you must know the administrator, or "owner" password. If you are the person who installed or initially setup the computer, you had to pick an owner password during the installation. If someone else did the installation, you'll need to get the password from them.

A Mac OS upgrade of Python has three broad steps.

1. Pre-upgrade: make backups and download the installation kit.
2. Installation: upgrade Python.
3. Post-installation: check to be sure everything worked.

We'll go through each of these in detail.

3.2.1 Macintosh Pre-Installation

Before installing software, back up your computer. While you can't easily burn a DVD of everything on your computer, you can usually burn a DVD of everything in your personal Mac OS X Home directory.

I've never had a single problem installing Python. I've worked with a number of people, however, who either have bad luck or don't read carefully and have managed to corrupt their Mac OS installation by downloading and installing software. While Python is safe, stable, reliable, virus-free, and well-respected, you may be someone with bad luck who has a problem. A backup is cheap insurance.

Download. After making a backup, go to the http://www.python.org web site and look for the Download area. In here, you're looking for the pre-built Mac OS X installer. This book will emphasize Python 2.6. In that case, the kit filename will start with `python-2.6.2.macosx`. Generally, the filename will have a date embedded in it and look like `python-2.6.2.macosx2009-04-16.dmg` When you click on the filename, your browser should start downloading the file. Save it in your `Downloads` folder.

Backup. Now is a good time to make a second backup. Seriously. It is still cheap insurance.

At this point, you have everything you need to install Python:

- A backup
- The Python installer

3.2.2 Macintosh Installation

When you double-click the `python-2.6.2-macosx2009-04-16.dmg`, it will create a disk image named `Universal MacPython 2.6.x` . This disk image has your license, a ReadMe file, and the `MacPython.mpkg`.

When you double-click the `MacPython.mpkg` fie, it will take all the necessary steps to install Python on your computer. The installer will take you through seven steps. Generally, you'll read the messages and click **Continue**.

Introduction. Read the message and click **Continue**.

Read Me. This is the contents of the ReadMe file on the installer disk image. Read the message and click **Continue**.

License. You can read the history of Python, and the terms and conditions for using it. To install Python, you must agree with the license. When you click **Continue** , you will get a pop-up window that asks if you agree. Click **Agree** to install Python.

Select Destination. Generally, your primary disk drive, usually named `Macintosh HD` will be highlighted with a green arrow. Click **Continue**.

Installation Type. If you've done this before, you'll see that this will be an upgrade. If this is the first time, you'll be doing an install. Click the **Install** or **Upgrade** button.

You'll be asked for your password. If, for some reason, you aren't the administrator for this computer, you won't be able to install software. Otherwise, provide your password so that you can install software.

Finish Up. The message is usually "The software was successfully installed". Click **Close** to finish.

3.2.3 Macintosh Post-Installation

In your Applications folder, you'll find a `MacPython 2.6` folder, which contains a number of applications.

- BuildApplet
- Extras
- IDLE
- PythonLauncher
- Update Shell Profile.command

Look in `/System/Library/Frameworks/Python.Framework/Versions` for the relevant files. In the `bin` , `Extras` and `Resources` directories you'll find the various applications. The `bin/idle` file will launch IDLE for us.

Once you've finished installation, you should check to be sure that everything is working correctly.

Important: Testing

From the terminal you can enter the **python** command.

You should see the following

```
MacBook-5:~ slott$ python
Python 2.6.3 (r263:75184, Oct  2 2009, 07:56:03)
[GCC 4.0.1 (Apple Inc. build 5493)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

Enter end-of-file `ctrl-D` to exit from Python.

3.3 GNU/Linux and UNIX Overview

In *Checking for Python* we'll provide a procedure for examining your current configuration to see if you have Python in the first place. If you have Python, and it's version 2.6, you're all done. Otherwise, you'll have to determine what tools you have for doing an installation or upgrade.

- If you have Yellowdog Updater Modified (**YUM**) see *YUM Installation*.
- If you have one of the GNU/Linux variants that uses the Red Hat Package Manager (**RPM**), see *RPM Installation*.

- The alternative to use the source installation procedure in *"Build from Scratch" Installation*.

Root Access. In order to install software in GNU/Linux, you must know the administrator, or "root" password. If you are the person who installed the GNU/Linux, you had to pick an administrator password during the installation. If someone else did the installation, you'll need to get the password from them.

Normally, we never log in to GNU/Linux as `root` except when we are installing software. In this case, because we are going to be installing software, we need to log in as `root`, using the administrative password.

If you are a GNU/Linux newbie and are in the habit of logging in as `root`, you're going to have to get a good GNU/Linux book, create another username for yourself, and start using a proper username, not `root`. When you work as `root`, you run a terrible risk of damaging or corrupting something. When you are logged on as anyone other than `root`, you will find that you can't delete or alter important files.

Unix is not Linux. For non-Linux commercial Unix installations (**Solaris**, **AIX**, **HP/UX**, etc.), check with your vendor (Oracle/Sun, IBM, HP, etc.) It is very likely that they have an extensive collection of open source projects like Python pre-built for your UNIX variant. Getting a pre-built kit from your operating system vendor is an easy way to install Python.

3.3.1 Checking for Python

Many GNU/Linux and Unix systems have Python installed. On some older Linuxes *[Linuxi? Lini? Linen?]* there may be an older version of Python that needs to be upgraded. Here's what you do to find out whether or not you already have Python.

We can't easily cover all variations. We'll use Fedora as a typical Linux distribution.

Run the **Terminal** tool. You'll get a window which prompts you by showing something like '`[slott@linux01 slott]$`' . In response to this prompt, enter '`env python`', and see what happens.

Here's what happens when Python is not installed.

```
[slott@linux01 slott]$ env python
tcsh: python: not found
```

Here's what you see when there is a properly installed, but out-of-date Python on your GNU/Linux box.

```
[slott@linux01 slott]$ env python
Python 2.3.5 (#1, Mar 20 2005, 20:38:20)
[GCC 3.3 20030304 (Apple Computer, Inc. build 1809)] on darwin
Type "help", "copyright", "credits" or "license" for more
information.
>>> ^D
```

We used an ordinary end-of-file (`Control-D`) to exit from Python.

In this case, the version number is 2.3.5, which is good, but we need to install an upgrade.

3.3.2 YUM Installation

If you are a Red Hat or Fedora user, you likely have a program named **Yum**. If you don't have Yum, you should upgrade to Fedora Core 11.

Note that Yum repositories do not cover every combination of operating system and Python distribution. In these cases, you should consider an operating system upgrade in order to introduce a new Python distribution.

If you have an out-of-date Python, you'll have to enter two commands in the Terminal window.

```
yum upgrade python
yum install tkinter
```

The first command will upgrade the Python 2.6 distribution. You can use the command " '`install`' " instead of " '`upgrade`' " in the unlikely event that you somehow have Yum, but don't have Python.

The second command will assure that the extension package named `tkinter` is part of your Fedora installation. It is not, typically, provided automatically. You'll need this to make use of the **IDLE** program used extensively in later chapters.

In some cases, you will also want a packaged called the "Python Development Tools". This includes some parts that are used by Python add-on packages.

3.3.3 RPM Installation

Many variants of GNU/Linux use the Red Hat Package Manager (RPM). The **rpm** tool automates the installation of software and the important dependencies among software components. If you don't know whether on not your GNU/Linux uses the Red Hat Package manager, you'll have to find a GNU/Linux expert to help you make that determination.

Red Hat Linux (and the related Fedora Core distributions) have a version of Python pre-installed. Sometimes, the pre-installed Python is an older release and needs an upgrade.

This book will focus on Fedora Core GNU/Linux because that's what I have running. Specifically, Fedora Core 8. You may have a different GNU/Linux, in which case, this procedure is close, but may not be precisely what you'll have to do.

The Red Hat and Fedora GNU/Linux installation of Python has three broad steps.

1. Pre-installation: make backups.
2. Installation: install Python. We'll focus on the simplest kind of installation.
3. Post-installation: check to be sure everything worked.

We'll go through each of these in detail.

3.3.4 RPM Pre-Installation

Before installing software, back up your computer.

You should also have a directory for saving your downloads. I recommend that you create a `/opt` directory for these kinds of options which are above and beyond the basic Linx installation. You can keep all of your various downloaded tools and utilities in this directory for two reasons. If you need to reinstall your software, you know exactly what you downloaded. When you get a new computer (or an additional computer), you know what needs to be installed on that computer.

3.3.5 RPM Installation

A typical scenario for installing Python is a command like the following. This has specific file names for Fedora Core 9. You'll need to locate appropriate RPM's for your distribution of Linux.

```
rpm -i http://download.fedora.redhat.com/pub/fedora/linux/development\
/i386/os/Packages/python-2.5.1-18.fc9.i386.rpm
```

Often, that's all there is to it. In some cases, you'll get warnings about the DSA signature. These are expected, since we didn't tell RPM the public key that was used to sign the packages.

3.3.6 RPM Post-Installation

Important: Testing

Run the Terminal tool. At the command line prompt, enter '`env python`', and see what happens.

```
[slott@localhost trunk]$ env python
Python 2.6 (r26:66714, Jun  8 2009, 16:07:26)
[GCC 4.4.0 20090506 (Red Hat 4.4.0-4)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

If you hit `Ctrl-D` (the GNU/Linux end-of-file character), Python will exit. The basic Python program works.

3.4 "Build from Scratch" Installation

There are many GNU/Linux variants, and we can't even begin to cover each variant. You can use a similar installation on Windows or the Mac OS, if you have the GCC compiler installed. Here's an overview of how to install using a largely manual sequence of steps.

1. **Pre-Installation**. Make backups and download the source kit. You're looking for the a file named `python-2.5.x.tgz`.
2. **Installation**. The installation involves a fairly common set of commands. If you are an experienced system administrator, but a novice programmer, you may recognize these.

   Change to the `/opt/python` directory with the following command.

   ```
   cd /opt/python
   ```

   Unpack the archive file with the following command.

   ```
   tar -zxvf Python-2.6.x.tgz
   ```

   Do the following four commands to configure the installation scripts and make the Python package. and then install Python on your computer.

   ```
   cd Python-2.6
   ./configure
   make
   ```

   As root, you'll need to do the following command. Either use **sudo** or **su** to temporarily elevate your privileges.

   ```
   make install
   ```

3. **Post-installation**. Check to be sure everything worked.

Important: Testing

Run the **Terminal** tool. At the command line prompt, enter '`env python`', and see what happens.

```
[slott@localhost trunk]$ env python
Python 2.6 (r26:66714, Jun  8 2009, 16:07:26)
[GCC 4.4.0 20090506 (Red Hat 4.4.0-4)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

If you hit `Ctrl-D` (the GNU/Linux end-of-file character), Python will exit. The basic Python program works.

Tip: Debugging Other Unix Installation

The most likely problem you'll encounter in doing a generic installation is not having the appropriate GNU GCC compiler. In this case, you will see error messages from **configure** which identifies the list of missing packages. Installing the GNU GCC can become a complex undertaking.

CHAPTER

FOUR

GETTING STARTED

Interacting with Python

Python is an interpreted, dynamic language. The Python interpreter can be used in two modes: interactive and scripted. In *interactive* mode, Python responds to each statement while we type. In *script* mode, we give Python a file of statements and turn it loose to interpret all of the statements in that script. Both modes produce identical results. When we're producing a finished application program, we set it up to run as a script. When we're experimenting or exploring, however, we may use Python interactively.

We'll describe the interactive command-line mode for entering simple Python statements in *Command-Line Interaction*. In *The IDLE Development Environment* we'll cover the basics of interactive Python in the IDLE environment. We'll describes the script mode for running Python program files in *Script Mode*.

We'll look at the help fiunction in *Getting Help*.

Once we've started interacting with Python, we can address some syntax issues in *Syntax Formalities*. We'll mention some other development tools in *Other Tools*. We'll also address some "style" issues in *Style Notes: Wise Choice of File Names*.

4.1 Command-Line Interaction

We'll look at interaction on the command line first, because it is the simplest way to interact with Python. It parallels scripted execution, and helps us visualize how Python application programs work. This is the heart of IDLE as well as the foundation for any application programs we build.

This is not the only way – or even the most popular way – to run Python. It is, however, the simplest and serves as a good place to start.

4.1.1 Starting and Stopping Command-Line Python

Starting and stopping Python varies with your operating system. Generally, all of the variations are nearly identical, and differ only in minor details.

Windows. There are two ways to start interactive Python under Windows.

1. You can run the command tool (`cmd.exe`) and enter the **python** command.
2. You can run the **Python (Command Line)** program under the **Python2.6** menu item on the **Start** menu.

To exit from Python, enter the end-of-file character sequence, `Control-Z` and `Return`.

Mac OS, GNU/Linux and Unix. You will run the **Terminal** tool. You can enter the command **python** to start interactive Python.

To exit from Python, enter the end-of-file character, `Control-D`.

4.1.2 Entering Python Statements

When we run the Python interpreter (called `python` , or `Python.exe` in Windows), we see a greeting like the following:

```
[slott@localhost trunk]$ env python
Python 2.6 (r26:66714, Jun  8 2009, 16:07:26)
[GCC 4.4.0 20090506 (Red Hat 4.4.0-4)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

When we get the `>>>` prompt, the Python interpreter is looking for input. We can type any Python statements we want.

Each complete statement is executed when it is entered.

In this section only, we'll emphasize the prompts from Python. This can help newbies see the complete cycle of interaction between themselves and the Python interpreter. In the long run we'll be writing scripts and won't emphasize this level of interaction.

We'll only cover a few key rules. The rest of the rules are in *Syntax Formalities*.

Rule 1. The essential rule of Python syntax is that a statement must be complete on a single line. There are some exceptions, which we'll get to below.

```
>>> 2 + 3
5
```

This shows Python doing simple integer arithmetic. When you entered `2 + 3` and then hit `Return`, the Python interpreter evaluated this statement. Since the statement was only an expression, Python printed the results.

We'll dig into to the various kinds of numbers in *Simple Numeric Expressions and Output*. For now, it's enough to know that you have integers and floating-point numbers that look much like other programming languages. As a side note, integers have two slightly different flavors – fast (but small) and long (but slow). Python prefers to use the fast integers (called `int`) until your numbers get so huge that it has to switch to `long`.

Arithmetic operators include the usual culprits: '`+`' , '`-`' , '`*`', '`/`' , '`%`' and '`**`' standing for addition, subtraction, multiplication, division, modulo (remainder after division) and raising to a power. The usual mathematical rules of operator precedence (multiplys and divides done before adds and subtracts) are in full force, and '`(`' and '`)`' are used to group terms against precedence rules.

For example, converting 65 °Fahrenheit to Celsius is done as follows:

```
>>> (65 - 32) * 5 / 9
18
>>> (65.-32)*5/9
18.333333333333332
>>>
```

Note that the first example used all integer values, and the result was an integer result. In the second example, the presence of a float caused all the values to be coerced to float.

Also note that Python has the standard "binary-to-decimal" precision issue. The actual value computed does not have a precise binary representation, and the default display of the decimal equivalent looks strange. We'll return to this in *Numeric Types and Operators*.

Incomplete Statements. What happens when an expression statement is obviously incomplete?

```
>>> ( 65 - 32 ) * 5 /
  File "<stdin>", line 1
    ( 65 - 32 ) * 5 /
                    ^
SyntaxError: invalid syntax
```

Parenthensis. There is an escape clause in the basic rule of "one statement one line". When the parenthesis are incomplete, Python will allow the statement to run on to multiple lines.

Python will change the prompt to `...` to show that the statement is incomplete, and more is expected.

```
>>> ( 65 - 32
... )*5 / 9
18
```

Rule 5. It is also possible to continue a long statement using a '\' escape at the end of the line.

```
>>> 5 + 6 *\
... 7
47
```

This *escape* allows you to break up an extremely long statement for easy reading.

Indentation. Python relies heavily on indendentation to make a program readable. When interacting with Python, we are often typing simple expression statements, which are not indented. Later, when we start typing compound statements, indentation will begin to matter.

Here's what happens if we try to indent a simple expression statement.

```
>>>       5+6
SyntaxError: invalid syntax
```

Note that some statements are called *compound statements* – they contain an indented suite of statements. Python will change the prompt to `...` and wait until the entire compound statement is entered before it does does the evaluation.

We'll return to these when it's appropriate in *Truth, Comparison and Conditional Processing*.

History. When we type an expression statement, Python evaluates it and displays the result. When we type all other kinds of statements, Python executes it silently. We'll see more of this, starting in *Variables, Assignment and Input*.

Small mistakes can be frustrating when typing a long or complex statement. Python has a reasonable command history capability, so you can use the `up-arrow` key to recover a previous statement. Generally, you'll prefer to create script files and run the scripts. When debugging a problem, however, interactive mode can be handy for experimenting.

One of the desirable features of well-written Python is that most things can be tested and demonstrated in small code fragments. Often a single line of easy-to-enter code is the desired style for interesting programming

features. Many examples in reference manuals and unit test scripts are simply captures of interactive Python sessions.

4.2 The IDLE Development Environment

There are a number of possible integrated development environments (IDE) for Python. Python includes the **IDLE** tool, which we'll emphasize. Additionally, you can download or purchase a number of IDE's that support Python. In *Other Tools* we'll look at other development tools.

Starting and stopping **IDLE** varies with your operating system. Generally, all of the variations are nearly identical, and differ only in minor details.

4.2.1 IDLE On Windows

There are several ways to start **IDLE** in Windows.

1. You can use **IDLE (Python GUI)** from the **Python2.6** menu on the **Start** menu.
2. You can also run **IDLE** from the command prompt. This requires two configuration settings in Windows.
   - Assure that `C:Python26\Lib\idlelib` on your system **PATH**. This directory contains `IDLE.BAT` .
   - Assure that `.pyw` files are associated with `C:\Python26\pythonw.exe`. In order to suppress creation of a console window for a GUI application, Windows offers `pythonw.exe`.

You can quit **IDLE** by using the **Quit** menu item under the **File** menu.

4.2.2 IDLE On Mac OS X

In the Mac OS, if you've done an upgrade, you may find the **IDLE** program in the `Python 2.6` folder in your `Applications` folder. You can double-click this icon to run **IDLE**.

If you have the baseline application, you'll have to find IDLE in the directory `/System/Library/Frameworks/Python.framework/Versions/Current/bin`. Generally, this is directory part of your **PATH** setting, and you can type the command **idle &** in a Terminal window to start IDLE.

When you run IDLE by double-clicking the `idle` icon, you'll notice that two windows are opened: a **Python Shell** window and a **Console** window. The **Console** window isn't used for much.

When you run **IDLE** from the **Terminal** window, no console window is opened. The Terminal window is the Python console.

You can quit **IDLE** by using the **Quit** menu item under the **File** menu. You can also quit by using the **Quit Idle** menu item under the **Idle** menu.

Since the Macintosh keyboard has a command key, , as well as a control key, `ctrl`, there are two keyboard mappings for **IDLE**. You can use the **Configure IDLE...** item under the **Options** menu to select any of the built-in Key Sets. Selecting the **IDLE Classic Mac** settings may be more comfortable for Mac OS users.

4.2.3 IDLE on GNU/Linux

We'll avoid the GNOME and KDE subtleties. Instead, we'll focus on running **IDLE** from the **Terminal** tool. Since the file path is rather long, you'll want to edit your `.profile` (or `.bash_profile`) to include the following alias definition.

```
alias idle='env python /usr/lib/python2.5/idlelib/idle.py &'
```

This allows you to run **IDLE** by entering the command **idle** in a **Terminal** window.

You can quit **IDLE** by using the **Exit** menu item under the **File** menu.

4.2.4 Basic IDLE Operations

Initially, you'll see the following greeting from **IDLE**.

```
Python 2.6.3 (r263:75184, Oct  2 2009, 07:56:03)
[GCC 4.0.1 (Apple Inc. build 5493)] on darwin
Type "copyright", "credits" or "license()" for more information.

    **********************************************************************
    Personal firewall software may warn about the connection IDLE
    makes to its subprocess using this computer's internal loopback
    interface.  This connection is not visible on any external
    interface and no data is sent to or received from the Internet.
    **********************************************************************

IDLE 2.6.3
>>>
```

You may notice a **Help** menu. This has the **Python Docs** menu item, which you can access through the menu or by hitting `F1`. This will launch **Safari** to show you the Python documents available on the Internet.

The personal firewall notification is a reminder that **IDLE** uses Internetworking Protocols (IP) as part of its debugger. If you have a software firewall on you development computer, and the firewall software complains, you can allow the connection.

IDLE has a simple and relatively standard text editor, which does Python syntax highlighting. It also has a **Python Shell** window which manages an interactive Python session. You will see that the **Python Shell** window has a **Shell** and a **Debug** menu.

When you use the **New** menu item in the **File** menu, you'll see a file window, which has a slightly different menu bar. A file window has name which is a file name (or *untitled*), and two unique menus, a **Run** and a **Format** menu.

Generally, you'll use **IDLE** in two ways:

- You'll enter Python statements in the **Python Shell** window.
- You'll create files, and run those module files using the **Run Module** item in the **Run** menu. This option is usually `F5`.

4.2.5 The Shell Window

The **Python Shell** window in **IDLE** presents a `>>>` prompt. At this prompt, you can enter Python expressions or statements for evaluation. This window has a complete command history, so you can use the `up arrow` to select a previous statement and make changes.

You can refer back to *Command-Line Interaction* ; those interactions will look and behave the same in **IDLE** as they do on the command line.

The **Shell Window** is essentially the command-line interface wrapped in a scrolling window. The **IDLE** interface, however, provides a consistent working environment, which is independent of each operating system's command-line interface.

The **Shell** and **Debug** menus provides functions you'll use when developing larger programs. For our first steps with Python, we won't need either of these menus. We'll talk briefly about the functions, but can't really make use of them until we've learned more of the language.

The Shell Menu. The **Shell** menu is used to restart the Python interpreter, or scroll back through the shell's log to locate the most recent restart. This is important when you are developing a module that is used as a library. When you change that module, you need to reset the shell so that the previous version is forgotten and the new version can be imported into a fresh, empty interpreter.

Generally, being able to work interactively is the best way to develop working programs. It encourages you to create tidy, simple-looking components which you can exercise directly.

The Debug Menu. The **Debug** menu provides some handy tools for watching how Python executes a program.

- The **Go to File/Line** item is used to locate the source file where an exception was raised. You click on the exception message which contains the file name and select the **Go to File/Line** menu item, and **IDLE** will open the file and highlight the selected line.
- The **Debugger** item opens an interactive debugger window that allows you to step through the executing Python program.
- The **Stack Viewer** item opens a window that displays the current Python stack. This shows the arguments and working variables in the Python interpereter. The stack is organized into local and global *namespaces*, a conceot we need to delve into in *Variables, Assignment and Input*.
- The **Auto-open Stack Viewer** option will open the **Stack Viewer** automatically when a program raises an unhandled exception. How exceptions are raised and handled is a concept we'll delve into in *Exceptions*.

4.2.6 The File Windows

Each file window in **IDLE** is a simple text editor with two additional menus. The **Format** menu has a series of items for fairly common source text manipulations. The formatting operations include indenting, commenting, handling tabs and formatting text paragraphs.

The **Run** menu makes it easy to execute the file you are editing.

- The **Python Shell** menu item brings up the **Python Shell** window.
- The **Check Module** item checks the syntax for your file. If there are any errors, **IDLE** will highlight the offending line so you can make changes. Additionally, this option will check for inconsistent use of tabs and spaces for indentation.
- The **Run Module** , `F5` , runs the entire file. You'll see the output in the **Python Shell** window.

4.3 Script Mode

In interactive mode, Python displays the results of expressions. In script mode, however, Python doesn't automatically display results.

In order to see output from a Python script, we'll introduce the **print** statement and the `print()` function.

The **print** statement is the Python 2.6 legacy construct.

The `print()` function is a new Python 3 construct that will replace the **print** statement. We'll visit this topic in depth in *Seeing Output with the print() Function (or print Statement)*.

For now, you can use either one. We'll show both. In the future, the **print** statement will be removed from the language.

4.3.1 The print Statement

The **print** statement takes a list of values and prints their string representation on the standard output file. The standard output is typically directed to the **Terminal** window.

```
print "PI = ", 355.0/113.0
```

We can have the Python interpreter execute our script files. Application program scripts can be of any size or complexity. For the following examples, we'll create a simple, two-line script, called `example1.py`.

example1.py

```
print 65, "F"
print ( 65 - 32 ) * 5 / 9, "C"
```

4.3.2 The `print()` function

The `print()` functions takes a list of values and prints their string representation on the standard output file. The standard output is typically directed to the **Terminal** window.

Until Python 3, we have to request the `print()` function with a special introductory statement: '`from __future__ import print_function`'.

```
from __future__ import print_function
print( "PI = ", 355.0/113.0 )
```

We can have the Python interpreter execute our script files. Application program scripts can be of any size or complexity. For the following examples, we'll create a simple, two-line script, called `example1.py`.

example1.py

```
from __future__ import print_function
print( 65, "F" )
print( ( 65 - 32 ) * 5 / 9, "C" )
```

4.3.3 Running a Script

There are several ways we can start the Python interpreter and have it evaluate our script file.

- Explicitly from the command line. In this case we'll be running Python and providing the name of the script as an argument.

  We'll look at this in detail below.

- Implicitly from the command line. In this case, we'll either use the GNU/Linux shell comment (sharp-bang marker) or we'll depend on the file association in Windows.

  This is slightly more complex, and we'll look at this in detail below.

- Manually from within **IDLE** . It's important for newbies to remember that **IDLE** shouldn't be part of the final delivery of a working application. However, this is a great way to start development of an application program.

  We won't look at this in detail because it's so easy. Hit `F5`. MacBook users may have to hit `fn` and `F5`.

Running Python scripts from the command-line applies to all operating systems. It is the core of delivering final applications. We may add an icon for launching the application, but under the hood, an application program is essentially a command-line start of the Python interpreter.

4.3.4 Explicit Command Line Execution

The simplest way to execute a script is to provide the script file name as a parameter to the **python** interpreter. In this style, we explicitly name both the interpreter and the input script. Here's an example.

```
python example1.py
```

This will provide the `example1.py` file to the Python interpreter for execution.

4.3.5 Implicit Command-Line Execution

We can streamline the command that starts our application. For POSIX-standard operating systems (GNU/Linux, UNIX and MacOS), we make the script file itself executable and directing the shell to locate the Python interpreter for us. For Windows users, we associate our script file with the `python.exe` interpreter. There are one or two steps to this.

1. Associate your file with the Python interpreter. Except for Windows, you make sure the first line is the following: '`#!/usr/bin/env python`' . For Windows, you must assure that `.py` files are associated with `python.exe` and `.pyw` files are associated with `pythonw.exe`.

   The whole file will look like this:

   ```
   #!/usr/bin/env python
   print 65, "F"
   print ( 65 - 32 ) * 5 / 9, "C"
   ```

2. For POSIX-standard operating systems, do a **chmod +x example1.py** to make the file *example1.py* executable. You only do this once, typically the first time you try to run the file. For Windows, you don't need to do this.

Now you can run a script in most GNU/Linux environments by saying:

```
./example1.py
```

4.3.6 Windows Configuration

Windows users will need to be sure that `python.exe` is on their **PATH**. This is done with the System control panel. Click on the **Advanced** tab. Click on the **Environment Variables...** button. Click on the System variables **Path** line, and click the **Edit...** button. This will often have a long list of items, sometimes starting with '`%SystemRoot%`'. At the end of this list, add '`";"`' and the direction location of `Python.exe`. On my machine, I put it in `C:\Python26`.

For Windows programmers, the windows command interpreter uses the last letters of the file name to associate a file with an interpreter. You can have Windows run the `python.exe` program whenever you double-click a `.py` file. This is done with the **Folder Options** control panel. The **File Types** tab allows you to pair a file type with a program that processes the file.

4.3.7 GNU/Linux Configuration

We have to be sure that the Python interpreter is in value of the **PATH** that our shell uses. We can't delve into the details of each of the available UNIX Shells. However, the general rule is that the person who administers your POSIX computer should have installed Python and updated the `/etc/profile` to make Python available to all users. If, for some reason that didn't get done, you can update your own `.profile` to add Python to your **PATH** variable.

The Sharp-Bang ("shebang") Comment

The '`#!`' technique depends on the way all of the POSIX shells handle scripting languages. When you enter a command that is the name of a file, the shell must first check the file for the "x" (execute) mode; this was the mode you added with **chmod +x**.
When execute mode is true, the shell must then check the first few bytes to see what kind of file it is. The first few bytes are termed the *magic number*; deep in the bowels of GNU/Linux there is a database that shows what the magic number means, and how to work with the various kinds of files. Some files are binary executables, and the operating system handles these directly.
When an executable file's content begins with '`#!`', it is a script file. The rest of the first line names the program that will interpret the script. In this case, we asked the **env** program to find the **python** interpreter. The shell finds the named program and runs it automatically, passing the name of script file as the last argument to the interpreter it found.
The very cool part of this trick is that '`#!`' is a *comment* to Python. This first line is, in effect, directed at the shell, and ignored by Python. The shell glances at it to see what the language is, and Python studiously ignores it, since it was intended for the shell.

4.3.8 Another Script Example

Throughout the rest of this book, we're going to use this script processing mode as the standard way to run Python programs. Many of the examples will be shown as though a file was sent to the interpreter.

For debugging and testing, it is sometimes useful to *import* the program definitions, and do some manipulations interactively. We'll touch on this in *Hacking Mode*.

Here's a second example. We'll create a new file and write another small Python program. We'll call it `example2.py`.

example2.py

```
#!/usr/bin/env python
"""Compute the odds of spinning red (or black) six times in a row
on an American roulette wheel. """
print (18.0/38.0)**6
```

This is a one-line Python program with a two line module document string. That's a good ratio to strive for.

After we finish editing, we mark this as executable using '`chmod +x example2.py`'. Since this is a property of the file, this remains true no matter how many times we edit, copy or rename the file.

When we run this, we see the following.

```
$ ./example2.py
0.0112962280375
```

Which says that spinning six reds in a row is about a one in eighty-nine probability.

4.4 Getting Help

Python has two closely-related help modes. One is the general "help" utility, the other is a help function that provides the documentation on a specific object, module, function or class.

4.4.1 The `help()` Utility

Help is available through the `help()` function.

If you enter just '`help()`' you will enter the online help utility. This help utility allows you to explore the Python documentation.

The interaction looks like this:

```
>>> help
Type help() for interactive help, or help(object) for help about object.
>>> help()

Welcome to Python 2.5!  This is the online help utility.

If this is your first time using Python, you should definitely check out
the tutorial on the Internet at http://www.python.org/doc/tut/.

Enter the name of any module, keyword, or topic to get help on writing
Python programs and using Python modules.  To quit this help utility and
return to the interpreter, just type "quit".

To get a list of available modules, keywords, or topics, type "modules",
"keywords", or "topics".  Each module also comes with a one-line summary
of what it does; to list the modules whose summaries contain a given word
such as "spam", type "modules spam".

help>
```

Note that the prompt changes from Python's standard '>>>' to a special help-mode prompt of 'help>'.

When you enter 'quit', you exit the help system and go back to Python's ordinary prompt.

To start, enter :samp:'modules', :samp:'keywords' or :samp:'topics' to see the variety of information available.

4.4.2 Help on a specific topic

If you enter 'help(object)' for some object, you will be given help on that specific object. This help is displayed using a "help viewer".

You'll enter something like this:

```
>>> help("EXPRESSIONS")
```

You'll get a page of output, ending with a special prompt from the program that's helping to display the help messages. The prompt varies: Mac OS and GNU/Linux will show one prompt, Windows will show another.

Mac OS and GNU/Linux. In standard OS's, you're interacting with a program named **less**; it will prompt you with : for all but the last page of your document. For the last page it will prompt you with (END).

This program is very sophisticated. The four most important commands you need to know are the following.

q Quit the **less** help viewer.

h Get help on all the commands which are available.

␣Enter a space to see the next page.

b Go back one page.

Windows. In Windows, you're interacting with a program named **more**; it will prompt you with -- More --. The four important commands you'll need to know are the following.

q Quit the **more** help viewer.

h Get help on all the commands which are available.

␣Enter a space to see the next page.

4.5 Syntax Formalities

What is a Statement?

Informally, we've seen that simple Python statements must be complete on a single line. As we will see in following chapters, compound statements are built from simple and compound statements.

Fundamentally, Python has a simple equivalence between the lexical line structure and the statements in a Python program. This forces us to write readable programs with one statement per line. There are nine formal rules for the lexical structure of Python.

1. Simple statements must be complete on a single Logical Line. Starting in *Truth, Comparison and Conditional Processing* we'll look at compound statements, which have indented suites of statements, and which span multiple Logical Lines. The rest of these rules will define how Logical Lines are built from Physical Lines through a few Line Joining rules.

2. Physical Lines are defined by the platform; they'll end in standard '`n`' or the Windows ASCII '`CR`' '`LF`' sequence ('`\r\n`').
3. Comments start with the '`#`' character outside a quoted string; comments end at the end of the physical line. These are not part of a statement; they may occur on a line by themselves or at the end of a statement.
4. Coding-Scheme Comments. Special comments that are by VIM or EMACS can be included in the first or second line of a Python file. For example, '`# -*- coding: latin1 -*-`'
5. Explicit Line Joining. A '\' at the end of a physical line joins it to the next physical line to make a logical line. This *escapes* the usual meaning of the line end sequence. The two or three-character sequences ('`\n`' or '`\r\n`') are treated as a single space.
6. Implicit Line Joining. Expressions with '`()`''s, '`[]`''s or '`{}`''s can be split into multiple physical lines.
7. Blank Lines. When entering statements interactively, an extra blank line is treated as the end of an indented block in a compound statement. Otherwise, blank lines have no signficance.
8. Indentation. The embedded suite of statements in a compound statement must be indented by a consistent number of spaces or tabs. When entering statements interactively or in an editor that knows Python syntax (like **IDLE**), the indentation will happen automatically; you will outdent by typing a single `backspace`. When using another text editor, you will be most successful if you configure your editor to use four spaces in place of a tab. This gives your programs a consisent look and makes them portable among a wide variety of editors.
9. Whitespace at the beginning of a line is part of indentation, and is significant. Whitespace elsewhere within a line is not significant. Feel free to space things out so that they read more like English and less like computer-ese.

4.6 Exercises

4.6.1 Command-Line Exercises

1. *Simple Commands.* Enter the following one-line commands to Python:
   - copyright
   - license
   - credits
   - help
2. *Simple Expressions.* Enter one-line commands to Python to compute the following:
   - 12345 + 23456
   - 98765 - 12345
   - 128 * 256
   - 22 / 7
   - 355 / 113
   - (18-32)*5/9
   - -10*9/5+32

4.6.2 IDLE Exercises

1. **Create an Exercises Directory**. Create a directory (or folder) for keeping your various exercise scripts. Be sure it is not in the same directory in which you installed Python.

2. **Use IDLE's Shell Window**. Start **IDLE** . Refer back to the exercises in *Command-Line Interaction* . Run these exercises using **IDLE** .

3. **Use the IDLE File Window**. Start **IDLE** . Note the version number. Use **New Window** under the **File** menu to create a simple file. The file should have the following content.

   ```
   """ My First File """
   print __doc__
   ```

   Save this file in your exercises directory; be sure the name ends with `.py` . Run your file with the **Run Module** menu item in the **Run** menu, usually `F5` .

4.6.3 Script Exercises

1. **Print Script**. Create and run Python file with commands like the following examples:

   ```
   print 12345 + 23456
   print 98765 - 12345
   print 128 * 256
   print 22 / 7
   ```

   Or, use the print function as follows.

   ```
   from __future__ import print_function
   print(12345 + 23456)
   print(98765 - 12345)
   print(128 * 256)
   print(22 / 7)
   ```

2. **Another Simple Print Script**. Create and run a Python file with commands like the following examples:

   ```
   print "one red", 18.0/38.0
   print "two reds in a row", (18.0/38.0)**2
   ```

   Or, use the print function as follows.

   ```
   from __future__ import print_function
   print("one red", 18.0/38.0)
   print("two reds in a row", (18.0/38.0)**2)
   ```

3. **Interactive Differences**. First, run **IDLE** (or Python) interactively and enter the following "commands": `copyright`, `license`, `credits`. These are special global objects that print interesting things on the interactive Python console.

   Create a Python file with the three commands, each one on a separate line: `copyright`, `license`, `credits`. When you run this, it doesn't produce any output, nor does it produce an error.

   Now create a Python file with three commands, each on a separate line: **print copyright**, **print license**, **print credits**.

Interestingly, these three global variables have different behavior when used in a script. This is rare. By default, there are just three more variables with this kind of behavior: `quit`, `exit` and `help`.

4. **Numeric Types**. Compare the results of 22/7 and 22.0/7. Explain the differences in the output.

4.7 Other Tools

This section lists some additional tools which are popular ways to create, maintain and execute Python programs. While IDLE is suitable for many purposes, you may prefer an IDE with a different level of sophistication.

4.7.1 Any Platform

The Komodo Edit is an IDE that is considerably more sophisticated than IDLE. It is - in a way - too sophisticated for this book. Our focus is on the language, not high-powered IDE's. As with IDLE, this is a tool that runs everywhere, so you can move seamlessly from GNU/Linux to Wiundows to the Mac OS with a single, powerful tool.

See http://www.komodo.com for more information on ordering and downloading.

4.7.2 Windows

Windows programmers might want to use a tool like **Textpad**. See http://www.textpad.com for information on ordering and downloading. Be sure to also download the `python.syn` file from http://www.textpad.com/add-ons which has a number of Python syntax coloring configurations.

To use **Textpad**, you have two setup steps. First, you'll need to add the Python document class. Second you'll need to tell **Textpad** about the Python tool.

The Python Document Class. You need to tell **Textpad** about the Python document class. Use the **Configure** menu; the **New Document Class...** menu item lets you add Python documents to **Textpad**. Name your new document class `Python` and click **Next**. Give your class members named `*.py` and click **Next**. Locate your `python.syn` file and click **Next**. Check the new Python document class, and click **Next** if everything looks right to create a new **Textpad** document class.

The Python Tool. You'll want to add the Python interpreter as a **Textpad** tool. Use the **Configure** menu again, this time selecting the **Preferences?** item. Scroll down the list of preferences on the left and click on **Tools**. On the right, you'll get a panel with the current set of tools and a prominent **Add** button on the top right-hand side. Click **Add**, and select **Program...** from the menu that appears. You'll get a dialog for locating a file; find the `Python.exe` file. Click **Okay** to save this program as a **Textpad** tool.

You can check this by using **Configure** menu and **Preferences...** item again. Scroll down the list to find **Tools** . Click the + sign and open the list of tools. Click the **Python** tool and check the following:

- The Command is the exact path to your copy of `Python.exe`
- The Parameters contains **$File**
- The Initial Folder contains **$FileDir**
- The "capture output" option should be checked

You might also want to turn off the Sound Alert option; this will beep when a program finishes running. I find this makes things a little too noisy for most programs.

4.7.3 Macintosh

Macintosh programmers might want to use a tool like **BBEdit**. **BBEdit** can also run the programs, saving the output for you. See http://www.barebones.com for more information on **BBEdit**.

To use **BBEdit**, you have two considerations when writing Python programs.

You must be sure to decorate each Python file with the following line: '`#!/usr/bin/env python`'. This tells **BBEdit** that the file should be interpreted by Python. We'll mention this again, when we get to script-writing exericses.

The second thing is to be sure you set the **chdir to Script's Folder** option when you use the the **run...** item in the **#!** ("shebang") menu. Without this, scripts are run in the root directory, not in the directory that contains your script file.

4.8 Style Notes: Wise Choice of File Names

There is considerable flexibility in the language; two people can arrive at different presentations of Python source. Throughout this book we will present the guidelines for formatting, taken from the Python Enhancement Proposal (PEP) 8, posted on http://python.org/dev/peps/pep-0008/.

We'll include guidelines that will make your programming consistent with the Python modules that are already part of your Python environment. These guidelines should also also make your programming look like other third-party programs available from vendors and posted on the Internet.

Python programs are meant to be readable. The language borrows a lot from common mathematical notation and from other programming languages. Many languages (C++ and Java) for instance, don't require any particular formatting; line breaks and indendentation become merely conventions; bad-looking, hard-to-read programs are common. On the other hand, Python makes the line breaks and indentations part of the language, forcing you to create programs that are easier on the eyes.

General Notes. We'll touch on many aspects of good Python style as we introduce each piece of Python programming. We haven't seen much Python yet, but we do need some guidance to prevent a few tiny problems that could crop up.

First, Python (like all of Linux) is case sensitive. Some languages that are either all uppercase, or insensitive to case. We have worked with programmers who actually find it helpful to use the Caps Lock key on their keyboard to expedite working in an all-upper-case world. Please don't do this. Python should look like English, where lower-case letters predominate.

Second, Python makes use of indentation. Most programmers indent very nicely, and the compiler or interpreter ignores this. Python doesn't ignore it. Indentation is useful for write clear, meaning documents and programs are no different.

Finally, your operating system allows a fairly large number of characters to appear in a file name. Until we start writing modules and packages, we can call our files anything that the operating system will tolerate. Starting in *Components, Modules and Packages*, however, we'll have to limit ourselves to filenames that use only letters, digits and '`_`'s. There can be just one ending for the filename: `.py` .

A file name like `exercise_1.py` is better than the name `execise-1.py`. We can run both programs equally well from the command line, but the name with the hyphen limits our ability to write larger and more sophisticated programs.

CHAPTER

FIVE

SIMPLE NUMERIC EXPRESSIONS AND OUTPUT

The print Statement and Numeric Operations

Basic *expressions* are the most central and useful feature of modern programming languages. To see the results of expressions, we'll use the **print** statement.

This chapter starts out with *Seeing Output with the print() Function (or print Statement)*, which covers the **print** statement. *Numeric Types and Operators* covers the basic numeric data types and operators that are integral to writing expressions Python. *Numeric Conversion (or "Factory") Functions* covers conversions between the various numeric types. *Built-In Math Functions* covers some of the built-in functions that Python provides.

5.1 Seeing Output with the `print()` Function (or print Statement)

Before delving into expressions and numbers, we'll look at the **print** statement. We'll cover just the essential syntax of the **print** statement; it has some odd syntax quirks that are painful to explain.

Note: Python 3.0

Python 3.0 will replace the irregular **print** statement with a built-in `print()` function that is perfectly regular, making it simpler to explain and use.

In order to use the `print()` function instead of the **print** statement, your script (or **IDLE** session) must start off with the following.

```
from __future__ import print_function
```

This replaces the **print** statement, with it's irregular syntax with the `print()` function.

5.1.1 print Statement Syntax Overview

The **print** statement takes a list of values and, well, prints them. Speaking strictly, it does two things:

1. it converts the objects to strings and
2. puts the characters of those strings on *standard output*.

Generally, standard output is the console window where Python was started, although there are ways to change this that are beyond the scope of this book.

Here's a quick summary of the more important features of **print** statement syntax. In short, the keyword, '`print`', is followed by a comma-separated list of expressions.

```
print expression ⟨ , ... ⟩
```

Note: Syntax Summary

This syntax summary isn't completely correct because it implies that the list of expressions is *terminated* with a comma. Rather than fuss around with complex syntax diagrams (that's what the Python reference manual is for) we've shown an approximation that is close enough.

The '**,**' in a **print** statement is used to *separate* the various expressions.

A '**,**' can also be used at the end of the **print** statement to change the formatting; this is an odd-but-true feature that is unique to **print** statement syntax.

It's hard to capture this sublety in a single syntax diagram. Further, this is completely solved by using the `print()` function.

One of the simplest kind of expressions is a quoted string. You can use either apostrophes ('') or quotes ("") to surround strings. This gives you some flexibility in your strings. You can put an apostrophe into a quoted string, and you can put quotes into an apostrophe'd string without the special *escapes* that some other languages require. The full set of quoting rules and alternatives, however, will have to wait for *Strings*.

For example, the following trivial program prints three strings and two numbers.

```
print "Hi, Mom", "Isn't it lovely?", 'I said, "Hi".', 42, 91056
```

Multi-Line Output. Ordinarily, each **print** statement produces one line of output. You can end the **print** statement with a trailing **,** to combine the results of multiple **print** statements into a single line. Here are two examples.

```
print "335/113=",
print 335.0/113.0
print "Hi, Mom", "Isn't it lovely?",
print 'I said, "Hi".', 42, 91056
```

Since the first **print** statement ends with a **,** it does not produce a complete line of output. The second **print** statement finishes the line of output.

Redirecting Output. The **print** statement's output goes to the operating system's standard output file. How do we send output to the system's standard error file? This involves some more advanced concepts, so we'll introduce it with a two-part recipe that we need to look at in more depth. We'll revisit these topics in *Components, Modules and Packages* .

First, you'll need access to the standard error object; you get this via the following statement.

```
import sys
```

Second, there is an unusual piece of syntax called a "chevron print" which can be used to redirect output to standard error. '`>>`'

```
print  file , ⟨ expression , ... ⟩
```

Two common files are `sys.stdout` and `sys.stderr`. We'll return to files in *Files*.

Here is an example of a small script which produces messages on both stderr and stdout.

mixedout.py

```
#!/usr/bin/env python
"""Mixed output in stdout and stderr."""
import sys
print >>sys.stderr, "This is an error message"
print "This is stdout"
print >>sys.stdout, "This is also stdout"
```

When you run this inside **IDLE**, you'll notice that the stderr is colored red, where the stdout is colored black. You'll also notice that the order of the output in **IDLE** doesn't match the order in our program. Most POSIX operating systems buffer stdout, but do not buffer stderr. Consequently, stdout messages don't appear until the buffer is full, or the program exits.

5.1.2 The `print()` Function

Python 3 replaces the relatively complex and irregular **print** statement with a simple and regular `print()` function.

In Python 2.6 we can use this new function by doing the following:

```
from __future__ import print_function
```

This statement must be one of the first executable statements in your script file. It makes a small – but profuound – change to Python syntax. The Python processor must be notified of this intended change up front.

This provides us with the following:

print(*[object, ...], [sep=' '], [end='n'], [file=sys.stdout]*)

This will convert each object to a string, and then write the characters on the given file.

The separator between objects is – by default – a single space. Setting a value for *sep* will set a different separator.

The end-of-line character is – by default – a single newline. Setting a value for *end* will set a different end-of-line character.

To change output files, provide a value for *file*.

Multiline Output. To create multiline output, do the following:

```
from __future__ import print_function

print( "335/113=", end="" )
print( 335.0/113.0 )
print( "Hi, Mom", "Isn't it lovely?", end="" )
print( 'I said, "Hi".', 42, 91056 )
```

Redirecting Output. The **print** statement's output goes to the operating system's standard output file. How do we send output to the system's standard error file? This involves some more advanced concepts, so

we'll introduce it with a two-part recipe that we need to look at in more depth. We'll revisit these topics in *Components, Modules and Packages*.

First, you'll need access to the standard error object.

Second, you'll provide the *file* option to the `print()` function.

```
from __future__ import print_function
import sys
print( "This is an error message", file=sys.stderr )
print( "This is stdout" )
print( "This is also stdout", file=sys.stdout )
```

Adding Features. You can – with some care – add features to the `print()` function.

When we look at function definitions, we'll look at how we can override the built-in `print()` function to add our own unique features.

5.1.3 print Notes and Hints

A program produces a number of kinds of output. The `print()` function (or **print** statement) is a handy jumping-off point. Generally, we'll replace this with more advanced techiques.

- Final Reports. Our desktop applications may produce text-based report files. These are often done with **print** statements.
- PDF or other format output files. A desktop application which produces PDF or other format files will need to use additional libraries to produce PDF files. For example, ReportLab offers PDF-production libraries. These applications won't make extensive use of **print** statements.
- Error messages and processing logs. Logs and errors are often directed to the standard error file. You won't often use the **print** statement for this, but use the `logging` library.
- Debugging messages. Debugging messages are often handled by the `logging` library.

The **print** statement (or `print()` function) is a very basic tool for debugging a complex Python program. Feel free to use **print** statements heavily to create a clear picture of what a program is actually doing. Ultimately, you are likely to replace **print** statements with other, more sophisticated methods.

5.2 Numeric Types and Operators

Python provides four built-in types of numbers: plain integers, long integers, floating point numbers and complex numbers.

Numbers all have several things in common. Principally, the standard arithmetic operators of '`+`', '`-`', '`*`', '`/`', '`%`' and '`**`' are all available for all of these numeric types. Additionally, numbers can be compared, using comparison operators that we'll look at in *Comparisons*. Also, numbers can be coerced from one type to another.

More sophisticated math is separated into the `math` module, which we will cover later. However, a few advanced math functions are an integral part of Python, including `abs()` and `pow()`.

5.2.1 Integers

Plain integers are at least 32 bits long. The range is at least -2,147,483,648 to 2,147,483,647 (approximately ± 2 billion).

Python represents integers as strings of decimal digits. A number does not include any punctuation, and cannot begin with a leading zero (0). Leading zeros are used for base 8 and base 16 numbers. We'll look at this below.

```
>>> 255+100
355
>>> 397-42
355
>>> 71*5
355
>>> 355/113
3
```

While most features of Python correspond with common expectations from mathematics and other programming languages, the division operator, '`/`', poses certain problems. Specifically, the distinction between the algorithm and the data representation need to be made explicit. Division can mean either exact floating-point results or integer results. Mathematicians have evolved a number of ways of describing precisely what they mean when discussing division. We need similar expressive power in Python.We'll look at more details of division operators in *Division Operators*.

Binary, Octal and Hexadecimal. For historical reasons, Python supports programming in octal and hexadecimal. I like to think that the early days of computing were dominated by people with 8 or 16 fingers.

A number with a leading '`0`' (zero) is octal, base 8, and uses the digits 0 to 7. `0123` is octal and equal to 83 decimal.

A number with a leading `0x` or `0X` is hexadecimal, base 16, and uses the digits 0 through 9, plus '`a`', '`A`', '`b`', '`B`', '`c`', '`C`', '`d`', '`D`', '`e`', '`E`', '`f`', and '`F`'. `0x2BC8` is hexadecimal and equal to 11208.

A number with a leading `0b` or `0B` is binary, base 2, and uses digits 0 and 1.

Important: Leading Zeroes

When using Python 2.6, watch for leading zeros in numbers. If you simply transcribe programs from other languages, they may use leading zeros on decimal numbers.

Important: Python 3

In Python 3, the octal syntax will change. Octal constants will begin with '`0o`' to match hexadecimal constants which begin with '`0x`'.

`0o123` will be octal and equal to 83 decimal.

5.2.2 Long Integers

One of the useful data types that Python offers are long integers. Unlike ordinary integers with a limited range, long integers have arbitrary length; they can have as many digits as necessary to represent an exact answer. However, these will operate more slowly than plain integers.

Long integers end in '`L`' or '`l`'. Upper case '`L`' is preferred, since the lower-case '`l`' looks too much like the digit '`1`'. Python is graceful about converting to long integers when it is necessary.

Important: Python 3

Python 3 will not require the trailing '`L`'. It will silently deduce if you need an integer or a long integer.

How many different combinations of 32 bits are there? The answer is there are 2^{32}; '`2**32`' in Python. The answer is too large for ordinary integers, and we get the result as a long integer.

```
>>> 2**32
4294967296L
>>> 2**64
18446744073709551616L
```

There are about 4 billion ways to arrange 32 bits. How many bits in 1K of memory? 1024×8 bits. How many combinations of bits are possible in 1K of memory? $2^{1024 \times 8}$.

```
print 2L**(1024*8)
```

I won't attempt to reproduce the output from Python. It has 2,467 digits. There are a lot of different combinations of bits in only 1K of memory. The computer I'm using has $512 \times 1024K$ bytes of memory; there are a lot of combinations of bits available in that memory.

Python will silently convert between ultra-fast integers and slow-but-large long integers. You can force a conversion using the `int()` or `long()` factory functions.

5.2.3 Floating-Point Numbers

Python offers floating-point numbers, often implemented as "double-precision" numbers, typically using 64 bits. Floating-point numbers are written in two forms: a simple string of digits that includes a decimal point, and a more complex form that includes an explicit exponent.

```
.0625
0.0625
6.25E-2
625E-4
```

The last two examples are based on *scientific notation*, where numbers are written as a *mantissa* and an *exponent*. The '`E`' (or code:e) , powers of 10 are used with the exponent, giving us numbers that look like this: 6.25×10^{-2} and 625×10^{-4}.

The last example isn't properly normalized, since the mantissa isn't between 0 and 10.

Generally, a number, n, is some mantissa, g, and an exponent of c. For human consumption, we use a base of 10.

Internally, most computers use a base of 2, not 10.

$$n = g \times 10^c$$
$$n = h \times 2^d$$

This differece in the mantissa leads to slight errors in converting certain values, which are exact in base 10, to approximations in base 2.

For example, 1/5th doesn't have a precise representation. This isn't generally a problem because we have string formatting operations which can make this tiny representation error invisible to users.

```
>>> 1./5.
0.20000000000000001
>>> .2
0.20000000000000001
```

5.2.4 Complex Numbers

Besides plain integers, long integers and floating point numbers, Python also provides for imaginary and complex numbers. These use the European convention of ending with '`J`' or '`j`'. People who don't use complex numbers should skip this section.

'`3.14J`' is an imaginary number = $3.14 \times \sqrt{-1}$.

A complex number is created by adding a real and an imaginary number: '`2 + 14j`'. Note that Python always prints these in ()'s; for example `(2+14j)`.

The usual rules of complex math work perfectly with these numbers.

```
>>> (2+3j)*(4+5j)
(-7+22j)
```

Python even includes the complex conjugate operation on a complex number. This operation follows the complex number separated by a dot ('`.`'). This notation is used because the conjugate is treated like a method function of a complex number object (we'll return to this method and object terminology in *Classes*).

For example:

```
>>> 3+2j.conjugate()
(3-2j)
```

5.3 Numeric Conversion (or "Factory") Functions

We can convert a number from one type to another. A conversion may involve a loss of precision because we've reduced the number of bits available. A conversion may also add a false sense of precision by adding bits which don't have any real meaning.

We'll call these *factory functions* because they are a factory for creating new objects from other objects. The idea of factory function is a very general one, and these are just the first of many examples of this pattern.

5.3.1 Numeric Factory Function Definitions

There are a number of conversions from one numeric type to another.

`int`(x)

Generates an integer from the object x. If x is a floating point number, digits to the right of the decimal point are truncated as part of creating an integer. If the floating point number is more than about 10 digits, a long integer object is created to retain the precision. If x is a long integer that is too large to be represented as an integer, there's no conversion. Complex values can't be turned into integers directly.

If x is a string, the string is parsed to create an integer value. It must be a string of digits with an optional sign ('`+`' or '`-`').

```
>>> int("1243")
1243
>>> int(3.14159)
3
```

`float`(*x*)
Generates a float from object *x*. If *x* is an integer or long integer, a floating point number is created. Note that long integers can have a large number of digits, but floating point numbers only have approximately 16 digits; there can be some loss of precision. Complex values can't be turned into floating point numbers directly.

If *x* is a string, the string is parsed to create an float value. It must be a string of digits with an optional sign ('`+`' or '`-`'). The digits can have a single decimal point ('`.`').

Also, a string can be in scientific notation and include '`e`' or '`E`' followed by the exponent as a simple signed integer value.

```
>>> float(23)
23.0
>>> float("6.02E24")
6.0200000000000004e+24
>>> float(22)/7
3.14285714286
```

`long`(*x*)
Generates a long integer from *x*. If *x* is a floating point number, digits to the right of the decimal point are truncated as part of creating a long integer.

```
>>> long(2)
2L
>>> long(6.02E23)
601999999999999995805696L
>>> long(2)**64
18446744073709551616L
```

`complex`(*real, [imag]*)
Generates a complex number from *real* and *imag*. If the imaginary part is omitted, it is 0.0.

Complex is not as simple as the others. A complex number has two parts, real and imaginary. Conversion to complex typically involves two parameters.

```
>>> complex(3,2)
(3+2j)
>>> complex(4)
(4+0j)
>>> complex("3+4j")
(3+4j)
```

Note that the second parameter, with the imaginary part of the number, is optional. This leads to a number of different ways to call this function. In the example above, we used three variations: two numeric parameters, one numeric parameter and one string parameter.

5.4 Built-In Math Functions

Python has a number of *built-in* functions, which are an integral part of the Python interpreter. We can't look at all of them because many are related to features of the language that we haven't addressed yet.

One of the built-in mathematical functions will have to wait for complete coverage until we've introduced the more complex data types, specifically *tuples*, in *Tuples*. The `divmod()` function returns a tuple object with the quotient and remainder in division.

5.4.1 Built-In Math Functions

The bulk of the math functions are in a separate module, called `math`, which we will cover in *The math Module* . The formal definitions of mathematical built-in functions are provided below.

abs(*number*)
Return the absolute value of the argument, $|x|$.

pow(*x, y, [z]*)
Raise x to the y power, x^y. If z is present, this is done modulo z, $x^y \mod z$.

round(*number, [digits]*)
Round *number* to *ndigits* beyond the decimal point.

If the *ndigits* parameter is given, this is the number of decimal places to round to. If *ndigits* is positive, this is decimal places to the right of the decimal point. If *ndigits* is negative, this is the number of places to the left of the decimal point.

Examples:

```
>>> print round(678.456,2)
678.46
>>> print round(678.456,-1)
680.0
```

5.4.2 String Conversion Functions

The string conversion functions provide alternate representations for numeric values. This list expands on the function definitions in *Numeric Conversion (or "Factory") Functions*.

hex(*number*)
Create a hexadecimal string representation of *number*. A leading '0x' is placed on the string as a reminder that this is hexadecimal.

```
>>> hex(684)
'0x2ac'
```

oct(*number*)
Create a octal string representation of *number*. A leading '0' is placed on the string as a reminder that this is octal not decimal.

```
>>> oct(509)
'0775'
```

bin(*number*)
Create a binary representation of *number*. A leading '0b' is placed on the string as a reminder that this is binary and not decimal.

```
>>> bin(509)
'0b111111101'
```

int(*string, [base]*)
Generates an integer from the string x. If *base* is supplied, x must be a string in the given base. If *base* is omitted, the string x must be decimal.

```
>>> int( '0775', 8 )
509
>>> int( '0x2ac', 16 )
684
>>> int( '101101101101', 2 )
2925
```

The `int()` function has two forms. The '`int(x)`' form converts a decimal string, *x*, to an integer. For example, '`int('25')`' is 25.

The '`int(x,b)`' form converts a string, *x*, in base *b* to an integer. For example, '`int('25',8)`' is 21.

str(*object*)
Generate a string representation of the given object. This is the a "readable" version of the value.

repr(*object*)
Generate a string representation of the given object. Generally, this is the a Python expression that can reconstruct the value; it may be rather long and complex.

For the numeric examples we've seen so far, the value of `repr()` is generally the same as the value of `str()`.

The `str()` and `repr()` functions convert any Python object to a string. The `str()` version is typically more readable, where the `repr()` version is an internalized representation. For most garden-variety numeric values, there is no difference. For the more complex data types, however, the resultsof `repr()` and `str()` can be very different. For classes you write (see *Classes*), your class definition must provide these string representation functions.

5.4.3 Collection Functions

These are several built-in functions which operate on simple collections of data elements.

max(*value, ...*)
Return the largest *value*.

```
>>> max(1,2,3)
3
```

min(*value, ...*)
Return the smallest *value*.

```
>>> min(1,2,3)
1
```

Additionally, there are several other collection-handling functions, including `any()`, `all()` and `sum()`. These will have to wait until we can look at collection objects in *Data Structures*.

5.5 Expression Exercises

There are two sets of exercises. The first section, *Basic Output and Functions*, covers simpler exercises to reinforce Python basics. The second section, *Numeric Types and Expressions*, covers more complex numeric expressions.

5.5.1 Basic Output and Functions

1. **Print Expression Results**. In *Command-Line Exercises*, we entered some simple expressions into the Python interpreter. Change these simple expressions into print statements.

   Be sure to print a label or identifier with each answer. Here's a sample.

   ```
   print "9-1's * 9-1's = ", 111111111*111111111
   ```

   Here's an example using the `print()` function.

   ```
   from __future__ import print_function
   print( "9-1's * 9-1's = ", 111111111*111111111 )
   ```

2. **Evaluate and Print Expressions**. Write short scripts to print the results of the following expressions. In most places, changing integers to floating point produces a notably different result. For example '`(296/167)**2`' and '`(296.0/167.0)**2`' . Use long as well as complex types to see the differences.
   - '`355/113 * ( 1 - 0.0003/3522 )`'
   - '`22/17 + 37/47 + 88/83`'
   - '`(553/312)**2`'
3. **Numeric Conversion**. Write a print statement to print the mixed fraction $3\frac{5}{8}$ as a floating point number and as an integer.
4. **Numeric Truncation**. Write a print statement to compute '`(22.0/7.0)-int(22.0/7.0)`'. What is this value? Compare it with '`22.0/7.0`'. What general principal does this illustrate?
5. **Illegal Conversions**. Try illegal conversions like '`int('A')`' or '`int( 3+4j )`'. Why are exceptions raised? Why can't a simple default value like zero or `None` be used instead?
6. **Evaluate and Print Built-in Math Functions**. Write short scripts to print the results of the following expressions.
   - '`pow( 2143/22, 0.25 )`'
   - '`pow(553/312,2)`'
   - '`pow( long(3), 64 )`'
   - '`long( pow(float(3), 64) )`'

   Why do the last two produce different results? What does the difference between the two results tell us about the number of digits of precision in floating-point numbers?
7. **Evaluate and Print Built-in Conversion Functions**. Here are some more expressions for which you can print the results.
   - hex(1234)
   - int(hex(1234), 16)
   - long('0xab')
   - int('0xab')
   - int('0xab', 16)
   - int('ab', 16)
   - cmp(2, 3)

5.5.2 Numeric Types and Expressions

1. **Stock Value**. Compute value from number of shares ×purchase price for a stock.

   Once upon a time, stock prices were quoted in fractions of a dollar, instead of dollars and cents. Create a simple print statement for 125 shares purchased at $3\frac{3}{8}$. Create a second simple print statement for 150 shares purchased at $2\frac{1}{4}$ plus an additional 75 shares purchased at $1\frac{7}{8}$.

   Don't manually convert $\frac{1}{4}$ to 0.25. Use a complete expression of the form '`2+1/4.0`', just to get more practice writing expressions.

2. **Convert Between |deg| C and |deg| F**. Convert temperatures from one system to another.

   Conversion Constants: 32 °F = 0 °C, 212 °F = 100 °C.

   The following two formulae converts between °C (Celsius) and °F (Fahrenheit).

   $$F = 32 + \frac{212 - 32}{100} \times C$$
   $$C = (F - 32) \times \frac{100}{212 - 32}$$

   Create a print statement to convert 18 °C to °F.

   Create a print statement to convert -4 °F to °C.

3. **Periodic Payment on a Loan**. How much does a loan really cost?

   Here are three versions of the standard mortgage payment calculation, with m = payment, p = principal due, r = interest rate, n = number of payments.

   Don't be surprised by the sign of the results; they're opposite the sign of the principle. With a positive principle, you get negative numbers; you are paying *down* a principle.

   $$m = p \times \left(\frac{r}{1 - (1 + r)^{-n}} \right)$$

   Mortgage with payments due at the end of each period:

   $$m = \frac{-rp(r + 1)^n}{(r + 1)^n - 1}$$

   Mortgage woth payments due at the beginning of each period:

   $$m = \frac{-rp(r + 1)^n}{[(r + 1)^n - 1](r + 1)}$$

   Use any of these forms to compute the mortgage payment, m, due with a principal, p, of $110,000, an interest rate, r, of 7.25% annually, and payments, n, of 30 years. Note that banks actually process things monthly. So you'll have to divide the interest rate by 12 and multiply the number of payments by 12.

4. **Surface Air Consumption Rate**. SACR is used by SCUBA divers to predict air used at a particular depth. For each dive, we convert our air consumption at that dive's depth to a normalized air consumption at the surface. Given depth (in feet), d , starting tank pressure (psi), s, final tank pressure (psi), f, and time (in minutes) of t, the SACR, c, is given by the following formula.

   $$c = \frac{33(s - f)}{t(d + 33)}$$

   Typical values for pressure are a starting pressure of 3000, final pressure of 500.

A medium dive might have a depth of 60 feet, time of 60 minutes.

A deeper dive might be to 100 feet for 15 minutes.

A shallower dive might be 30 feet for 60 minutes, but the ending pressure might be 1500. A typical *c* (consumption) value might be 12 to 18 for most people.

Write print statements for each of the three dive profiles given above: medium, deep and shallow.

Given the SACR, *c* , and a tank starting pressure, *s*, and final pressure, *f*, we can plan a dive to depth (in feet), *d*, for time (in minutes), *t*, using the following formula. Usually the $33(s-f)/c$ is a constant, based on your SACR and tanks.

$$\frac{33(s-f)}{c} = t(d+33)$$

For example, tanks you own might have a starting pressure of 2500 and and ending pressure of 500, you might have a *c* (SACR) of 15.2. You can then find possible combinations of time and depth which you can comfortably dive.

Write two print statements that shows how long one can dive at 60 feet and 70 feet.

5. **Force on a Sail**. How much force is on a sail?

   A sail moves a boat by transferring force to its mountings. The sail in the front (the jib) of a typical fore-and-aft rigged sailboat hangs from a stay. The sail in the back (the main) hangs from the mast. The forces on the stay (or mast) and sheets move the boat. The sheets are attached to the clew of the sail.

   The force on a sail, *f*, is based on sail area, *a* (in square feet) and wind speed, v‘w‘ (in miles per hour).

   $$f = w^2 \times 0.004 \times a$$

   For a small racing dinghy, the smaller sail in the front might have 61 square feet of surface. The larger, mail sail, might have 114 square feet.

   Write a print statement to figure the force generated by a 61 square foot sail in 15 miles an hour of wind.

6. **Craps Odds**. What are the odds of winning on the first throw of the dice? There are 36 possible rolls on 2 dice that add up to values from 2 to 12. There is just 1 way to roll a 2, 6 ways to roll a 7, and 1 way to roll a 12. We'll take this as given until a later exercise where we have enough Python to generate this information.

   Without spending a lot of time on probability theory, there are two basic rules we'll use time and again. If any one of multiple alternate conditions needs to be true, usually expressed as “or”, we add the probabilities. When there are several conditions that must all be true, usually expressed as “and”, we multiply the probabilities.

   Rolling a 3, for instance, is rolling a 1-2 *or* rolling a 2-1. We add the probabilities: $1/36 + 1/36 = 2/36 = 1/18$.

   On a come out roll, we win immediately if 7 or 11 is rolled. There are two ways to roll 11 (2/36) or 6 ways to roll 7 (6/36).

   Write a print statement to print the odds of winning on the come out roll. This means rolling 7 or rolling 11. Express this as a fraction, not as a decimal number; that means adding up the numerator of each number and leaving the denominator as 36.

7. **Roulette Odds**. How close are payouts and the odds?

   An American (double zero) roulette wheel has numbers 1-36, 0 and 00. 18 of the 36 numbers are red, 18 are black and the zeroes are green. The odds of spinning red, then are 18/38. The odds of zero or double zero are 2/36.

Red pays 2 to 1, the real odds are 38/18.

Write a print statement that shows the difference between the pay out and the real odds.

You can place a bet on 0, 00, 1, 2 and 3. This bet pays 6 to 1. The real odds are 5/36.

Write a print statement that shows the difference between the pay out and the real odds.

5.6 Expression Style Notes

Spaces are used sparingly in expressions. Spaces are never used between a function name and the ()'s that surround the arguments. It is considered poor form to write:

```
int (22.0/7)
```

The preferred form is the following:

```
int(22.0/7)
```

A long expression may be broken up with spaces to enhance readability. For example, the following separates the multiplication part of the expression from the addition part with a few wisely-chosen spaces.

```
b**2 - 4*a*c
```

CHAPTER

SIX

ADVANCED EXPRESSIONS

The `math` and `random` Modules, Bit-Level Operations, Division

This chapter covers some more advanced topics. *The math Module* cover the `math` module. The *The random Module* covers elements of the `random` module.

Division Operators covers the important distinction between the division operators. We also provide some supplemental information that is more specialized. *Bit Manipulation Operators* covers some additional bit-fiddling operators that work on the basic numeric types. *Expression Style Notes* has some notes on style.

6.1 Using Modules

A Python *module* extends the Python execution environment by adding new classes, functions and helpful constants. We tell the Python interpreter to fetch a module with a variation on the **import** statement. There are several variations on **import**, which we'll cover in depth in *Components, Modules and Packages*.

For now, we'll use the simple **import**:

```
import m
```

This will import module `m`. Only the module's name, `m` is made available. Every name inside the module `m` must be *qualified* by prepending the module name and a '`.`'. So if module `m` had a function called `spam()`, we'd refer to it as `m.spam()`.

There are dozens of standard Python modules. We'll get to the most important ones in *Components, Modules and Packages*. For now, we'll focus on extending the math capabilities of the basic expressions we've looked so far.

6.2 The `math` Module

The `math` module is made available to your programs with:

```
import math
```

The `math` module contains a number of common trigonometric functions.

`acos`(x)
: Arc cosine of x; result in radians.

`asin(`x`)`
arc sine of x; result in radians.

`atan(`x`)`
arc tangent of x; result in radians.

`atan2(`y, x`)`
arc tangent of $y \div x$: $arctan(\frac{y}{x})$; result in radians.

`cos(`x`)`
cosine of x in radians.

`cosh(`x`)`
hyperbolic cosine of x in radians.

`exp(`x`)`
e^x, inverse of $log(x)$.

`hypot(`x, y`)`
Euclidean distance, $\sqrt{x^2 + y^2}$; the length of the hypotenuse of a right triangle with height of :replaceable:y‘ and length of x.

`log(`x`)`
Natural logarithm (base e) of x. Inverse of `exp()`. $n = e^{\ln n}$.

`log10(`x`)`
natural logarithm (base 10) of x , inverse of 10** x. $n = 10^{\log n}$.

`pow(`x, y`)`
x^y.

`sin(`x`)`
sine of x in radians.

`sinh(`x`)`
hyperbolic sine of x in radians.

`sqrt(`x`)`
square root of x. This version returns an error if you ask for ‘`sqrt(-1)`’, even though Python understands complex and imaginary numbers. A second module, `cmath`, includes a version of `sqrt()` which correctly creates imaginary numbers.

`tan(`x`)`
tangent of x in radians.

`tanh(`x`)`
hyperbolic tangent of x in radians.

Additionally, the following constants are also provided.

math.pi the value of π, 3.1415926535897931

math.e the value of e, 2.7182818284590451, used for the `exp()` and `log()` functions.

Conversion between radians, r, and degrees, d, is based on the following definition:

$$360 \text{ degrees} = 2 \times \pi \text{ radians}$$

From that, we get the following relationships:

$$d \times \pi = r \times 180$$

$$d = \frac{r \times 180}{\pi}, r = \pi \times \frac{d}{180}$$

The `math` module contains the following other functions for dealing with floating point numbers.

`ceil`(x)
Next larger whole number.

```
>>> import math
>>> math.ceil(5.1)
6.0
>>> math.ceil(-5.1)
-5.0
```

`fabs`(x)
Absolute value of the real x.

`floor`(x)
Next smaller whole number.

```
>>> import math
>>> math.floor(5.9)
5.0
>>> math.floor(-5.9)
-6.0
```

`fmod`(x, y)
Floating point remainder after division of $\lfloor x \div y \rfloor$. This depends on the platform C library and may handle the signs differently than the Python '`x % y`'.

```
>>> math.fmod( -22, 7 )
-1.0
>>> -22 % 7
6
```

`modf`(x)
Creates a tuple with the fractional and integer parts of x. Both results carry the sign of x so that x can be reconstructed by adding them. We'll return to tuples in *Tuples*.

```
>>> math.modf( 123.456 )
(0.45600000000000307, 123.0)
```

`frexp`(x)
This function unwinds the usual base-2 floating point representation. A floating point number is $m \times 2^e$, where m is always a fraction $\frac{1}{2} \leq m \leq 1$, and e is an integer. This function returns a tuple with m and e. The inverse is '`ldexp(m,e)`'.

`ldexp`(m, e)
Calculat $m \times 2^e$, the inverse of '`frexp(x)`'.

6.3 The `random` Module

The `random` module contains a large number of functions for working with distributions of random numbers. There are numerous functions available, but the later exercises will only use these functions.

The `random` module is made available to your program with:

```
import random
```

Here are the definitions of some commonly-used functions.

`choice`(*sequence*)
Chooses a random value from the sequence *sequence*.

```
>>> import random
>>> random.choice( ['red', 'black', 'green'] )
'red'
```

`random`()
A random floating point number, r, such that $0 \leq r < 1.0$.

`randrange`(*[start], stop, [step]*)
Choose a random element from '`range( start, stop, step )`'.

- '`randrange(6)`' returns a number, r, such that $0 \leq r < 6$. There are 6 values between 0 and 5.
- '`randrange(1,7)`' returns a number, r, such that $1 \leq r < 7$. There are 6 values between 1 and 6.
- '`randrange(10,100,5)`' returns a number, such that $10 \leq 5k < 100$. for some integer value of k. These are values $10, 15, 20, ..., 95$.

`randint`(*a, b*)
Choose a random number, r, such that $a \leq r \leq b$. Unlike `randrange()`, this function includes both end-point values.

`uniform`(*a, b*)
Returns a random floating point number, r, such that $a \leq r < b$.

The `randrange()` has two optional values, making it particularly flexible. Here's an example of some of the alternatives.

demorandom.py

```
#!/usr/bin/env python
import random
# Simple Range 0 <= r < 6
print random.randrange(6), random.randrange(6)
# More complex range 1 <= r < 7
print random.randrange(1,7), random.randrange(1,7)
# Really complex range of even numbers between 2 and 36
print random.randrange(2,37,2)
# Odd numbers from 1 to 35
print random.randrange(1,36,2)
```

This demonstrates a number of ways of generating random numbers. It uses the basic `random.randrange()` with a variety of different kinds of arguments.

6.4 Advanced Expression Exercises

1. **Evaluate These Expressions**. The following expressions are somewhat more complex, and use functions from the math module.

   '`math.sqrt( 40.0/3.0 - math.sqrt(12.0) )`'

   '`6.0/5.0*( (math.sqrt(5)+1) / 2 )**2`'

   '`math.log( 2198 ) / math.sqrt( 6 )`'

2. **Run demorandom.py**. Run the `demorandom.py` script several times and save the results. Then add the following statement to the script and run it again several times. What happens when we set an explicit seed?

```
#!/usr/bin/env python
import random
random.seed(1)
...everything else the same
```

Try the following variation, and see what it does.

```
#!/usr/bin/env python
import random, time
random.seed(time.clock())
...everything else the same
```

3. **Wind Chill**. Wind chill is used by meteorologists to describe the effect of cold and wind combined. Given the wind speed in miles per hour, V, and the temperature in °F, T, the Wind Chill, w, is given by the formula below.

Wind Chill, new model

$$35.74 + 0.6215 \times T - 35.75 \times (V^{0.16}) + 0.4275 \times T \times (V^{0.16})$$

Wind Chill, old model

$$0.081 \times (3.71 \times \sqrt{V} + 5.81 - 0.25 \times V) \times (T - 91.4) + 91.4$$

Wind speeds are for 0 to 40 mph, above 40, the difference in wind speed doesn't have much practical impact on how cold you feel.

Write a print statement to compute the wind chill felt when it is -2 °F and the wind is blowing 15 miles per hour.

4. **How Much Does The Atmosphere Weigh? Part 1** From *Slicing Pizzas, Racing Turtles, and Further Adventures in Applied Mathematics*, [Banks02]. Pressure is measured in Newtons, N, $\text{kg} \cdot \text{m/sec}^2$. Air Pressure is is measured in Newtons of force per square meter, N/m^2.

Air Pressure (at sea level) P_0. This is the long-term average.

$$P_0 = 1.01325 \times 10^5$$

Acceleration is measured in m/sec^2. Gravity acceleration (at sea level) g.

$$g = 9.82$$

We can use g to get the kg of mass from the force of air pressure P_0. Apply the acceleration of gravity (in m/sec^2) to the air pressure (in $\text{kg} \cdot \text{m/sec}^2$). This result is mass of the atmosphere in kilograms per square meter (kg/m^2).

$$M_{m^2} = P_0 \times g$$

Given the mass of air per square meter, we need to know how many square meters of surface to apply this mass to.

Radius of Earth R in meters, m. This is an average radius; our planet isn't a perfect sphere.

$$R = 6.37 \times 10^6$$

The area of a Sphere.

$$A = 4\pi r^2$$

Mass of atmosphere (in Kg) is the weight per square meter, times the number of square meters.

$$M_a = P_0 \times g \times A$$

Check: somewhere around 10^{18} kg.

5. **How Much Does The Atmosphere Weigh? Part 2**. From *Slicing Pizzas, Racing Turtles, and Further Adventures in Applied Mathematics*, [Banks02].

   The exercise *How Much Does the Atmosphere Weigh, Part 1* assumes the earth to be an entirely flat sphere. The averge height of the land is actually 840m. We can use the ideal gas law to compute the pressure at this elevation and refine the number a little further.

   Pressure at a given elevation

   $$P = P_0 \times e^{\frac{mg}{RT}z}$$

   Molecular weight of air $m = 28.96 \times 10^{-3}$kg/mol.

   $$m = 28.96 \times 10^{-3}$$

   Gas constant R, in joule/(K $\cdot$ mol).

   $$R = 8.314$$

   Gravity g, in m/sec^2.

   $$g = 9.82$$

   Temperature T, in °K based on temperature C, in °C. We'll just assume that C is 15 °C.

   $$T = 273 + C$$

   Elevation z, in meters, m.

   $$z = 840$$

   This pressure can be used for the air over land, and the pressure computed in *How Much Does the Atmosphere Weigh, Part 1* can be used for the air over the oceans. How much land has this reduced pressure? Reference material gives the following areas in m^2, square meters.

   ocean area: $A_o = 3.61 \times 10^{14}$

   land area: $A_l = 1.49 \times 10^{14}$

   Weight of Atmosphere, adjusted for land elevation

   $$M_l = P_0 \times g \times A_0 + P \times g \times A_l$$

6.5 Bit Manipulation Operators

We've already seen the usual math operators: '`+`', '`-`', '`*`', '`/`', '`%`', '`**`'; as well as the `abs()` and `pow()` functions. There are several other operators available to us. Principally, these are for manipulating the individual bits of an integer value.

We'll look at '`~`', '`&`', '`^`', '`|`', '`<<`' and '`>>`'.

The unary '`~`' operator flops all the bits in a plain or long integer. 1's become 0's and 0's become 1's. Since most hardware uses a technique called 2's complement, this is mathematically equivalent to adding 1 and switching the number's sign.

```
>>> print ~0x12345678
-305419897
```

There are binary bit manipulation operators, also. These perform simple Boolean operations on all bits of the integer at once.

The binary '`&`' operator returns a 1-bit if the two input bits are both 1.

```
>>> print 0&0, 1&0, 1&1, 0&1
0 0 1 0
```

Here's the same kind of example, combining sequences of bits. This takes a bit of conversion to base 2 to understand what's going on.

```
>>> print 3&5
1
```

The number 3, in base 2, is `0011`. The number 5 is `0101`. Let's match up the bits from left to right:

```
  0 0 1 1
& 0 1 0 1
  -------
  0 0 0 1
```

The binary '`^`' operator returns a 1-bit if one of the two inputs are 1 but not both. This is sometimes called the exclusive or.

```
>>> print 3^5
6
```

Let's look at the individual bits

```
  0 0 1 1
^ 0 1 0 1
  -------
  0 1 1 0
```

Which is the binary representation of the number 6.

The binary '`|`' operator returns a 1-bit if either of the two inputs is 1. This is sometimes called the inclusive or. Sometimes this is written *and/or*.

```
>>> print 3|5
7
```

Let's look at the individual bits.

```
  0 0 1 1
| 0 1 0 1
  -------
  0 1 1 1
```

Which is the binary representation of the number 7.

There are also bit shifting operations. These are mathematically equivalent to multiplying and dividing by powers of two. Often, machine hardware can execute these operations faster than the equivalent multiply or divide.

The '<<' is the left-shift operator. The left argument is the bit pattern to be shifted, the right argument is the number of bits.

```
>>> print 0xA << 2
40
```

0xA is hexadecimal; the bits are 1-0-1-0. This is 10 in decimal. When we shift this two bits to the left, it's like multiplying by 4. We get bits of 1-0-1-0-0-0. This is 40 in decimal.

The '>>' is the right-shift operator. The left argument is the bit pattern to be shifted, the right argument is the number of bits. Python always behaves as though it is running on a 2's complement computer. The left-most bit is always the sign bit, so sign bits are shifted in.

```
>>> print 80 >> 3
10
```

The number 80, with bits of 1-0-1-0-0-0-0, shifted right 3 bits, yields bits of 1-0-1-0, which is 10 in decimal.

There are some other operators available, but, strictly speaking, they're not arithmetic operators, they're logic operations. We'll return to them in *Truth, Comparison and Conditional Processing*.

6.6 Division Operators

In general, the data type of an expresion depends on the types of the arguments. This rule meets our expectations for most operators: when we add two integers, the result should be an integer. However, this doesn't work out well for division because there are two different expectations. Sometimes we expect division to create precise answers, usually the floating-point equivalents of fractions. Other times, we want a rounded-down integer result.

The classical Python definition of '/' followed the pattern for other operators: the results depend entirely on the arguments. '685/252' was 2 because both arguments where integers. However, '685./252.' was 2.7182539682539684 because the arguments were floating point.

This definition often caused problems for applications where data types were used that the author hadn't expected. For example, a simple program doing Celsius to Fahrenheit conversions will produce different answers depending on the input. If one user provides '18' and another provides '18.0', the answers were different, even though all of the inputs all had the equal numeric values.

```
>>> 18*9/5+32
64
>>> 18.0*9/5+32
64.400000000000006
>>> 18 == 18.0
True
```

This unexpected inaccuracy was generally due to the casual use of integers where floating-point numbers were more appropriate. (This can also occur using integers where complex numbers were implictly expected.) An explicit conversion function (like float()) can help prevent this. The idea, however, is for Python be a simple and sparse language, without a dense clutter of conversions to cover the rare case of an unexpected data type.

Starting with Python 2.2, a new division operator was added to clarify what is required. There are two division operators: '/' and '//'. The '/' operator should return floating-point results; the '//' operator will always return rounded-down results.

In Python 2.5 and 2.6, the '/' operator can either use "classical" or "old" rules (results depend on the values) or it can use the "new" rule (result is floating-point.) In Python 3.x, this transitional meaning of '/' goes away and it always produces a floating-point result.

Important: Python 3

In Python 3, the '/' operator will always produces a floating-point result. The '//' operator will continue to produce an integer result.

To help with the transition, two tools were made available. This gives programmers a way to keep older applications running; it also gives them a way to explicitly declare that their program uses the newer operator definition. There are two parts to this: a program statememt that can be placed in a program, as well as command-line options that can be used when starting the Python interpreter.

Program Statements. To ease the transition from older to newer language features, there is a `__future__` module available. This module includes a `division` definition that changes the definition of the '/' operator from classical to future. You can include the following **import** statement to state that your program depends on the future definition of division. We'll look at the **import** statement in depth in *Components, Modules and Packages*.

```
from __future__ import division
print 18*9/5+32
print 18*9//5+32
```

This produces the following output. The first line shows the new use of the '/' operator to produce floating point results, even if both arguments are integers. The second line shows the '//' operator, which produces rounded-down results.

```
64.4
64
```

The **from ___future___** statement will set the expectation that your script uses the new-style floating-point division operator. This allows you to start writing programs with version 2.6 that will work correctly with all future versions. By version 3.0, this **import** statement will no longer be necessary, and these will have to be removed from the few modules that used them.

Command Line Options. Another tool to ease the transition are command-line options used when running the Python interpreter. This can force old-style interpretation of the '/' operator or to warn about old-style use of the '/' operator between integers. It can also force new-style use of the '/' operator and report on all potentially incorrect uses of the '/' operator.

The Python interpreter command-line option of '`-Q`' will force the '/' operator to be treated classically ("old"), or with the future ("new") semantics. If you run Python with '`-Qold`' , the '/' operator's result depends on the arguments. If you run Python with '`-Qnew`', the '/' operator's result will be floating point. In either case, the '//' operator returns a rounded-down integer result.

You can use '`-Qold`' to force old modules and programs to work with version 2.2 and higher. When Python 3.0 is released, however, this transition will no longer be supported; by that time you should have fixed your programs and modules.

To make fixing easier, the '`-Q`' command-line option can take two other values: '`warn`' and '`warnall`' . If you use '`-Qwarn`', then the '/' operator applied to integer arguments will generate a run-time warning. This will allow you to find and fix situations where the '//' operator might be more appropriate. If you use '`-Qwarnall`', then all instances of the '/' operator generate a warning; this will give you a close look at your programs.

You can include the command line option when you run the Python interpreter. For Linux and MacOS users, you can also put this on the '`#!`' line at the beginning of your script file.

```
#!/usr/local/bin/python -Qnew
```

CHAPTER

SEVEN

VARIABLES, ASSIGNMENT AND INPUT

The = , augmented = and del Statements

Variables hold the state of our program. In *Variables* we'll introduce variables, then in *The Assignment Statement* we'll cover the basic *assignment* statement for changing the value of a variable. This is followed by an exercise section that refers back to exercises from *Simple Numeric Expressions and Output*. In *Input Functions* we introduce some primitive interactive input functions that are built-in. This is followed by some simple exercises that build on those from section *The Assignment Statement*. We'll cover the multiple assignment statement in *Multiple Assignment Statement*. We'll round on this section with the **del** statement, for removing variables in *The del Statement*.

7.1 Variables

As a procedural program makes progress through the steps from launch to completion, it does so by undergoing changes of state. The state of our program as a whole is the state of all of the program's variables. When one variable changes, the overall state has changed.

Variables are the names your program assigns to the results of an expression. Every variable is created with an initial value. Variables will change to identify new objects and the objects identified by a variable can change their internal state. These three kinds of state changes (variable creation, object assignment, object change) happen as inputs are accepted and our program evaluates expressions. Eventually the state of the variables indicates that we are done, and our program can exit.

A Python variable name must be at least one letter, and can have a string of numbers, letters and '_'s to any length. Names that start with '_' or '__' have special significance. Names that begin with '_' are typically private to a module or class. We'll return to this notion of privacy in *Classes* and *Modules*. Names that begin with '__' are part of the way the Python interpreter is built.

Example variable names:

```
a
pi
aVeryLongName
a_name
__str__
_hidden
```

Tip: Tracing Execution

We can trace the execution of a program by simply following the changes of value of all the variables in the program. For programming newbies, it helps to create a list of variables and write down their changes when studying a program. We'll show an example in the next section.

Python creates new objects as the result of evaluating an expression. Python assigns these objects to new variables with an **assignment** statement. Python removes variables with a **del** statement. The underlying object is later garbage-collected when there are no more variables referring to the object.

Some Consequences. A Python variable is little more than a name which refers to an object. The central issue is to recognize that the underlying object is the essential part of our program; a variable name is just a meaningful label. This has a number of important consequences.

One consequence of a variable being simply a label is that any number of variables can refer to the same object. In other languages (C, C++, Java) there are two kinds of values: primitive and objects, and there are distinct rules for handling the two kinds of values. In Python, every variable is a simple reference to an underlying object. When talking about simple immutable objects, like the number 3, multiple variables referring to a common object is functionally equivalent to having a distinct copy of a primitive value. When talking about mutable objects, like lists, mappings, or complex objects, distinct variable references can change the state of the common object.

Another consequences is that the Python object fully defines it's own *type*. The object's type defines the representation, the range of values and the allowed operations on the object. The type is established when the object is created. For example, floating point addition and long integer objects have different representations, operations of adding these kinds of numbers are different, the objects created by addition are of distinct types. Python uses the type information to choose which addition operation to perform on two values. In the case of an expression with mixed types Python uses the type information to coerce one or both values to a common type.

This also means the "casting" an object to match the declared type of a variable isn't meaningful in Python. You don't use C++ or Java-style casting.

We've already worked with the four numeric types: plain integers, long integers, floating point numbers and complex numbers. We've touched on the string type, also. There are several other built-in types that we will look at in detail in *Data Structures*. Plus, we can use class definitions to define new types to Python, something we'll look at in *Data + Processing = Objects*.

We commonly say that a *static* language associates the type information with the variable. Only values of a certain type can be assigned to a given variable. Python, in contrast, is a *dynamic* language; a variable is just a label or tag attached to the object. Any variable can be associated with an object of any type.

The final consequence of variables referring to objects is that a variable's scope can be independent of the object itself. This means that variables which are in distinct namespaces can refer to the same object. When a function completes execution and the namespace is deleted, the variables are deleted, and the number of variables referring to an object is reduced. Additional variables may still refer to an object, meaning that the object will continue to exist. When only one variable refers to an object, then removing the last variable removes the last reference to the object, and the object can be removed from memory.

Also note that expressions generally create new objects; if an object is not saved in a variable, it silently vanishes. We can safely ignore the results of a function.

Scope and Namespaces. A Python variable is a name which refers to an object. To be useful, each variable must have a *scope* of visibility. The scope is defined as the set of statements that can make use of this variable. A variable with *global scope* can be referenced anywhere. On the other hand, a variable with *local scope* can only be referenced in a limited suite of statements.

This notion of scope is essential to being able to keep a intellectual grip on a program. Programs of even moderate complexity need to keep pools of variables with separate scopes. This allows you to reuse variable names without risk of confusion from inadvertantly changing the value of a variable used elsewhere in a program.

Python collects variables into pools called *namespaces* . A new namespace is created as part of evaluating the body of a function or module, or creating a new object. Additionally, there is one global namespace. This means that each variable (and the state that it implies) is isolated to the execution of a single function or module. By separating all locally scoped variables into separate namespaces, we don't have an endless clutter of global variables.

In the rare case that you need a global variable, the **global** statement is available to assign a variable to the global namespace.

When we introduce functions in *Functions*, classes in *Classes* and modules in *Components, Modules and Packages*, we'll revisit this namespace technique for managing scope. In particular, see *Functions and Namespaces* for a digression on this.

7.2 The Assignment Statement

Assignment is fundamental to Python; it is how the objects created by an expression are preserved. We'll look at the basic assignment statement, plus the augmented assignment statement. Later, in *Multiple Assignment Statement*, we'll look at multiple assignment.

7.2.1 Basic Assignment

We create and change variables primarily with the *assignment* statement. This statement provides an expression and a variable name which will be used to label the value of the expression.

```
variable = expression
```

Here's a short script that contains some examples of assignment statements.

example3.py

```
#!/usr/bin/env python
# Computer the value of a block of stock
shares= 150
price= 3 + 5.0/8.0
value= shares * price
print value
```

1. We have an object, the number `150`, which we assign to the variable `shares`.
2. We have an expression '`3+5.0/8.0`', which creates a floating-point number, which we save in the variable `price`.
3. We have another expression, '`shares * price`', which creates a floating-point number; we save this in `value` so that we can print it. This script created three new variables.

Since this file is new, we'll need to do the **chmod +x example3.py** once, after we create this file. Then, when we run this progam, we see the following.

```
$ ./example3.py
543.75
```

7.2.2 Augmented Assignment

Any of the usual arithmetic operations can be combined with assignment to create an *augmented assignment* statement.

For example, look at this augmented assignment statement:

```
a += v
```

This statement is a shorthand that means the same thing as the following:

```
a = a + v
```

Here's a larger example

portfolio.py

```
#!/usr/bin/env python
# Total value of a portfolio made up of two blocks of stock
portfolio = 0
portfolio += 150 * 2 + 1/4.0
portfolio += 75 * 1 + 7/8.0
print portfolio
```

First, we'll do the **chmod +x portfolio.py** on this file. Then, when we run this progam, we see the following.

```
$ ./portfolio.py
376.125
```

The other basic math operations can be used similarly, although the purpose gets obscure for some operations. These include '`-=`', '`*=`', '`/=`', '`%=`', '`&=`', '`^=`', '`|=`', '`<<=`' and '`>>=`'.

Here's a lengthy example. This is an extension of *Craps Odds* in *Numeric Types and Expressions*.

In craps, the first roll of the dice is called the "come out roll". This roll can be won immediately if the number is 7 or 11. It can be lost immediately if the number is 2, 3 or 12. All of the remaining numbers will establish a point and the game continues.

craps.py

```
#!/usr/bin/env python
# Compute the odds of winning on the first roll
win = 0
win += 6/36.0 # ways to roll a 7
win += 2/36.0 # ways to roll an 11
print "first roll win", win
# Compute the odds of losing on the first roll
lose = 0
lose += 1/36.0 # ways to roll 2
lose += 2/36.0 # ways to roll 3
lose += 1/36.0 # ways to roll 12
print "first roll lose", lose
# Compute the odds of rolling a point number (4, 5, 6, 8, 9 or 10)
```

```
point = 1 # odds must total to 1
point -= win # remove odds of winning
point -= lose # remove odds of losting
print "first roll establishes a point", point
```

There's a 22.2% chance of winning, and a 11.1% chance of losing. What's the chance of establishing a point? One way is to figure that it's what's left after winning or loosing. The total of all probabilities always add to 1. Subtract the odds of winning and the odds of losing and what's left is the odds of setting a point.

Here's another way to figure the odds of rolling 4, 5, 6, 8, 9 or 10.

```
point = 0
point += 2*3/36.0 # ways to roll 4 or 10
point += 2*4/36.0 # ways to roll 5 or 9
point += 2*5/36.0 # ways to roll 6 or 8
print point
```

By the way, you can add the statement '`print win + lose + point`' to confirm that these odds all add to 1. This means that we have defined all possible outcomes for the come out roll in craps.

Tip: Tracing Execution

We can trace the execution of a program by simply following the changes of value of all the variables in the program.

We can step through the planned execution of our Python source statements, writing down the variables and their values on a sheet of paper. From this, we can see the state of our calculation evolve.

When we encounter an assignment statement, we look on our paper for the variable. If we find the variable, we put a line through the old value and write down the new value. If we don't find the variable, we add it to our page with the initial value.

Here's our example from *craps.py script* through the first part of the script. The `win` variable was created and set to '`0`', then the value was replaced with '`0.16`', and then replaced with '`0.22`'. The `lose` variable was then created and set to '`0`'. This is what our trace looks like so far.

win:	0.0	0.16	0.22
lose:	0		

Here's our example when *craps.py script* is finished. We changed the variable `lose` several times. We also added and changed the variable `point`.

win:	0.0	0.16	0.22	
lose:	0.0	0.027	0.083	0.111
point:	1.0	0.77	0.66	

We can use this trace technique to understand what a program means and how it proceeds from its initial state to its final state.

As with many things Python, there is some additional subtlety to assignment, but we'll cover those topics later. For example, *multiple-assignment* statement is something we'll look into in more deeply in *Tuples*.

7.3 Input Functions

Python provides two simplistic built-in functions to accept input and set the value of variables. These are not really suitable for a complete application, but will do for our initial explorations.

Typically, interactive programs which run on a desktop use a complete *graphic user interface* (GUI), often written with the `Tkinter` module or the `pyGTK` module. Interactive programs which run over the Internet use HTML forms.

The primitive interactions we're showing with `input()` and `raw_input()` are only suitable for very simple programs.

Important: Python 3.x

In Python 3, the `raw_input()` function will be renamed to `input()`.

The Python 2 `input()` function will be removed. It's that useless.

Note that some IDE's buffer the program's output, making these functions appear to misbehave. For example, if you use Komodo, you'll need to use the "Run in a New Console" option. If you use BBEdit, you'll have to use the "Run in Terminal" option.

You can enhance these functions somewhat by including the statement '`import readline`'. This module silently and automatically enhances these input functions to give the user the ability to scroll backwards and reuse previous inputs.

You can also '`import rlcompleter`'. This module allows you to define sophisticated keyword auto-completion for these functions.

7.3.1 The `raw_input()` Function

The first way to get interactive input is the `raw_input()` function. This function accepts a string parameter, which is the user's prompt, written to standard output. The next line available on standard input is returned as the value of the function.

`raw_input`(*[prompt]*)
: If a prompt is present, it is written to `sys.stdout`.

  Input is read from `sys.stdin` and returned as a string.

The `raw_input()` function reads from a file often called `sys.stdin`. When running from the command-line, this will be the keyboard, and what you type will be echoed in the command window or **Terminal** window. If you try, however, to run these examples from Textpad, you'll see that Textpad doesn't have any place for you to type any input. In BBEdit, you'll need to use the **Run In Terminal** item in the **#!** menu.

Here's an example script that uses `raw_input()`.

rawdemo.py

```
#!/usr/bin/env python
# show how raw_input works
a= raw_input( "yes?" )
print "you said", a
```

When we run this script from the shell prompt, it looks like the following.

```
MacBook-3:Examples slott$ python rawdemo.py
yes?why not?
you said why not?
```

1. This program begins by evaluating the `raw_input()` function. When `raw_input()` is applied to the parameter of `"yes?"`, it writes the prompt on standard output, and waits for a line of input.

(a) We entered `why not?`.

(b) Once that line was complete, the input string is returned as the value of the function.

(c) The `raw_input()` function's value was assigned to the variable `a`.

2. The second statement printed that variable along with some text.

If we want numeric input, we must convert the resulting string to a number.

stock.py

```
#!/usr/bin/env python
# Compute the value of a block of stock
shares = int( raw_input("shares: ") )
price = float( raw_input("dollars: ") )
price += float( raw_input("eights: ") )/8.0
print "value", shares * price
```

We'll **chmod +x stock.py** this program; then we can run it as many times as we like to get results.

```
MacBook-3:Examples slott$ ./stock.py
shares: 150
dollars: 24
eights: 3
value 3656.25
```

The `raw_input()` mechanism is very limited. If the string returned by `raw_input()` is not suitable for use by `int()`, an exception is raised and the program stops running. We'll cover exception handling in detail in *Exceptions*.

As a teaser, here's what it looks like.

```
MacBook-5:Examples slott$ python stock.py
shares: a bunch
Traceback (most recent call last):
  File "stock.py", line 3, in <module>
    shares = int( raw_input("shares: ") )
ValueError: invalid literal for int() with base 10: 'a bunch'
```

7.3.2 The `input()` Function

In addition to the `raw_input()` function, which returns the exact string of characters, there is the `input()` function. This applies the `eval()` function to the input, which will typically convert numeric input to the appropriate objects.

Important: Python 3

This function will be removed. It's best not to make use of it.

The value of the `input()` function is '`eval( raw_input( prompt ) )`'.

7.4 Multiple Assignment Statement

The basic assignment statement can do more than assign the result of a single expression to a single variable. The assignment satement can also assign multiple variables at one time.

The essential rule is that the left and right side must have the same number of elements.

For example, the following script has several examples of multiple assignment.

line.py

```
#!/usr/bin/env python
# Compute line between two points.
x1,y1 = 2,3 # point one
x2,y2 = 6,8 # point two
m,b = float(y1-y2)/(x1-x2), y1-float(y1-y2)/(x1-x2)*x1
print "y=",m,"*x+",b
```

When we run this program, we get the following output

```
MacBook-3:Examples slott$ ./line.py
y = 1.25 *x+ 0.5
```

We set variables `x1`, `y1`, `x2` and `y2`. Then we computed `m` and `b` from those four variables. Then we printed the `m` and `b`.

The basic rule is that Python evaluates the entire right-hand side of the = statement. Then it matches values with destinations on the left-hand side. If the lists are different lengths, an exception is raised and the program stops.

Because of the complete evaluation of the right-hand side, the following construct works nicely to swap to variables. This is often quite a bit more complicated in other languages.

```
a,b = 1,4
b,a = a,b
print a,b
```

We'll return to this in *Tuples*, where we'll see additional uses for this feature.

7.5 The del Statement

An **assignment** statement creates or locates a variable and then assigns a new object to the variable. This change in state is how our program advances from beginning to termination. Python also provides a mechanism for removing variables, the **del** statement.

The **del** statement looks like this:

```
del object ⟨ , ... ⟩
```

Each *object* is any kind of Python object. Usually these are variables, but they can be functions, modules or classes.

The **del** statement works by *unbinding* the name, removing it from the set of names known to the Python interpreter. If this variable was the last remaining reference to an object, the object will be removed from memory. If, on the other hand, other variables still refer to this object, the object won't be deleted.

C++ Comparison

Programmers familiar with C++ will be pleased to note that memory management is silent and automatic, making programs much more reliable with much less effort. This removal of objects is called *garbage collection*, something that can be rather difficult to manage in larger applications. When garbage collection is done incorrectly, it can lead to *dangling references*: a variable that refers to an object that was deleted prematurely. Poorly designed garbage collection can also lead to *memory leaks*, where unreferenced objects are not properly removed from memory. Because of the automated garbage collection in Python, it suffers from none of these memory management problems.

The **del** statement is typically used only in rare, specialized cases. Ordinary namespace management and garbage collection are generally sufficient for most purposes.

7.6 Interactive Mode Revisited

When we first looked at interactive Python in *Command-Line Interaction* we noted that Python executes assignment statements silently, but prints the results of an expression statement. Consider the following example.

```
>>> pi=355/113.0
>>> area=pi*2.2**2
>>> area
15.205309734513278
```

The first two inputs are complete statements, so there is no response. The third input is just an expression, so there is a response.

It isn't obvious, but the value assigned to `pi` isn't correct. Because we didn't see anything displayed, we didn't get any feedback from our computation of `pi`.

Python, however, has a handy way to help us. When we type a simple expression in interactive Python, it secretly assigns the result to a temporary variable named `_`. This isn't a part of scripting, but is a handy feature of an interactive session.

This comes in handy when exploring something rather complex. Consider this interactive session. We evaluate a couple of expressions, each of which is implicitly assigned to `_`. We can then save the value of `_` in a second variable with an easier-to-remember name, like `pi` or `area`.

```
>>> 335/113.0
2.9646017699115044
>>> 355/113.0
3.1415929203539825
>>> pi=_
>>> pi*2.2**2
15.205309734513278
>>> area=_
>>> area
15.205309734513278
```

Note that we created a floating point object (2.964...), and Python secretly assigned this object to _. Then, we computed a new floating point object (3.141...), which Python assigned to _.

What happened to the first float, 2.964...? Python garbage-collected this object, removing it from memory.

The second float that we created (3.141) was assigned to _. We then assigned it to `pi`, also, giving us two references to the object. When we computed another floating-point value (15.205...), this was assigned to _.

Does this mean our second float, 3.141... was garbage collected? No, it wasn't garbage collected; it was still referenced by the variable `pi`.

7.7 Variables, Assignment and Input Function Exercises

7.7.1 Variables and Assignment

1. **Extend Previous Exercises**. Rework the exercises in *Numeric Types and Expressions*.

   Each of the previous exercises can be rewritten to use variables instead of expressions using only constants. For example, if you want to tackle the Fahrenheit to Celsius problem, you might write something like this:

   ```
   #!/usr/bib/env python
   # Convert 8 C to F
   C=8
   F=32+C*(9./5.)
   print "celsius",C,"fahrenheit",F
   ```

   You'll want to rewrite these exercises using variables to get ready to add input functions.

2. **State Change**. Is it true that all programs simply establish a state?

   It can argued that a controller for a device (like a toaster or a cruise control) simply *maintains* a steady state. The notion of state change as a program moves toward completion doesn't apply because the software is always on. Is this the case, or does the software controlling a device have internal state changes?

   For example, consider a toaster with a thermostat, a "browness" sensor and a single heating element. What are the inputs? What are the outputs? Are there internal states while the toaster is making toast?

7.7.2 Input Functions

Refer back to the exercises in *Numeric Types and Expressions* for formulas and other details. Each of these can be rewritten to use variables and an input conversion. For example, if you want to tackle the Fahrenheit to Celsius problem, you might write something like this:

```
C = raw_input('Celsius: ')
F = 32+C*(9./5.)
print "celsius",C,"fahrenheit",F
```

1. **Stock Value**. Input the number of shares, dollar price and number of 8th's. From these three inputs, compute the total dollar value of the block of stock.
2. **Convert from |deg| C to |deg| F**. Write a short program that will input °C and output °F. A second program will input °F and output °C.

3. **Periodic Payment**. Input the principal, annual percentage rate and number of payments. Compute the monthly payment. Be sure to divide rate by 12 and multiple payments by 12.
4. **Surface Air Consumption Rate**. Write a short program will input the starting pressure, final pressure, time and maximum depth. Compute and print the SACR.

   A second program will input a SACR, starting pressure, final pressure and depth. It will print the time at that depth, and the time at 10 feet more depth.
5. **Wind Chill**. Input a temperature and a wind speed. Output the wind chill.
6. **Force from a Sail**. Input the height of the sail and the length. The surface area is 1/2 ×h ×l. For a wind speed of 25 MPH, compute the force on the sail. Small boat sails are 25-35 feet high and 6-10 feet long.

7.8 Variables and Assignment Style Notes

Spaces are used sparingly in Python. It is common to put spaces around the assignment operator. The recommended style is

```
c = (f-32)*5/9
```

Do not take great pains to line up assignment operators vertically. The following has too much space, and is hard to read, even though it is fussily aligned.

```
a                   = 12
b                   = a*math.log(a)
aVeryLongVariable   = 26
d                   = 13
```

This is considered poor form because Python takes a lot of its look from natural languages and mathematics. This kind of horizontal whitespace is hard to follow: it can get difficult to be sure which expression lines up with which variable. Python programs are meant to be reasonably compact, more like reading a short narrative paragraph or short mathematical formula than reading a page-sized UML diagram.

Variable names are often given as `mixedCase`; variable names typically begin with lower-case letters. The `lower_case_with_underscores` style is also used, but is less popular.

In addition, the following special forms using leading or trailing underscores are recognized:

- `single_trailing_underscore_`: used to avoid conflicts with Python keywords. For example: '`print_ = 42`'
- `__double_leading_and_trailing_underscore__`: used for special objects or attributes, e.g. `__init__`, `__dict__` or `__file__`. These names are reserved; do not use names like these in your programs unless you specifically mean a particular built-in feature of Python.
- `_single_underscore`: means that the variable is "private".

CHAPTER

EIGHT

TRUTH, COMPARISON AND CONDITIONAL PROCESSING

Truth, Comparison and the if Statement, pass and assert Statements.

This section leading up to the **for** and **while** statements, as well as the **break** and **continue** statements.

The elements of Python we've seen so far give us some powerful capabilities. We can write programs that implement a wide variety of requirements. State change is not always as simple as the examples we've seen in *Variables, Assignment and Input*. When we run a script, all of the statements are executed unconditionally. Our programs can't handle alternatives or conditions.

Python provides decision-making mechanisms similar to other programming languages. In *Truth and Logic* we'll look at truth, logic and the logic operators. The exercises that follow examine some subtleties of Python's evaluation rules. In *Comparisons* we'll look at the comparison operators. Then, *Conditional Processing: the if Statement* describes the **if** statement. In *The assert Statement* we'll introduce a handy diagnostic tool, the **assert** statement.

In the next chapter, *Loops and Iterative Processing*, we'll look at looping constructs.

8.1 Truth and Logic

Many times the exact change in state that our program needs to make depends on a condition. A condition is a Boolean expression; an expression that is either `True` or `False`. Generally conditions are on comparisons among variables using the comparison operations.

We'll look at the essential definitions of truth, the logic operations and the comparison operations. This will allow us to build conditions.

8.1.1 Truth

Python represents truth and falsity in a variety of ways.

- `False`. Also 0, the special value `None`, zero-length strings `""`, zero-length lists `[]`, zero-length tuples `()`, empty mappings `{}` are all treated as `False`.
- `True`. Anything else that is not equivalent to `False`.

We try to avoid depending on relatively obscure rules for determining `True` vs. `False`. We prefer to use the two explicit keywords, `True` and `False`. Note that a previous version of Python didn't have the boolean literals, and some older open-source programs will define these values.

Python provides a factory function to collapse these various forms of truth into one of the two explicit boolean objects.

`bool`(*object*)
Returns `True` when the argument `object` is one the values equivalent to truth, `False` otherwise.

8.1.2 Logic

Python provides three basic logic operators that work on this Boolean domain. Note that this Boolean domain, with just two values, `True` and `False`, and these three operators form a complete algebraic system, sometimes called Boolean algebra, after the mathemetician George Boole. The operators supported by Python are **not**, **and** and **or** . We can fully define these operators with rule statements or truth tables.

This truth table shows the evaluation of **not** *x*.

```
print "x", "not x"
print True, not True
print False, not False
```

x	not x
True	False
False	True

This table shows the evaluation of *x* **and** *y* for all combination of `True` and `False`.

```
print "x", "y", "x and y"
print True, True, True and True
print True, False, True and False
print False, True, False and True
print False, False, False and False
```

x	y	x and y
True	True	True
True	False	False
False	True	False
False	False	False

An important feature of **and** is that it does not evaluate all of its parameters before it is applied. If the left-hand side is `False` or one of the equivalent values, the right-hand side is not evaluated, and the left-hand value is returned. We'll look at some examples of this later.

For now, you can try things like the following.

```
print False and 0
print 0 and False
```

This will show you that the first false value is what Python returns for **and**.

This table shows the evaluation of *x* **or** *y* for all combination of `True` and `False`.

x	y	x or y
True	True	True
True	False	True
False	True	True
False	False	False

Parallel with the **and** operator, **or** does not evaluate the right-hand parameter if the left-hand side is `True` or one of the equivalent values.

As a final note, **and** is a high priority operator (analogous to multiplication) and **or** is lower priority (analogous to addition). When evaluating expressions like '`a or b and c`', the **and** operation is evaluated first, followed by the **or** operation.

8.1.3 Exercises

1. **Logic Short-Cuts**. We have several versions of false: `False`, `0`, `None`, `''`, `()`, `[]` and `{}`. We'll cover all of the more advanced versions of false in *Data Structures*. For each of the following, work out the value according to the truth tables and the evaluation rules. Since each truth or false value is unique, we can see which part of the expression was evaluated.
   - '`False and None`'
   - '`0 and None or () and []`'
   - '`True and None or () and []`'
   - '`0 or None and () or []`'
   - '`True or None and () or []`'
   - '`1 or None and 'a' or 'b'`'

8.2 Comparisons

We'll look at the basic comparison operators. We'll also look at the partial evaluation rules of the logic operators to show how we can build more useful expressions. Finally, we'll look at floating-point equality tests, which are sometimes done incorrectly.

8.2.1 Basic Comparisons

We compare values with the comparison operators. These correspond to the mathematical functions of $<$, $\leq$, $>$, $\geq$, $=$ and $\neq$. Conditional expressions are often built using the Python comparison operators: '`<`', '`<=`', '`>`', '`>=`', '`==`' and '`!=`' for less than, less than or equal to, greater than, greater than or equal to, equal to and not equal to.

```
>>> p1 = 22./7.
>>> p2 = 355/113.
>>> p1
3.1428571428571428
>>> p2
3.1415929203539825
>>> p1 < p2
False
>>> p2 >= p2
True
```

When applying a comparison operator, we see a number of steps.

1. Evaluate both argument values.
2. Apply the comparison to create a boolean result.
   (a) Convert both parameters to the same type. Numbers are converted to progressively longer types: plain integer to long integer to float to complex.

(b) Do the comparison.

(c) Return `True` or `False`.

We call out these three steps explicitly because there are some subtleties in comparison among unlike types of data; we'll come to this later when we cover sequences, mappings and classes in *Data Structures*. Generally, it doesn't make sense to compare unlike types of data. After all, you can't ask "Which is larger, the Empire State Building or the color green?"

Comparisons can be combined in Python, unlike most other programming languages. We can ask: '`0 <= a < 6`' which has the usual mathematical meaning. We're not forced to use the longer form: '`0 <= a and a < 6`'.

This is useful when `a` is actually some complex expression that we'd rather not repeat.

Here is an example.

```
>>> 3 < p1 < 3.2
True
>>> 3 < p1 and p1 < 3.2
True
```

Note that the preceding example had a mixture of integers and floating-point numbers. The integers were coerced to floating-point in order to evaluate the expressions.

8.2.2 Partial Evaluation

We can combine the logic operators, comparisons and math. This allows us to use comparisons and logic to prevent common mathematical blunders like attempting to divide by zero, or attempting to take the square root of a negative number.

For example, let's start with this program that will figure the average of 95, 125 and 132.

```
sum = 95 + 125 + 132
count = 3
average = float(sum)/count
print average
```

Initially, we set the variables `sum` and `count` . Then we compute the `average` using `sum` and `count`.

Assume that the statement that computes the average ('`average=...`') is part of a long and complex program. Sometimes that long program will try to compute the average of no numbers at all. This has the same effect as the following short example.

```
sum, count = 0, 0
average = float(sum)/count
print average
```

In the rare case that we have no numbers to average we don't want to crash when we foolishly attempt to divide by zero. We'd prefer to have some more graceful behavior.

Recall from *Truth and Logic* that the **and** operator doesn't evaluate the right-hand side unless the left-hand side is `True`. Stated the other way, the **and** operator *only* evaluates the right side if the left side is `True`. We can guard the division like this:

```
average = count != 0 and sum/count
print average
```

This is an example that can simplify certain kinds of complex processing. If the count is non-zero, the left side is true and the right side must be checked. If the count is zero, the left side is `False`, the result of the complete **and** operation is `False`.

This is a consequence of the meaning of the word *and*. The expression *a and b* means that `a` is true as well as `b` is true. If `a` is false, the value of `b` doesn't really matter, since the whole expression is clearly false. A similar analysis holds for the word *or*. The expression *a or b* means that one of the two is true; it also means that neither of the two is false. If `a` is true, then the value of `b` doesn't change the truth of the whole expression.

The statement "It's cold and rainy" is completely false when it is warm; rain doesn't matter to falsifying the whole statement. Similarly, "I'm stopping for coffee or a newspaper" is true if I've stopped for coffee, irrespective of whether or not I got a newspaper.

8.2.3 Floating-Point Comparisons

Exact equality between floating-point numbers is a dangerous concept. After a lengthy computation, round-off errors in floating point numbers may have infinitesimally small differences. The answers are close enough to equal for all practical purposes, but every single one of the 64 bits may not be identical.

The following technique is the appropriate way to do floating point comparisons.

```
abs(a-b)<0.0001
```

Rather than ask if the two floating point values are the same, we ask if they're close enough to be considered the same. For example, run the following tiny program.

floatequal.py

```
#!/usr/bin/env python
# Are two floating point values really completely equal?
a,b = 1/3.0, .1/.3
print a,b,a==b
print abs(a-b)<0.00001
```

When we run this program, we get the following output

```
$ python floatequal.py
0.333333333333 0.333333333333 False
True
```

The two values appear the same when printed. Yet, on most platforms, the == test returns `False`. They are not precisely the same. This is a consequence of representing real numbers with only a finite amount of binary precision. Certain repeating decimals get truncated, and these truncation errors accumulate in our calculations.

There are ways to avoid this problem; one part of this avoidance is to do the algebra necessary to postpone doing division operations. Division introduces the largest number erroneous bits onto the trailing edge of our numbers. The other part of avoiding the problem is never to compare floating point numbers for exact equality.

8.3 Conditional Processing: the if Statement

Many times the program's exact change in state depends on a condition. Conditional processing is done by setting statements apart in suites with conditions attached to the suites. The Python syntax for this is an **if** statement.

8.3.1 The if Statement

The basic form of an **if** statement provides a condition and a suite of statements that are executed when the condition is true. It looks like this:

```
if expression :
    suite
```

The *suite* is an indented block of statements. Any statement is allowed in the block, including indented **if** statements. You can use either tabs or spaces for indentation. The usual style is four spaces.

This is our first *compound statement*. See *Python Syntax Rules* for some additional guidance on syntax for compound statements.

The **if** statement evaluates the condition *expression* first. When the result is `True`, the *suite* of statements is executed. Otherwise the suite is skipped.

For example, if two dice show a total of 7 or 11, the throw is a winner. In the following snippet, `d1` and `d2` are two dice values that range from 1 to 6.

```
if d1+d2 == 7 or d1+d2 == 11:
    print "winner", d1+d2
```

Here we have a typically complex expression. The **or** operator evaluates the left side first. Python evaluates and applies the high-precendence arithmetic operator before the lower-precendence comparison operator. If the left side is true (`d1 + d2` is 7), the **or** expression is true, and the suite is executed. If the left side is false, then the right side is evaluated. If it is true (`d1 + d2` is 11), the **or** expression is true, and the suite is executed. Otherwise, the suite is skipped.

Python Syntax Rules

Python syntax is very simple. We've already seen how basic expressions and some simple statements are formatted. Here are some syntax rules and examples. Look at *Syntax Formalities* for an overview of the lexical rules.
Compound statements, including **if**, **while**, **for**, have an indented suite of statements. You have a number of choices for indentation; you can use tab characters or spaces. While there is a lot of flexibility, the most important thing is to be consistent.
Further, the recommendation is to use spaces. That's what we'll show. The generally accepted way to format Python code is to set your editor to replace tabs with 4 spaces.
We'll show an example with spaces, shown via ␣.

```
a=0
if␣a==0:
␣␣␣␣print␣"a␣is␣zero"
else:
␣␣␣␣print␣"a␣is␣not␣zero"
if␣a%2==0:
␣␣␣␣print␣"a␣is␣even"
else:
␣␣␣␣print␣"a␣is␣odd"
```

IDLE uses four spaces for indentation automatically. If you're using another editor, you can set it to use four spaces, also.

8.3.2 The elif Clause

Often there are several conditions that need to be handled. This is done by adding **elif** clauses. This is short for "else-if". We can add an unlimited number of **elif** clauses. The **elif** clause has almost the same syntax as the **if** clause.

```
elif expression :
    suite
```

Here is a somewhat more complete rule for the come out roll in a game of craps:

```
result= None
if d1+d2 == 7 or d1+d2 == 11:
    result= "winner"
elif d1+d2 == 2 or d1+d2 == 3 or d1+d2 == 12:
    result= "loser"
print result
```

First, we checked the condition for winning; if the first condition is true, the first suite is executed and the entire **if** statement is complete. If the first condition is false, then the second condition is tested. If that condition is true, the second suite is executed, and the entire **if** statement is complete. If neither condition is true, the **if** statement has no effect.

8.3.3 The else Clause

Python also gives us the capability to put a "catch-all" suite at the end for all other conditions. This is done by adding an **else** clause. The else clause has the following syntax.

```
else:
    suite
```

Here's the complete come-out roll rule, assuming two values `d1` and `d2`.

```
point= None
if d1+d2 == 7 or d1+d2 == 11:
    print "winner"
elif d1+d2 == 2 or d1+d2 == 3 or d1+d2 == 12:
    print "loser"
else:
    point= d1+d2
    print  "point is", point
```

Here, we use the **else:** suite to handle all of the other possible rolls. There are six different values (4, 5, 6, 8, 9, or 10), a tedious typing exercise if done using **or**. We summarize this with the **else:** clause.

While handy in one respect, this **else:** clause is also dangerous. By not explicitly stating the condition, it is possible to overlook simple logic errors.

Consider the following complete **if** statement that checks for a winner on a field bet. A field bet wins on 2, 3, 4, 9, 10, 11 or 12. The payout odds are different on 2 and 12.

```
outcome= 0
if d1+d2 == 2 or d1+d2 == 12:
    outcome= 2
    print "field pays 2:1"
elif d1+d2==4 or d1+d2==9 or d1+d2==10 or d1+d2==11:
    outcome= 1
    print "field pays even money"
else:
    outcome= -1
    print "field loses"
```

Here we test for 2 and 12 in the first clause; we test for 4, 9, 10 and 11 in the second. It's not obvious that a roll of 3 is missing from the even money pay out. This fragment incorrectly treats 3, 5, 6, 7 and 8 alike in the **else:**. While the **else:** clause is used commonly as a catch-all, a more proper use for **else:** is to raise an exception because a condition was not matched by any of the **if** or **elif** clauses.

8.4 The pass Statement

The **pass** statement does nothing. Sometimes we need a placeholder to fill the syntactic requirements of a compound statement. We use the **pass** statement to fill in the required suite of statements.

The syntax is trivial.

```
pass
```

Here's an example of using the pass statement.

```
if n%2 == 0:
    pass # Ignore even values
else:
    count += 1 # Count the odd values
```

Yes, technically, we can invert the logic in the if-clause. However, sometimes it is more clear to provide the explicit "do nothing" than to determine the inverse of the condition in the **if** statement.

As programs grow and evolve, having a **pass** statement can be a handy reminder of places where a program can be expanded.

Also, when we come to class declarations in *Data + Processing = Objects*, we'll see one other use for the **pass** statement.

8.5 The assert Statement

An assertion is a condition that we're claiming should be true at this point in the program. Typically, it summarizes the state of the program's variables. Assertions can help explain the relationships among variables, review what has happened so far in the program, and show that **if** statements and **for** or **while** loops have the desired effect.

When a program is correct, all of the assertions are true no matter what inputs are provided. When a program has an error, at least one assertion winds up false for some combination of inputs.

Python directly supports assertions through an **assert** statement. There are two forms:

```
assert condition
```

```
assert condition , expression
```

If the *condition* is `False`, the program is in error; this statement raises an `AssertionError` exception.

If the *condition* is `True`, the program is correct, this statement does nothing more.

If the second form of the statement is used, and an *expression* is given, an exception is raised using the value of the expression. We'll cover exceptions in detail in *Exceptions*. If the expression is a string, it becomes an the value associated with the `AssertionError` exception.

Note: Additional Features

There is an even more advanced feature of the **assert** statement. If the expression evaluates to a class, that class is used instead of `AssertionError`. This is not widely used, and depends on elements of the language we haven't covered yet.

Here's a typical example:

```
max= 0
if a < b: max= b
if b < a: max= a
assert (max == a or max == b) and max >= a and max >= b
```

If the assertion condition is true, the program continues. If the assertion condition is false, the program raises an `AssertionError` exception and stops, showing the line where the problem was found.

Run this program with `a` equal to `b` and not equal to zero; it will raise the `AssertionError` exception. Clearly, the **if** statements don't set `max` to the largest of `a` and `b` when `a = b` . There is a problem in the **if** statements, and the presence of the problem is revealed by the assertion.

8.6 The if-else Operator

There are situations where an expression involves a simple condition and a full-sized **if** statement is distracting syntatic overkill. Python has a handy logic operator that evalutes a condition, then returns either of two values depending on that condition.

"Ternary Operator"

Most arithmetic and logic operators have either one or two values. An operation that applies to a single value is called *unary*. For example '`-a`' and '`abs(b)`' are examples of unary operations: unary negation and unary absolute value. An operation that applies to two values is called binary. For example, '`a*b`' shows the binary multiplication operator.
The if-else operator trinary (or "ternary") It involves a conditional expression and two alternative expressions. Consequently, it doesn't use a single special character, but uses two keywords: '`if`' and '`else`'.
Some folks will mistakenly call it *the* ternary operator as if this is the only possible ternary operator.

The basic form of the operator is

```
expression if condition else expression
```

Python evaluates the condition – in the middle – first. If the condition is `True`, then the left-hand expression is evaluated, and that's the value of the operation. If the condition is `False`, then the right-hand expression is evaluated, and that's the value of the operation.

Note that the condition is always evaluated. Only one of the other two expressions is evaluated, making this a kind of short-cut operator like **and** and **or**.

Here are a couple of examples.

```
average = sum/count if count != 0 else None
```

```
oddSum = oddSum + ( n if n % 2 == 1 else 0 )
```

The intent is to have an English-like reading of the statement. "The average is the sum divided by the count if the count is non-zero; else the average is None".

The wordy alterative to the first example is the following.

```
if count != 0:
    average= sum/count
else:
    average= None
```

This seems like three extra lines of code to prevent an error in the rare situation of there being no values to average.

Similarly, the wordy version of the second example is the following:

```
if n % 2 == 0:
    pass
else:
    oddSum = oddSum + n
```

For this second example, the original statement registered our intent very clearly: we were summing the odd values. The long-winded if-statement tends to obscure our goal by making it just one branch of the if-statement.

8.7 Condition Exercises

1. **Develop an "or-guard"**. In the example above we showed the "and-guard" pattern:

   ```
   average = count != 0 and float(sum)/count
   ```

   Develop a similar technique using **or**.

   Compare this with the **if-else** operator.

2. **Come Out Win**. Assume `d1` and `d2` have the numbers on two dice. Assume this is the come out roll in Craps. Write the expression for winning (7 or 11). Write the expression for losing (2, 3 or 12). Write the expression for a point (4, 5, 6, 8, 9 or 10).

3. **Field Win**. Assume `d1` and `d2` have the numbers on 2 dice. The field pays on 2, 3, 4, 9, 10, 11 or 12. Actually there are two conditions: 2 and 12 pay at one set of odds (2:1) and the other 5 numbers pay at even money. Write two two conditions under which the field pays.

4. **Hardways**. Assume `d1` and `d2` have the numbers on 2 dice. A hardways proposition is 4, 6, 8, or 10 with both dice having the same value. It's the hard way to get the number. A hard 4, for instance is '`d1+d2 == 4 and d1 == d2`'. An easy 4 is '`d1+d2 == 4 and d1 != d2`'.

   You win a hardways bet if you get the number the hard way. You lose if you get the number the easy way or you get a seven. Write the winning and losing condition for one of the four hard ways bets.

5. **Sort Three Numbers**. This is an exercise in constructing if-statements. Using only simple variables and if statements, you should be able to get this to work; a loop is not needed.

   Given 3 numbers (X, Y, Z), assign variables `x`, `y`, `z` so that $x \leq y \leq z$ and `x` , `y`, and `z` are from X, Y, and Z. Use only a series of if-statements and assignment statements.

   Hint. You must define the conditions under which you choose between `x` $\leftarrow X$, `x` $\leftarrow Y$ or `x` $\leftarrow Z$. You will do a similar analysis for assigning values to `y` and `z`. Note that your analysis for setting `y` will depend on the value set for `x`; similarly, your analysis for setting `z` will depend on values set for `x` and `y`.

6. **Come Out Roll**. Accept `d1` and `d2` as input. First, check to see that they are in the proper range for dice. If not, print a message.

   Otherwise, determine the outcome if this is the come out roll. If the sum is 7 or 11, print winner. If the sum is 2, 3 or 12, print loser. Otherwise print the point.

7. **Field Roll**. Accept `d1` and `d2` as input. First, check to see that they are in the proper range for dice. If not, print a message.

   Otherwise, check for any field bet pay out. A roll of 2 or 12 pays 2:1, print "pays 2"; 3, 4, 9, 10 and 11 pays 1:1, print "pays even"; everything else loses, print "loses"

8. **Hardways Roll**. Accept `d1` and `d2` as input. First, check to see that they are in the proper range for dice. If not, print a message.

   Otherwise, check for a hard ways bet pay out. Hard 4 and 10 pays 7:1; Hard 6 and 8 pay 9:1, easy 4, 6, 8 or 10, or any 7 loses. Everything else, the bet still stands.

9. **Partial Evaluation**. This partial evaluation of the **and** and **or** operators appears to violate the evaluate-apply principle espoused in *The Evaluate-Apply Cycle*. Instead of evaluating all parameters, these operators seem to evaluate only the left-hand parameter before they are applied. Is this special case a problem? Can these operators be removed from the language, and replaced with the simple **if** -statement? What are the consequences of removing the short-circuit logic operators?

8.8 Condition Style Notes

Now that we have introduced compound statements, you may need to make an adjustment to your editor. Set your editor to use spaces instead of tabs. Most Python is typed using four spaces instead of the ASCII tab character (`^I`). Most editors can be set so that when you hit the `Tab` key on your keyboard, the editor inserts four spaces. **IDLE** is set up this way by default. A good editor will follow the indents so that once you indent, the next line is automatically indented.

We'll show the spaces explicitly as ␣ in the following fragment.

```
if␣a␣>=␣b:
␣␣␣␣m␣=␣a
if␣b␣>=␣a:
␣␣␣␣m␣=␣b
```

This is has typical spacing for a piece of Python programming.

Note that the colon (':') immediately follows the condition. This is the usual format, and is consistent with the way natural languages (like English) are formatted.

These **if** statements can be collapsed to one-liners, in which case they would look like this:

```
if␣a␣>=␣b:␣m␣=␣a
if␣b␣>=␣a:␣m␣=␣b
```

It helps to limit your lines to 80 positions or less. You may need to break long statements with a \\ at the end of a line. Also, parenthesized expressions can be continued onto the next line without a \\. Some programmers will put in extra ()'s just to make line breaks neat.

While spaces are used sparingly, they are always used to set off comparison operators and boolean operators. Other mathematical operators may or may not be set off with spaces. This makes the comparisons stand out in an **if** statement or **while** statement.

```
if␣b**2-4*a*c␣<␣0:
␣␣␣␣print␣"no␣root"
```

This shows the space around the comparison, but not the other arithmetic operators.

CHAPTER

NINE

LOOPS AND ITERATIVE PROCESSING

The for, while, break, continue Statements

The elements of Python we've seen so far give us some powerful capabilities. We can write programs that implement a wide variety of requirements. State change is not always as simple as the examples we've seen in *Variables, Assignment and Input*.

In *Truth, Comparison and Conditional Processing* we saw how to make our programs handle handle alternatives or conditions. In this section, we'll see how to write programs which do their processing "for all" pieces of data. For example, when we compute an average, we compute a sum *for all* of the values.

Python provides iteration (sometimes called looping) similar to other programming languages. In *Iterative Processing: For All and There Exists* we'll describe the semantics of iterative statements in general. In *Iterative Processing: The for Statement* we'll describe the **for** statement. We'll cover the **while** statements in *Iterative Processing: The while Statement*.

This is followed by some of the most interesting and challenging short exercises in this book. We'll add some iteration control in *More Iteration Control: break and continue*, describing the **break** and **continue** statements. We'll conclude this chapter with a digression on the correct ways to develop iterative and conditional statements in *A Digression*.

9.1 Iterative Processing: For All and There Exists

There are two common qualifiers used for logical conditions. These are sometimes called the universal and existential qualifiers. We can call the "for all" and "there exists". We can also call them the "all" and "any" qualifiers.

A program may involve a state that is best described as a "for all" state, where a number of repetitions of some task are required. For example, if we were to write a program to simulate 100 rolls of two dice, the terminating condition for our program would be that we had done the simulation *for all* 100 rolls.

Similary, we may have a condition that looks for existence of a single example. We might want to know if a file contains a line with "ERROR" in it. In this case, we want to write a program with a terminating condition would be that *there exists* an error line in the log file.

It turns out that All and Any are logical inverses. We can always rework a "for any" condition to be a "for all" condition. A program that determines if there exists an error line is the same as a program that determines that all lines are not error lines.

Any time we have a "for all" or "for any" condition, we have an iteration: we will be iterating through the set of values, evaluating the condition. We have a choice of two Python statements for expressing this iteration. One is the **for** statement and the other is the **while** statement.

9.2 Iterative Processing: The for Statement

The simplest **for** statement looks like this:

```
for variable in iterable :
    suite
```

The *suite* is an indented block of statements. Any statement is allowed in the block, including indented **for** statements.

The *variable* is a variable name. The *suite* will be executed iteratively with the variable set to each of the values in the given *iterable*. Typically, the *suite* will use the *variable*, expecting it to have a distinct value on each pass.

There are a number of ways of creating the necessary *iterable* collection of values. The most common is to use the `range()` function to generate a suitable list. We can also create the list manually, using a sequence display; we'll show some examples here. We'll return to the details of sequences in *Sequences: Strings, Tuples and Lists*.

The `range()` function has 3 forms:

- '`range(x)`' generates x distinct values, from 0 to x-1, incrementing by 1.

  Mathematicians describe this as a "half-open interval" and write it $[0, x)$.

- '`range(x, y)`' generates $y - x$ distinct values from x to y-1, incrementing by 1. $[x, y)$.

- '`range(x, y, z)`' generates values from x to y-1, incrementing by z: $[x, x + z, x + 2z, ..., x + kz < y]$, for some integer k.

A sequence display looks like this: '`[`''`]`'

```
 expression ⟨ , ... ⟩
```

It's a list of expressions, usually simply numbers, separated by commas. The square brackets are essential for marking a sequence.

Here are some examples.

```
for i in range(6):
    print i+1
```

This first example uses `range()` to create a sequence of 6 values from 0 to just before 6. The **for** statement iterates through the sequence, assigning each value to the local variable `i`. The **print** statement has an expression that adds one to `i` and prints the resulting value.

```
for j in range(1,7):
    print j
```

This second example uses the `range()` to create a sequence of 6 values from 1 to just before 7. The **for** statement iterates through the sequence, assigning each value to the local variable `j` . The **print** statement prints the value.

```
for o in range(1,36,2):
    print o
```

This example uses `range()` to create a sequence of 36/2=18 values from 1 to just before 36 stepping by 2. This will be a list of odd values from 1 to 35. The **for** statement iterates through the sequence, assigning each value to the local variable `o`. The **print** statement prints all 18 values.

```
for r in [1,3,5,7,9,12,14,16,18,19,21,23,25,27,30,32,34,36]:
    print r, "red"
```

This example uses an explicit sequence of values. These are all of the red numbers on a standard roulette wheel. It then iterates through the sequence, assigning each value to the local variable `r`. The **print** statement prints all 18 values followed by the word "red".

Here's a more complex example, showing nested **for** statements. This enumerates all the 36 outcomes of rolling two dice.

```
for d1 in range(6):
    for d2 in range(6):
        print d1+1,d2+1,'=',d1+d2+2
```

1. The outer **for** statement uses `range()` to create a sequence of 6 values, and iterates through the sequence, assigning each value to the local variable `d1`.
2. For each value of `d1`, the inner loop creates a sequence of 6 values, and iterates through that sequence, assigning each value to `d2`.
3. The **print** statement will be executed 36 times.

Here's the example alluded to earlier, which does 100 simulations of rolling two dice.

```
import random
for i in range(100):
    d1= random.randrange(6)+1
    d2= random.randrange(6)+1
    print d1+d2
```

1. The **for** statement uses `range()` to create a sequence of 100 values, assigns each value to the local variable `i`.

   Note that the suite of statements never actually uses the value of `i`. The value of `i` marks the state changes until the loop is complete, but isn't used for anything else.
2. For each value of `i`, two values are created, `d1` and `d2`.
3. The sum of `d1` and `d2` is printed.

There are a number of more advanced forms of the **for** statement, which we'll cover in the section on sequences in *Sequences: Strings, Tuples and Lists*.

9.3 Iterative Processing: The while Statement

The **while** statement looks like this:

```
while expression :
    suite
```

The *suite* is an indented block of statements. Any statement is allowed in the block, including indented **while** statements.

As long as the *expression* is true, the *suite* is executed. This allows us to construct a suite that steps through all of the necessary tasks to reach a terminating condition. It is important to note that the suite of statements must include a change to at least one of the variables in the **while** *expression*. When it is possible to execute the suite of statements without changing any of the variables in the **while** *expression*, the loop will not terminate.

Let's look at some examples.

```
t, s = 1, 1
while t != 9:
    t, s = t + 2, s + t
```

1. The loop is initialized with `t` and `s` each set to 1.
2. We specify that the loop continues while $t \neq 9$.
3. In the body of the loop, we increment `t` by 2, so that it will be an odd value; we increment `s` by `t`, summing a sequence of odd values.

When this loop is done, `t` is 9, and `s` is the sum of odd numbers less than 9: 1+3+5+7. Also note that the **while** condition depends on `t`, so changing `t` is absolutely critical in the body of the loop.

Here's a more complex example. This sums 100 dice rolls to compute an average.

```
s, r = 0, 0
while r != 100:
    d1,d2=random.randrange(6)+1,random.randrange(6)+1
    s,r = s + d1+d2, r + 1
print s/r
```

1. We initialize the loop with `s` and `r` both set to zero.
2. The **while** statement specifies that during the loop `r` will not be 100; when the loop is done, `r` will be 100.
3. The body of the loop sets `d1` and `d2` to random numbers; it increments `s` by the sum of those dice, and it increments `r` by 1.

When the loop is over, `s` will be the sum of 100 rolls of two dice. When we print, '`s/r`' we print the average rolled on two dice. The loop condition depends on `r`, so each trip through the loop must update `r`.

9.4 More Iteration Control: break and continue

Python offers several statements for more subtle loop control. The point of these statements is to permit two common simplifications of a loop. In each case, these statements can be replaced with **if** statements; however, those **if** statement versions might be considered rather complex for expressing some fairly common situations.

The **break** statement terminates a loop prematurely.

The syntax is trivial:

```
break
```

A **break** statement is always found within an **if** statement within the body of a **for** or **while** loop. A **break** statement is typically used when the terminating condition is too complex to write as an expression in the **while** clause of a loop. A **break** statement is also used when a **for** loop must be abandoned before the end of the sequence has been reached.

The **coninue** statement skips the rest of a loop's indented suite.

The syntax is trivial:

```
continue
```

A **continue** statements is always found within an **if** statement within a **for** or **while** loop. The **continue** statement is used instead of deeply nested **else** clauses.

Here's an example that has a complex **break** condition. We are going to see if we get six odd numbers in a row, or spin the roulette wheel 100 times.

We'll look at this in some depth because it pulls a number of features together in one program. This program shows both **break** and **continue** constructs. Most programs can actually be simplified by eliminating the **break** and **continue** statements. In this case, we didn't simplify, just to show how the statements are used.

Note that we have a two part terminating condition: 100 spins *or* six odd numbers in a row. The hundred spins is relatively easy to define using the `range()` function. The six odd numbers in a row requires testing and counting and then, possibly, ending the loop. The overall ending condition for the loop, then, is the number of spins is 100 or the count of odd numbers in a row is six.

sixodd.py

```
from __future__ import print_function
import random
oddCount= 0
for s in range(100):
    spinCount= s
    n= random.randrange(38)
    # Zero
    if n == 0 or n == 37: # treat 37 as 00
        oddCount = 0
        continue
    # Odd
    if n%2 == 1:
        oddCount += 1
        if oddCount == 6: break
        continue
    # Even
    assert n%2 == 0 and 0 < n <= 36
    oddCount = 0
print( oddCount, spinCount )
```

1. We import the `print_function` module to allow use of the `print()` function intead of the **print** statement.
2. We import the `random` module, so that we can generate a random sequence of spins of a roulette wheel.
3. We initialize `oddCount`, our count of odd numbers seen in a row. It starts at zero, because we haven't seen any add numbers yet.
4. The **for** statement will assign 100 different values to `s`, such that $0 \leq s < 100$. This will control our experiment to do 100 spins of the wheel.

5. We save the current value of `s` in a variable called `spinCount`, setting up part of our post condition for this loop. We need to know how many spins were done, since one of the exit conditions is that we did 100 spins and never saw six odd values in a row. This "never saw six in a row" exit condition is handled by the **for** statement itself.

6. We'll treat 37 as if it were 00, which is like zero. In Roulette, these two numbers are neither even nor odd. The `oddCount` is set to zero, and the loop is continued. This **continue** statement resumes loop with the next value of `s`. It restarts processing at the top of the **for** statement suite.

7. We check the value of `oddCount` to see if it has reached six. If it has, one of the exit conditions is satisfied, and we can break out of the loop entirely. We use the **break** statement will stop executing statements in the suite of the **for** statement. If `oddCount` is not six, we don't break out of the loop, we use the **continue** statement to restart the **for** statement statement suite from the top with a new value for `s`.

8. We threw in an **assert** statement (see the next section, *The assert Statement* for more information) to claim that the spin, `n`, is even and not 0 or 37. This is kind of a safety net. If either of the preceding **if** statements were incorrect, or a **continue** statement was omitted, this statement would uncover that fact. We could do this with another **if** statement, but we wanted to introduce the **assert** statement.

At the end of the loop, `spinCount` is the number of spins and `oddCount` is the most recent count of odd numbers in a row. Either `oddCount` is six or `spinCount` is 99. When `spinCount` is 99, that means that spins 0 through 99 were examined; there are 100 different numbers between 0 and 99.

9.5 Iteration Exercises

1. **Greatest Common Divisor**. The greatest common divisor is the largest number which will evenly divide two other numbers. Examples: GCD(5, 10) = 5, the largest number that evenly divides 5 and 10. GCD(21, 28) = 7, the largest number that divides 21 and 28. GCD's are used to reduce fractions. Once you have the GCD of the numerator and denominator, they can both be divided by the GCD to reduce the fraction to simplest form. 21/28 reduces to 3/4.

Greatest Common Divisor of two integers, *p* and *q*

Loop. Loop until $p = q$.

Swap. If $p < q$ then swap p and q, $p \leftrightarrows q$.

Subtract. If $p > q$ then subtract q from p, $p \leftarrow p - q$.

Result. Print p

2. **Extracting the Square Root**. This is a procedure for approximating the square root. It works by dividing the interval which contains the square root in half. Initially, we know the square root of the number is somewhere between 0 and the number. We locate a value in the middle of this interval and determine of the square root is more or less than this midpoint. We continually divide the intervals in half until we arrive at an interval which is small enough and contains the square root. If the interval is only 0.001 in width, then we have the square root accurate to 0.001

Square Root of a number, *n*

Two Initial Guesses.

$g_1 \leftarrow 0$

$g_2 \leftarrow n$

At this point, $g_1 \times g_1 - n \leq 0 \leq g_2 \times g_2 - n$.

Loop. Loop until $|g_1 \times g_1 - n| \div n < 0.001$.

Midpoint. $mid \leftarrow (g_1 + g_2) \div 2$

Midpoint Squared vs. Number. $cmp \leftarrow mid \times mid - n$

Which Interval?

if $cmp \leq 0$ then $g_1 \leftarrow mid$.

if $cmp \geq 0$ then $g_2 \leftarrow mid$.

if $cmp = 0$, mid is the exact answer!

Result. Print g_1

3. **Sort Four Numbers**. This is a challenging exercise in if-statement construction. For some additional insight, see [Dijkstra76], page 61.

   Given 4 numbers (W, X, Y, Z)

   Assign variables `w`, `x`, `y`, `z` so that $w \leq x \leq y \leq z$ and `w`, `x`, `y`, `z` are from W, X, Y, and Z.

   Do not use an array. One way to guarantee the second part of the above is to initialize `w`, `x`, `y`, `z` to W, X, Y, Z, and then use swapping to rearrange the variables.

   Hint: There are only a limited combination of out-of-order conditions among four variables. You can design a sequence of if statements, each of which fixes one of the out-of-order conditions. This sequence of if statements can be put into a loop. Once all of the out-of-order conditions are fixed, the numbers are in order, the loop can end.

4. **Highest Power of 2**. This can be used to determine how many bits are required to represent a number. We want the highest power of 2 which is less than or equal to our target number. For example $64 \leq 100 < 128$. The highest power of $2^5 \leq 100 < 2^6$.

   Given a number n, find a number p such that $2^p \leq n < 2^{p+1}$.

   This can be done with only addition and multiplication by 2. Multiplication by 2, but the way, can be done with the '`<<`' shift operator. Do not use the `pow()` function, or even the '`**`' operator, as these are too slow for our purposes.

   Consider using a variable c, which you keep equal to 2^p. An initialization might be '`p = 1`', '`c = 2`'. When you increment p by 1, you also double c.

   Develop your own loop. This is actually quite challenging, even though the resulting program is tiny. For additional insight, see [Gries81], page 147.

5. **How Much Effort to Produce Software?** The following equations are the basic COCOMO estimating model, described in [Boehm81]. The input, K, is the number of 1000's of lines of source; that is total source lines divided by 1000. Development Effort, where K is the number of 1000's of lines of source. E is effort in staff-months.

   $$E = 2.4 \times K^{1.05}$$

   Development Cost, where E is effort in staff-months, R is the billing rate. C is the cost in dollars (assuming 152 working hours per staff-month)

   $$C = E \times R \times 152$$

Project Duration, where E is effort in staff-months. D is duration in calendar months.

$$D = 2.5 \times E^{0.38}$$

Staffing, where E is effort in staff-months, D is duration in calendar months. S is the average staff size.

$$S = \frac{E}{D}$$

Evaluate these functions for projects which range in size from 8,000 lines ($K = 8$) to 64,000 lines ($K = 64$) in steps of 8. Produce a table with lines of source, Effort, Duration, Cost and Staff size.

6. **Wind Chill Table**. Wind chill is used by meteorologists to describe the effect of cold and wind combined. Given the wind speed in miles per hour, V, and the temperature in °F, T, the Wind Chill, w, is given by the formula below. See *Wind Chill* in *Numeric Types and Expressions* for more information.

$$35.74 + 0.6215 \times T - 35.75 \times (V^{0.16}) + 0.4275 \times T \times (V^{0.16})$$

Wind speeds are for 0 to 40 mph, above 40, the difference in wind speed doesn't have much practical impact on how cold you feel.

Evaluate this for all values of V (wind speed) from 0 to 40 mph in steps of 5, and all values of T (temperature) from -10 to 40 in steps of 5.

7. **Celsius to Fahrenheit Conversion Tables**. We'll make two slightly different conversion tables. For values of Celsius from -20 to +30 in steps of 5, produce the equivalent Fahrenheit temperature. The following formula converts C (Celsius) to F (Fahrenheit).

$$F = 32 + \frac{212 - 32}{100} \times C$$

For values of Fahrenheit from -10 to 100 in steps of 5, produce the equivalent Celsius temperatures. The following formula converts F (Fahrenheit) to C (Celsius).

$$C = (F - 32) \times \frac{100}{212 - 32}$$

8. **Dive Planning Table**. Given a surface air consumption rate, c, and the starting, s, and final, f, pressure in the air tank, a diver can determine maximum depths and times for a dive. For more information, see *Surface Air Consumption Rate* in *Numeric Types and Expressions*. Accept c, s and f from input, then evaluate the following for d from 30 to 120 in steps of 10. Print a table of t and d.

For each diver, c is pretty constant, and can be anywhere from 10 to 20, use 15 for this example. Also, s and f depend on the tank used, typical values are s =2500 and f =500.

$$t = \frac{33(s - f)}{c(d + 33)}$$

9. **Computing** π. Each of the following series compute increasingly accurate values of π (3.1415926...)

- $\frac{\pi}{4} = 1 - \frac{1}{3} + \frac{1}{5} - \frac{1}{7} + \frac{1}{9} - \frac{1}{11} + \cdots$
- $\frac{\pi^2}{6} = 1 + \frac{1}{2^2} + \frac{1}{3^2} + \frac{1}{4^2} + \cdots$
- $\pi = \sum_{0 \le k < \infty} \left(\frac{1}{16}\right)^k \left(\frac{4}{8k+1} - \frac{2}{8k+4} - \frac{1}{8k+5} - \frac{1}{8k+6}\right)$

- $\pi = 1 + \frac{1}{3} + \frac{1 \cdot 2}{3 \cdot 5} + \frac{1 \cdot 2 \cdot 3}{3 \cdot 5 \cdot 7} + \cdots$

10. **Computing** *e*. A logarithm is a power of some base. When we use logarithms, we can effectively multiply numbers using addition, and raise to powers using multiplication. Two Python built-in functions are related to this: `math.log()` and `math.exp()` . Both of these compute what are called natural logarithms, that is, logarithms where the base is e . This constant, e, is available in the `math` module, and it has the following formal definition: Definition of e.

$$e = \sum_{0 \le k < \infty} \frac{1}{k!}$$

For more information on the (Σ) operator, see *Digression on The Sigma Operator*.

The $n!$ operator is "factorial". Interestingly, it's a post-fix operator, it comes *after* the value it applies to.

$$n! = n \times (n-1) \times (n-2) \times \cdots \times 1.$$

For example, $4! = 4 \times 3 \times 2 \times 1 = 24$. By definition, $0! = 1$.

If we add up the values $\frac{1}{0!} + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \cdots$ we get the value of e. Clearly, when we get to about 1/10!, the fraction is so small it doesn't contribute much to the total.

We can do this with two loops, an outer loop to sum up the $\frac{1}{k!}$ terms, and an inner loop to compute the $k!$.

However, if we have a temporary value of $k!$, then each time through the loop we can multiply this temporary by k, and then add $1/temp$ to the sum.

You can test by comparing your results against `math.e`, $e \approx 2.71828$ or '`math.exp(1.0)`'.

11. *Hailstone Numbers*. For additional information, see [Banks02].

Start with a small number, n, $1 \le n < 30$.

There are two transformation rules that we will use:

- If n is odd, multiple by 3 and add 1 to create a new value for n.
- If n is even, divide by 2 to create a new value for n.

Perform a loop with these two transformation rules until you get to $n = 1$. You'll note that when $n = 1$, you get a repeating sequence of 1, 4, 2, 1, 4, 2, ...

You can test for oddness using the % (remainder) operation. If '`n % 2 == 1`' , the number is odd, otherwise it is even.

The two interesting facts are the "path length", the number of steps until you get to 1, and the maximum value found during the process.

Tabulate the path lengths and maximum values for numbers 1..30. You'll need an outer loop that ranges from 1 to 30. You'll need an inner loop to perform the two steps for computing a new n until $n == 1$; this inner loop will also count the number of steps and accumulate the maximum value seen during the process.

Check: for 27, the path length is 111, and the maximum value is 9232.

9.6 Condition and Loops Style Notes

As additional syntax, the **for** and **while** statements permits an **else** clause. This is a suite of statements that are executed when the loop terminates normally. This suite is skipped if the loop is terminated by a

break statement. The **else** clause on a loop might be used for some post-loop cleanup. This is so unlike other programming languages, that it is hard to justify using it.

An **else** clause always raises a small problem when it is used. It's never perfectly clear what conditions lead to execution of an **else** clause. The condition that applies has to be worked out from context. For instance, in **if** statements, one explicitly states the exact condition for all of the **if** and **elif** clauses. The logical inverse of this condition is assumed as the **else** condition. It is, unfortunately, left to the person reading the program to work out what this condition actually is.

Similarly, the **else** clause of a **while** statement is the basic loop termination condition, with all of the conditions on any **break** statements removed. The following kind of analysis can be used to work out the condition under which the else clause is executed.

```
while not BB:
    if C1: break
    if C2: break
else:
    assert BB and not C1 and not C2
assert BB or C1 or C2
```

Because this analysis can be difficult, it is best to avoid the use of **else** clauses in loop constructs.

9.7 A Digression

For those new to programming, here's a short digression, adapted from chapter 8 of Edsger Dijkstra's book, *A Discipline of Programming* [Dijkstra76].

Let's say we need to set a variable, `m`, to the larger of two input values, `a` and `b`. We start with a state we could call "`m` undefined". Then we want to execute a statement after which we are in a state of ($m = a$ or $m = b$) and $m \leq a$ and $m \leq b$.

Clearly, we need to choose correctly between two different **assignment** statements. We need to do either '`m=a`' or '`m=b`'. How do we make this choice? With a little logic, we can derive the condition by taking each of these statement's effects out of the desired end-state.

For the statement '`m=a`' to be the right statement to use, we show the effect of the statement by replacing `m` with the value `a`, and examining the end state: ($a = a$ or $a = b$) and $a \leq a$ and $a \leq b$. Removing the parts that are obviously true, we're left with $a \leq b$. Therefore, the assignment '`m=a`' is only useful when '`a <= b`'.

For the statement **m=b** to be the right statement to establish the necessary condition, we do a similar replacement of `b` for `m` and examine the end state: ($b = a$ or $b = b$) and $b \leq a$ and $b \leq b$. Again, we remove the parts that are obviously true and we're left with $b \leq a$. Therefore, the assignment '`m=b`' is only useful when '`b <= a`'.

Each assignment statement can be "guarded" by an appropriate condition.

```
if a>=b: m=a
elif b>=a: m=b
```

Is the correct statement to set `m` to the larger of `a` or `b`.

Note that the hard part is establishing the post condition. Once we have that stated correctly, it's relatively easy to figure the basic kind of statement that might make some or all of the post condition true. Then we do a little algebra to fill in any guards or loop conditions to make sure that only the correct statement is executed.

Successful Loop Design. There are several considerations when using the **while** statement. This list is taken from David Gries', *The Science of Programming* [Gries81].

1. The body condition must be initialized properly.
2. At the end of the suite, the body condition is just as true as it was after initialization. This is called the *invariant* , because it is always true during the loop.
3. When this body condition is true and the while condition is false, the loop will have completed properly.
4. When the while condition is true, there are more iterations left to do. If we wanted to, we could define a mathematical function based on the current state that computes how many iterations are left to do; this function must have a value greater than zero when the while condition is true.
5. Each time through the loop we change the state of our variables so that we are getting closer to making the while condition false; we reduce the number of iterations left to do.

While these conditions seem overly complex for something so simple as a loop, many programming problems arise from missing one of them.

Gries recommends putting comments around a loop showing the conditions before and after the loop. Since Python provides the **assert** statement; this formalizes these comments into actual tests to be sure the program is correct.

Designing a Loop. Let's put a particular loop under the microscope. This is a small example, but shows all of the steps to loop construction. We want to find the least power of 2 greater than or equal to some number greater than 1, call it `x`. This power of 2 will tell us how many bits are required to represent `x`, for example.

We can state this mathematically as looking for some number, `n`, such that $2^{n-1} < x \leq 2^n$. If `x` is a power of 2, for example 64, we'd find 2^6. If `x` is another number, for example 66, we'd find $2^6 < 66 \leq 2^7$, which is $64 < 66 \leq 128$.

We can start to sketch our loop already.

```
assert x > 1

... initialize ...

... some loop ...

assert 2**(n-1) < x <= 2**n
```

We work out the initialization to make sure that the invariant condition of the loop is initially true. Since `x` must be greater than or equal to 1, we can set `n` to 1. $2^{1-1} = 2^0 = 1 < x$. This will set things up to satisfy rule 1 and 2.

```
assert x > 1
n= 1

... some loop ...

assert 2**(n-1) < x <= 2**n
```

In loops, there must be a condition on the body that is invariant, and a terminating condition that changes. The terminating condition is written in the **while** clause. In this case, it is invariant (always true) that $2^{n-1} < x$. That means that the other part of our final condition is the part that changes.

```
assert x > 1
n= 1
while not ( x <= 2**n ):
    n= n + 1
```

```
    assert 2**(n-1) < x
assert 2**(n-1) < x <= 2**n
```

The next to last step is to show that when the **while** condition is true, there are more than zero trips through the loop possible. We know that `x` is finite and some power of 2 will satisfy this condition. There's some `n` such that $n - 1 < log_2 x \leq n$, which limits the trips through the loop.

The final step is to show that each cycle through the loop reduces the trip count. We can argue that increasing `n` gets us closer to the upper bound of $log_2 x$.

We should add this information on successful termination as comments in our loop.

CHAPTER

TEN

FUNCTIONS

The heart of programming is the *evaluate-apply* cycle, where function arguments are evaluated and then the function is applied to those argument values. We'll review this in *Semantics*.

In *Function Definition: The def and return Statements* we introduce the syntax for defining a function. In *Function Use*, we'll describe using a function we've defined.

Some languages make distinctions between varieties of functions, separating them into "functions" and "subroutines". We'll visit this from a Python perspective in *Function Varieties*.

We'll look at some examples in *Some Examples*. We'll look at ways to use **IDLE** in *Hacking Mode*.

We introduce some of the alternate argument forms available for handling optional and keyword parameters in *More Function Definition Features*.

Further sophistication in how Python handles parameters has to be deferred to *Advanced Parameter Handling For Functions*, as it depends on a knowledge of dictionaries, introduced in *Mappings and Dictionaries*.

In *Object Method Functions* we will describe how to use *method functions* as a prelude to *Data Structures*; real details on method functions are deferred until *Classes*.

We'll also defer examination of the **yield** statement until *Iterators and Generators*. The **yield** statement creates a special kind of function, one that is most useful when processing complex data structures, something we'll look at in *Data Structures*.

10.1 Semantics

A function, in a mathematical sense, is often described as a mapping from domain values to range values. Given a domain value, the function returns the matching range value.

If we think of the square root function, it maps a positive number, n, to another number, s, such that $s^2 = n$.

If we think of multplication as a function, it maps a pair of values, a and b, to a new value, c, such that $c = a \times b$. When we memorize multiplication tables, we are memorizing these mappings.

In Python, this narrow definition is somewhat relaxed. Python lets us create functions which do not need a domain value, but create new objects. It also allows us to have functions that don't return values, but instead have some other effect, like reading user input, or creating a directory, or removing a file.

What We Provide. In Python, we create a new function by providing three pieces of information: the name of the function, a list of zero or more variables, called *parameters*, with the domain of input values, and a suite of statements that creates the output values. This definition is saved for later use. We'll show this first in *Function Definition: The def and return Statements*.

Typically, we create function definitions in script files because we don't want to type them more than once. Almost universally, we **import** a file with our function definitions so we can use them.

We use a function in an expression by following the function's name with '`()`'. The Python interpreter evaluates the argument values in the '`()`', then applies the function. We'll show this second in *Function Use*.

Applying a function means that the interpreter first evaluates all of the argument values, then assigns the argument values to the function parameter variables, and finally evaluates the suite of statements that are the function's body. In this body, any **return** statements define the resulting range value for the function. For more information on this evaluate-apply cycle, see *The Evaluate-Apply Cycle*.

Namespaces and Privacy. Note that the parameter variables used in the function definition, as well as any variables in a function are private to that function's suite of statements. This is a consequence of the way Python puts all variables in a namespace. When a function is being evaluated, Python creates a temporary namespace. This namespace is deleted when the function's processing is complete. The namespace associated with application of a function is different from the global namespace, and different from all other function-body namespaces.

While you can change the standard namespace policy (see *The global Statement*) it generally will do you more harm than good. A function's interface is easiest to understand if it is only the parameters and return values and nothing more. If all other variables are local, they can be safely ignored.

Terminology: argument and parameter. We have to make a firm distinction between an argument *value*, an object that is created or updated during execution, and the defined parameter *variable* of a function. The argument is the object used in particular application of a function; it may be referenced by other variables or objects. The parameter is a variable name that is part of the function, and is a local variable within the function body.

The Evaluate-Apply Cycle

The evaluate-apply cycle shows how any programming language computes the value of an expression. Consider the following expression:

```
math.sqrt( abs( b*b-4*a*c ) )
```

What does Python do?
For the purposes of analysis, we can restructure this from the various mathematical notation styles to a single, uniform notation. We call this *prefix* notation, because all of the operations prefix their operands. While useful for analysis, this is cumbersome to write for real programs.

```
math.sqrt( abs( sub( mul(b,b), mul(mul(4,a),c) ) ) )
```

We've replaced '`x*y`' with '`mul(x,y)`' , and replaced '`x-y`' with '`sub(x,y)`' . This allows us to more clearly see how evaluate-apply works. Each part of the expression is now written as a function with one or two arguments. First the arguments are evaluated, then the function is applied to those arguments. In order for Python to evaluate this '`math.sqrt(...)`' expression, it evaluates the argument, '`abs(...)`', and then applies `math.sqrt()` to it. This leads Python to a nested evaluate-apply process for the '`abs(...)`' expression. We'll show the whole process, with indentation to make it clearer.
We're going to show this as a list of steps, with '`>`' to show how the various operations nest inside each other.

```
Evaluate the arg to math.sqrt:
> Evaluate the args to sub:
> > Evaluate the args to mul:
> > > Get the value of b
> > Apply mul to b and b, creating r3=mul( b, b ).
> > Evaluate the args to mul:
> > > Evaluate the args to mul:
> > > > Get the value of a
> > > Apply mul to 4 and a, creating r5=mul( 4, a ).
> > > Get the value of c
> > Apply mul to r5 and c, creating r4=mul( mul( 4, a ), c ).
> Apply sub to r3 and r4, creating r2=sub( mul( b, b ), mul( mul( 4, a ), c ) ).
Apply math.sqrt to r2, creating r1=math.sqrt( sub( mul( b, b ), mul( mul( 4, a ), c ) ) ).
```

Notice that a number of intermediate results were created as part of this evaluation. If we were doing this by hand, we'd write these down as steps toward the final result.
The apply part of the evalute-apply cycle is sometimes termed a function *call*. The idea is that the main procedure "calls" the body of a function; the function does its work and returns to the main procedure. This is also called a function *invocation*.

10.2 Function Definition: The def and return Statements

We create a function with a **def** statement. This provides the name, parameters and the suite of statements that creates the function's result.

```
def name ( parameter ⟨ , ... ⟩ ):
    suite
```

The *name* is the name by which the function is known. The *parameters* is a list of variable names; these names are the local variables to which actual argument values will be assigned when the function is applied. The *suite* (which must be indented) is a block of statements that computes the value for the function.

The first line of a function's suite is expected to be a document string (generally a triple-quoted string) that provides basic documentation for the function. This is traditionally divided in two sections, a summary section of exactly one line and the detail section. We'll return to this style guide in *Functions Style Notes*.

The **return** statement specifies the result value of the function. This value will become the result of applying the function to the argument values. This value is sometimes called the effect of the function.

```
return expression
```

The **yield** statement specifies one of the result values of an iterable function. We'll return to this in *Iterators and Generators*.

Let's look at a complete example.

```
def odd( spin ):
    """Return true if this spin is odd."""
    if spin % 2 == 1:
        return True
    return False
```

1. We name this function `odd()`, and define it to accept a single parameter, named `spin`.
2. We provide a docstring with a short description of the function.
3. In the body of the function, we test to see if the remainder of `spin` /2 is 1; if so, we return `True`.
4. Otherwise, we return `False`.

10.3 Function Use

When Python evaluates '`odd(n)`', the following things will happen.

1. It evaluates `n`. For a simple variable, the value is the object to which the variable refers. For an expression, the expression is evaluated to result in an object.
2. It assigns this argument value to the local parameter of `odd()` (named `spin`).
3. It applies `odd()`: the suite of statements is executed, ending with a **return** statement.
4. This value on the **return** statement is returned to the calling statement so that it can finish it's execution.

We would use this `odd()` function like this.

```
s = random.randrange(37)
# 0 <= s <= 36, single-0 roulette
if s == 0:
    print "zero"
elif odd(s):
    print s, "odd"
else:
    print s, "even"
```

1. We evaluate a function named random.randrange to create a random number, `s`.
2. The **if** clause handles the case where `s` is zero.

3. The first **elif** clause evaluates our `odd()` function. To do this evaluation, Python must set `spin` to the value of `s` and execute the suite of statements that are the body of `odd()`. The suite of statements will return either `True` or `False`.
4. Since the **if** and **elif** clauses handle zero and odd cases, all that is left is for `s` to be even.

10.4 Function Varieties

Some programming languages make a distinction between various types of functions or "subprograms". There can be "functions" or "subroutines" or "procedure functions". Python (like Java and C++) doesn't enforce this kind of distinction.

Instead, Python imposes some distinction based on whether the function uses parameters and returns a value or yields a collection of values.

"Ordinary" Functions. Functions which follow the classic mathematical definitions will map input argument values to a resulting value. These are, perhaps, a common kind of function. They include a **return** statement to express the resulting value.

Procedure Functions. One common kind of function is one that doesn't return a result, but instead carries out some procedure. This function would omit any **return** statement. Or, if a **return** statement is used to exit from the function, the statement would have no value to return.

Carrying out an action is sometimes termed a side-effect of the function. The primary effect is always the value returned.

Here's an example of a function that doesn't return a value, but carries out a procedure.

```
from __future__ import print_function
def report( spin ):
    """Report the current spin."""
    if spin == 0:
        print( "zero" )
        return
    if odd(spin):
        print( spin, "odd" )
        return
    print( spin, "even" )
```

This function, `report()`, has a parameter named `spin`, but doesn't return a value. Here, the **return** statements exit the function but don't return values.

This kind of function would be used as if it was a new Python language statement, for example:

```
for i in range(10):
    report( random.randrange(37) )
```

Here we execute the `report()` function as if it was a new kind of statement. We don't evaluate it as part of an expression.

There's actually no real subtlety to this distinction. Any expression can be used as a Python statement. A function call is an expression, and an expression is a statement. This greatly simplifies Python syntax. The docstring for a function will explain what kind of value the function returns, or if the function doesn't return anything useful.

The simple **return** statement, by the way, returns the special value `None`. This default value means that you can define your function like `report()`, above, use it in an expression, and everything works nicely because the function does return a value.

```
for i in range(10):
    t= report( random.randrange(37) )
print t
```

You'll see that `t` is `None` .

Factory Functions. Another common form is a function that doesn't take a parameter. This function is a factory which generates a value.

Some factory functions work by accessing some object encapsulated in a module. In the following example, we'll access the random number generator encapsulated in the `random` module.

```
def spinWheel():
    """Return a string result from a roulette wheel spin."""
    t= random.randrange(38)
    if t == 37:
        return "00"
    return str(t)
```

This function's evaluate-apply cycle is simplified to just the apply phase. To make `0` (zero) distinct from `00` (double zero), it returns a string instead of a number.

Generators. A generator function contains the **yield** statement. These functions look like conventional functions, but they have a different purpose in Python. We will examine this in detail in *Iterators and Generators*.

These functions have a persistent internal processing state; ordinary functions can't keep data around from any previous calls without resorting to global variables. Further, these functions interact with the **for** statement. Finally, these functions don't make a lot of sense until we've worked with sequences in *Sequences: Strings, Tuples and Lists*.

10.5 Some Examples

Here's a big example of using the `odd()` , `spinWheel()` and `report()` functions.

functions.py

```
#!/usr/bin/env python
import random

def odd( spin ):
    """odd(number) -&gt; boolean."""
    return spin%2 == 1

def report( spin ):
    """Reports the current spin on standard output.  Spin is a String"""
    if int(spin) == 0:
        print "zero"
        return
    if odd(int(spin)):
        print spin, "odd"
        return
    print spin, "even"
```

```
def spinWheel():
    """Returns a string result from a roulette wheel spin."""
    t= random.randrange(38)
    if t == 37:
        return "00"
    return str(t)

for i in range(12):
    n= spinWheel()
    report( n )
```

1. We've defined a function named `odd()`. This function evaluates a simple expression; it returns `True` if the value of it's parameter, `spin`, is odd.
2. The function called `report()` uses the `odd()` function to print a line that describes the value of the parameter, `spin`. Note that the parameter is private to the function, so this use of the variable name `spin` is technically distinct from the use in the `odd()` function. However, since the `report()` function provides the value of `spin` to the `odd()` function, their two variables often happen to have the same value.
3. The `spinWheel()` function creates a random number and returns the value as a string.
4. The "main" part of this program is the for loop at the bottom, which calls `spinWheel()`, and then `report()`. The `spinWheel()` function uses `random.randrange()`; the `report()` function uses the `odd()` function. This generates and reports on a dozen spins of the wheel.

   For most of our exercises, this free-floating main script is acceptable. When we cover modules, in *Components, Modules and Packages*, we'll need to change our approach slightly to something like the following.

   ```
   def main():
       for i in range(12):
           n= spinWheel()
           report( n )

   main()
   ```

   This makes the main operation of the script clear by packaging it as a function. Then the only free-floating statement in the script is the call to `main()`.

10.6 Hacking Mode

On one hand we have interactive use of the Python interpreter: we type something and the interpreter responds immediately. We can do simple things, but when our statements get too long, this interaction can become a niusance. We introduced this first, in *Command-Line Interaction*.

On the other hand, we have scripted use of the interpreter: we present a file as a finished program to execute. While handy for getting useful results, this isn't the easiest way to get a program to work in the first place. We described this in *Script Mode*.

In between the interactive mode and scripted mode, we have a third operating mode, that we might call *hacking mode*. The idea is to write most of our script and then exercise portions of our script interactively. In this mode, we'll develop script files, but we'll exercise them in an interactive environment. This is handy for developing and debugging function definitions.

The basic procedure is as follows.

1. In our favorite editor, write a script with our function definitions. We often leave this editor window open. **IDLE**, for example, leaves this window open for us to look at.
2. Open a Python shell. **IDLE**, for example, always does this for us.
3. In the Python Shell, **import** the script file. In **IDLE**, this is effectively what happens when we run the module with `F5`.

   This will execute the various **def** statements, creating our functions in our interactive shell.
4. In the Python Shell, test the function interactively. If it works, we're done.
5. If the functions in our module didn't work, we return to our editor window, make any changes and save the file.
6. In the Python Shell, clear out the old definition by restarting the shell. In **IDLE**, we can force this with `F6`. This happens automatically when we run the module using `F5`
7. Go back to step 3, to import and test our definitions.

The interactive test results can be copied and pasted into the docstring for the file with our function definitions. We usually copy the contents of the Python Shell window and paste it into our module's or function's docstring. This record of the testing can be validated using the `doctest` module.

Example. Here's the sample function we're developing. If you look carefully, you might see a serious problem. If you don't see the problem, don't worry, we'll find it by doing some debugging.

In **IDLE**, we created the following file.

function1.py Initial Version

```
def odd( number ):
    """odd(number) -> boolean

    Returns True if the given number is odd.
    """
    return number % 2 == "1"
```

We have two windows open: **function1.py** and **Python Shell**.

Here's our interactive testing session. In our **function1.py** window, we hit `F5` to run the module. Note the line that shows that the Python interpreter was restarted; forgetting any previous definitions. Then we exercised our function with two examples.

```
Python 2.5.1 (r251:54863, Oct  5 2007, 21:08:09)
[GCC 4.0.1 (Apple Inc. build 5465)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
    **********************************************************
    Personal firewall software may warn about the connection IDLE
    makes to its subprocess using this computer's internal loopback
    interface.  This connection is not visible on any external
    interface and no data is sent to or received from the Internet.
    **********************************************************

IDLE 1.1.4
>>> ================================ RESTART ================================
>>>
>>> odd(2)
False
```

```
>>> odd(3)
False
```

Clearly, it doesn't work, since 3 is odd. When we look at the original function, we can see the problem.

The expression '`number % 2 == "1"`' should be '`number % 2 == 1`'.

We need to fix `function1.py`. Once the file is fixed, we need to remove the old stuff from Python, re-import our function and rerun our test. **IDLE** does this for us when we hit `F5` to rerun the module. It shows this with the prominent restart message.

If you are not using **IDLE**, you will need to restart Python to clear out the old definitions. Python optimizes import operations; if it's seen the module once, it doesn't import it a second time. To remove this memory of which modules have been imported, you will need to restart Python.

10.7 More Function Definition Features

Python provides a mechanism for optional parameters. This allows us to create a single function which has several alternative forms. In other languages, like C++ or Java, these are called overloaded functions; they are actually separate function definitions with the same name but different parameter forms. In Python, we can write a single function that accepts several parameter forms.

Python has three mechanisms for dealing with optional parameters and a variable number of parameters. We'll cover the basics of optional parameters in this section. The other mechanisms for dealing with variable numbers of parameters will be deferred until *Advanced Parameter Handling For Functions* because these mechanisms use some more advanced data structures.

Python functions can return multiple values. We'll look at this, also.

10.7.1 Default Values for Parameters

The most common way to implement optional parameters is by providing a default value for the optional parameters. If no argument is supplied for the parameter, the default value is used.

```
def report( spin, count=1 ):
    print spin, count, "times in  a row"
```

This silly function can be used in two ways:

```
report( n )
report( n, 2 )
```

The first form provides a default argument of 1 for the `count` parameter. The second form has an explicit argument value of 2 for the `count` parameter.

If a parameter has no default value, it is not optional. If a parameter has a default value, it is optional. In order to disambiguate the assignment of arguments to parameters, Python uses a simple rule: all required parameters must be first, all optional parameters must come after the required parameters.

The `int()` function does this. We can say '`int("23")`' to do decimal conversion and '`int("23",16)`' to do hexadecimal conversion. Clearly, the second argument to `int()` has a default value of 10.

Important: Red Alert

It's very, very important to note that default values must be immutable objects. We'll return to this concept of mutability in *Data Structures*.

For now, be aware that numbers, strings, `None`, and `tuple` objects are immutable.

As we look at various data type, we'll find that lists, sets and dictionaries are mutable, and cannot be used as default values for function parameters.

Fancy Defaults. When we look at the Python `range()` function, we see a more sophisticated version of this.

'`range(x)`' is the same as '`range(0,x,1)`'.

'`range(x,y)`' is the same as '`range(x,y,1)`'.

It appears from these examples that the *first* parameter is optional. The authors of Python use a pretty slick trick for this that you can use also. The `range()` function behaves as though the following function is defined.

```
def range(x, y=None, z=None):
    if y==None:
        start, stop, step = 0, x, 1
    elif z==None:
        start, stop, step = x, y, 1
    else:
        start, stop, step = x, y, z
     Real work is done with start, stop and step
```

By providing a default value of `None`, the function can determine whether a value was supplied or not supplied. This allows for complex default handling within the body of the function.

Conclusion. Python *must* find a value for all parameters. The basic rule is that the values of parameters are set in the order in which they are declared. Any missing parameters will have their default values assigned. These are called positional parameters, since the position is the rule used for assigning argument values when the function is applied.

If a mandatory parameter (a parameter without a default value) is missing, this is a basic `TypeError`.

For example:

badcall.py

```
#!/usr/bin/env python
def hack(a,b):
    print a+b
hack(3)
```

When we run this example, we see the following.

```
MacBook-5:Examples slott$ python badcall.py
Traceback (most recent call last):
  File "badcall.py", line 4, in <module>
    hack(3)
TypeError: hack() takes exactly 2 arguments (1 given)
```

10.7.2 Providing Argument Values by Keyword

In addition to supplying argument values by position, Python also permits argument values to be specified by name. Using explicit keywords can make programs much easier to read.

First, we'll define a function with a simple parameter list:

```
import random
def averageDice( samples=100 ):
    """Return the average of a number of throws of 2 dice."""
    s = 0
    for i in range(samples):
        d1,d2 = random.randrange(6)+1,random.randrange(6)+1
        s += d1+d2
    return float(s)/float(samples)
```

Next, we'll show three different kinds of arguments: keyword, positional, and default.

```
test1 = averageDice( samples=200 )
test2 = averageDice( 300 )
test3 = averageDice()
```

When the `averageDice()` function is evaluated to set `test1`, the keyword form is used. The second call of the `averageDice()` function uses the positional form. The final example relies on a default for the parameter.

Conclusion. This gives us a number of variations including positional parameters and keyword parameters, both with and without defaults. Positional parameters work well when there are few parameters and their meaning is obvious. Keyword parameters work best when there are a lot of parameters, especially when there are optional parameters.

Good use of keyword parameters mandates good selection of keywords. Single-letter parameter names or obscure abbreviations do not make keyword parameters helpfully informative.

Here are the rules we've seen so far:

1. Supply values for all parameters given by name, irrespective of position.
2. Supply values for all remaining parameters by position; in the event of duplicates, raise a `TypeError`.
3. Supply defaults for any parameters that have defaults defined; if any parameters still lack values, raise a `TypeError`.

There are still more options available for handling variable numbers of parameters. It's possible for additional positional parameters to be collected into a sequence object. Further, additional keyword parameters can be collected into a dictionary object. We'll get to them when we cover dictionaries in *Advanced Parameter Handling For Functions*.

10.7.3 Returning Multiple Values

One common desire among programmers is a feature that allows a function to return multiple values. Python has some built-in functions that have this property. For example, `divmod()` returns the divisor and remainder in division. We could imagine a function, `rollDice()` that would return two values showing the faces of two dice.

In Python, it is done by returning a `tuple`. We'll wait for *Tuples* for complete information on `tuple`s. The following is a quick example of how multiple assignment works with functions that return multiple values.

rolldice.py

```
import random
def rollDice():
    return ( 1 + random.randrange(6), 1 + random.randrange(6) )
d1,d2=rollDice()
print d1,d2
```

This shows a function that creates a two-valued `tuple`. You'll recall from *Multiple Assignment Statement* that Python is perfectly happy with multiple expressions on the right side of =, and multiple destination variables on the left side. This is one reason why multiple assignment is so handy.

10.8 Function Exercises

1. **Fast exponentiation**. This is a fast way to raise a number to an integer power. It requires the fewest multiplies, and does not use logarithms.

   ### Fast Exponentiation of integers, raises *n* to the *p* power

   (a) **Base Case**. If $p = 0$: return 1.0.

   (b) **Odd**. If p is odd: return $n \times \text{fastexp}(n, p-1)$.

   (c) **Even**. If p is even:

   compute $t \leftarrow \text{fastexp}(n, \frac{p}{2})$;

   return $t \times t$.

2. **Greatest Common Divisor**. The greatest common divisor is the largest number which will evenly divide two other numbers. You use this when you reduce fractions. See *Greatest Common Divisor* for an alternate example of this exercise's algorithm. This version can be slightly faster than the loop we looked at earlier.

   ### Greatest Common Divisor of two integers, *p* and *q*

   (a) **Base Case**. If $p = q$: return p.

   (b) $\mathbf{p < q}$. If $p < q$: return $\text{GCD}(q, p)$.

   (c) $\mathbf{p > q}$. If $p > q$: return $\text{GCD}(p, p-q)$.

3. **Factorial Function**. Factorial of a number n is the number of possible arrangements of 0 through n things. It is computed as the product of the numbers 1 through n. That is, $1 \times 2 \times 3 \times \cdots \times n$.

   The formal definition is

   $$n! = n \times (n-1) \times (n-2) \times \cdots \times 1$$

   $$0! = 1$$

   We touched on this in *Computing e*. This function definition can simplify the program we wrote for that exercise.

Factorial of an integer, *n*

(a) **Base Case**. If $n = 0$, return 1.

(b) **Multiply**. If $n > 0$: return $n \times \text{factorial}(n-1)$.

4. **Fibonacci Series**. Fibonacci numbers have a number of interesting mathematical properties. The ratio of adjacent Fibonacci numbers approximates the golden ratio ($(1+\sqrt{5})/2$, about 1.618), used widely in art and architecture.

The *n*th Fibonacci Number, F_n.

(a) **F(0) Case**. If $n = 0$: return 0.

(b) **F(1) Case**. If $n = 1$: return 1.

(c) **F(n) Case**. If $n > 1$: return $\text{F}(n-1) + \text{F}(n-2)$.

5. **Ackermann's Function**. An especially complex algorithm that computes some really big results. This is a function which is specifically designed to be complex. It cannot easily be rewritten as a simple loop. Further, it produces extremely large results because it describes extremely large exponents.

Ackermann's Function of two numbers, *m* and *n*

(a) **Base Case**. If $m = 0$: return $n + 1$.

(b) **N Zero Case**. If $m \neq 0$ **and** $n = 0$: return $\text{ackermann}(m-1, 1)$.

(c) **N Non-Zero Case**. If $m \neq 0$ **and** $n \neq 0$: return $\text{ackermann}(m-1, \text{ackermann}(m, n-1))$.

Yes, this requires you to compute $\text{ackermann}(m, n-1)$ before you can compute $\text{ackermann}(m-1, \text{ackermann}(m, n-1))$.

6. **Maximum Value of a Function**. Given some integer-valued function `f()`, we want to know what value of x has the largest value for `f()` in some interval of values. For additional insight, see [Dijkstra76].

   Imagine we have an integer function of an integer, call it `f()`. Here are some examples of this kind of function.

   - '`def f1(x): return x`'
   - '`def f2(x): return -5/3*x-3`'
   - '`def f3(x): return -5*x*x+2*x-3`'

   The question we want to answer is what value of x in some fixed interval returns the largest value for the given function? In the case of the first example, '`def f1(x): return x`', the largest value of `f1()` in the interval $0 \leq x < 10$ occurs when x is 9.

   What about `f3()` in the range $-10 \leq x < 10$?

Max of a Function, *F*, in the interval *low* to *high*

(a) **Initialize**.

$x \leftarrow low$;

$max \leftarrow x$;

$max_F \leftarrow \mathrm{F}(max)$.

(b) **Loop**. While $low \leq x < high$.

i. **New Max?** If $\mathrm{F}(x) > max_F$:

$max \leftarrow x$;

$max_F \leftarrow \mathrm{F}(max)$.

ii. **Next X**. Increment x by 1.

(c) **Return**. Return max as the value at which $\mathrm{F}(x)$ had the largest value.

7. **Integration**. This is a simple rectangular rule for finding the area under a curve which is continuous on some closed interval.

We will define some function which we will integrate, call it `f(x)()`. Here are some examples.

- '`def f1(x): return x*x`'
- '`def f2(x): return 0.5 * x * x`'
- '`def f3(x): return exp( x )`'
- '`def f4(x): return 5 * sin( x )`'

When we specify $y = f(x)$, we are specifying two dimensions. The y is given by the function's values. The x dimension is given by some interval. If you draw the function's curve, you put two limits on the x axis, this is one set of boundaries. The space between the curve and the y axis is the other boundary.

The x axis limits are a and b. We subdivide this interval into s rectangles, the width of each is $h = \frac{b-a}{s}$. We take the function's value at the corner as the average height of the curve over that interval. If the interval is small enough, this is reasonably accurate.

Integrate a Function, *F*, in the interval *a* to *b* in *s* steps

(a) **Initialize**.

$x \leftarrow a$

$h \leftarrow \dfrac{b-a}{s}$

$sum \leftarrow 0.0$

(b) **Loop**. While $a \leq x < b$.

i. **Update Sum.** Increment sum by $F(x) \times h$.

ii. **Next X.** Increment x by h.

(c) **Return.** Return sum as the area under the curve `F()` for $a \leq x < b$.

8. **Field Bet Results**. In the dice game of Craps, the Field bet in craps is a winner when any of the numbers 2, 3, 4, 9, 10, 11 or 12 are rolled. On 2 and 12 it pays 2:1, on any of the other numbers, it pays 1:1.

Define a function '`win( dice, num, pays)`'. If the value of `dice` equals `num`, then the value of `pays` is returned, otherwise 0 is returned. Make the default for `pays` a 1, so we don't have to repeat this value over and over again.

Define a function '`field( dice )`'. This will call `win()` 7 times: once with each of the values for which the field pays. If the value of dice is a 7, it returns -1 because the bet is a loss. Otherwise it returns 0 because the bet is unresolved.

It would start with

```
def field( dice ):
    win( dice, 2, pays=2 )
    win( dice, 3, pays=1 )
     ...
```

Create a function '`roll()`' that creates two dice values from 1 to 6 and returns their sum. The sum of two dice will be a value from 2 to 12.

Create a main program that calls `roll()` to get a dice value, then calls `field()` with the value that is rolled to get the payout amount. Compute the average of several hundred experiments.

9. `range()` **Function Keywords**. Does the range function permit keywords for supplying argument values? What are the keywords?

10. **Optional First Argument**. Optional parameters must come last, yet range fakes this out by appearing to have an optional parameter that comes first. The most common situation is '`range(5)`' , and having to type '`range(0,5)`' seems rather silly. In this case, convenience trumps strict adherence to the rules. Is this a good thing? Is strict adherence to the rules more or less important than convenience?

10.9 Object Method Functions

We've seen how we can create functions and use those functions in programs and other functions. Python has a related technique called *methods* or *method functions*. The functions we've used so far are globally available. A method function, on the other hand, belongs to an object. The object's class defines what methods and what properties the object has.

We'll cover method functions in detail, starting in *Classes*. For now, however, some of the Python data types we're going to introduce in *Data Structures* will use method functions. Rather than cover too many details, we'll focus on general principles of how you use method functions in this section.

The syntax for calling a method function looks like this:

```
someObject.aMethod( argument list )
```

A single '`.`' separates the owning object (`someObject`) from the method name (`aMethod()`).

We glanced at a simple example when we first looked at complex numbers. The complex conjugate function is actually a method function of the complex number object. The example is in *Complex Numbers*.

In the next chapter, we'll look at various kinds of sequences. Python defines some generic method functions that apply to any of the various classes of sequences. The `string` and `list` classes, both of which are special kinds of sequences, have several methods functions that are unique to strings or lists.

For example:

```
>>> "Hi Mom".lower()
'hi mom'
```

Here, we call the `lower()` method function, which belongs to the string object `"Hi Mom"`.

When we describe modules in *Components, Modules and Packages*, we'll cover module functions. These are functions that are imported with the module. The `array` module, for example, has an `array()` function that creates `array` objects. An `array` object has several method functions. Additionally, an `array` object is a kind of sequence, so it has all of the methods common to sequences, also.

`file` objects have an interesting life cycle, also. A `file` object is created with a built-in function, `file()`. A file object has numerous method functions, many of which have side-effects of reading from and writing to external files or devices. We'll cover files in *Files*, listing most of the methods unique to file objects.

10.10 Functions Style Notes

The suite within a compound statement is typically indented four spaces. It is often best to set your text editor with tab stops every four spaces. This will usually yield the right kind of layout.

We'll show the spaces explicitly as ␣ in the following fragment.

```
def␣max(a,␣b):
␣␣␣␣if␣a␣>=␣b:
␣␣␣␣␣␣␣␣m␣=␣a
␣␣␣␣if␣b␣>=␣a:
␣␣␣␣␣␣␣␣m␣=␣b
␣␣␣␣return␣m
```

This is has typical spacing for a piece of Python programming.

Also, limit your lines to 80 positions or less. You may need to break long statements with a '\' at the end of a line. Also, parenthesized expressions can be continued onto the next line without a '\'. Some programmers will put in extra '`()`' just to make line breaks neat.

Names. Function names are typically `mixedCase()`. However, a few important functions were done in `CapWords()` style with a leading upper case letter. This can cause confusion with class names, and the recommended style is a leading lowercase letter for function names.

In some languages, many related functions will all be given a common prefix. Functions may be called `inet_addr()`, `inet_network()`, `inet_makeaddr()`, `inet_lnaof()`, `inet_netof()`, `inet_ntoa()`, etc. Because Python has classes (covered in *Data + Processing = Objects*) and modules (covered in *Components, Modules and Packages*), this kind of function-name prefix is not used in Python programs. The class or module name is the prefix. Look at the example of `math` and `random` for guidance on this.

Parameter names are also typically `mixedCase`. In the event that a parameter or variable name conflicts with a Python keyword, the name is extended with an '`_`'. In the following example, we want our parameter to be named `range`, but this conflicts with the builtin function `range()`. We use a trailing '`_`' to sort this out.

```
def integrate( aFunction, range_ ):
    """Integrate a function over a range."""
     ...
```

Blank lines are used sparingly in a Python file, generally to separate unrelated material. Typicaly, function definitions are separated by single blank lines. A long or complex function might have blank lines within the body. When this is the case, it might be worth considering breaking the function into separate pieces.

Docstrings. The first line of the body of a function is called a *docstring*. The recommended forms for docstrings are described in Python Extension Proposal (PEP) 257.

Typically, the first line of the docstring is a pithy summary of the function. This may be followed by a blank line and more detailed information. The one-line summary should be a complete sentence.

```
def fact( n ):
    """fact( number ) -> number

    Returns the number of permutations of n things."""
```

```
    if n == 0: return 1L
    return n*fact(n-1L)

def bico( n, r ):
    """bico( number, number ) -> number

    Returns the number of combinations of n things
    taken in subsets of size r.
    Arguments:
    n -- size of domain
    r -- size of subset
    """
    return fact(n)/(fact(r)*fact(n-r))
```

The docsting can be retrieved with the `help()` function.

help(*object*)
Provides help about the given object.

Here's an example, based on our `fact()` shown above.

```
>>> help(fact)

    Help on function fact in module __main__:

    fact(n)
        fact( number ) -> number

        Returns the number of permutations of n things.
```

Note that you will be in the help reader, with a prompt of `(END)`. Hit `q` to quit the help reader. For more information, see *Getting Help*.

CHAPTER

ELEVEN

ADDITIONAL NOTES ON FUNCTIONS

The global Statement

In *Functions and Namespaces* we'll describe some of the internal mechanisms Python uses for storing variables. We'll introduce the **global** statement in *The global Statement*.

We'll include a digression on the two common argument binding mechanisms: call by value and call by reference in *Call By Value and Call By Reference*. Note that this is a distinction that doesn't apply to Python, but if you have experience in languages like C or C++, you may wander where and how this is implemented.

Finally, we'll cover some aspects of functions as first-class objects in *Function Objects*.

11.1 Functions and Namespaces

This is an overview of how Python determines the meaning of a name. We'll omit some details to hit the more important points. For more information, see section 4.1 of the *Python Language Reference*.

The important issue is that we want variables created in the body of a function to be private to that function. If all variables are global, then each function runs a risk of accidentally disturbing the value of a global variable. In the COBOL programming language (without using separate compilation or any of the modern extensions) all variables are globally declared in the data division, and great care is required to prevent accidental or unintended use of a variable.

To achieve privacy and separation, Python maintains several dictionaries of variables. These dictionaries define the context in which a variable name is understood. Because these dictionaries are used for resolution of variables, which name objects, they are called *namespaces*. A global namespace is available to all modules that are part of the currently executing Python script. Each module, class, function, lambda, or anonymous block of code given to the **exec** command has its own private namespace.

Names are resolved using the nested collection of namespaces that define an execution environment. Python always checks the most-local dictionary first, ending with the global dictionary.

Consider the following script.

```
def deep( a, b ):
     print "a=", a
     print "b=", b
```

```
def shallow( hows, things ):
    deep( hows, 1 )
    deep( things, coffee )

hows= 1
coffee= 2
shallow( "word", 3.1415926 )
shallow( hows, coffee )
```

1. The `deep()` function has a local namespace, where two variables are defined: `a` and `b`. When `deep()` is called from `shallow()`, there are three nested scopes that define the environment: the local namespace for `deep()`: the local namespace for `shallow()`, and the global namespace for the main script.

2. The `shallow()` function has a local namespace, where two variables are defined: `hows` and `things`.

   When `shallow()` is called from the main script, the local `hows` is resolved in the local namespace. It hides the global variable with the same name.

   The reference to `coffee` is not resolved in the local namespace, but is resolved in the global namespace. This is called a *free* variable, and is sometimes a symptom of poor software design.

3. The main script – by definition – executes in the global namespace, where two variables (`hows` and `coffee`) are defined, along with two functions, `deep()` and `shallow()`.

Built-in Functions. If you evaluate the function `globals()`, you'll see the mapping that contains all of the global variables Python knows about. For these early programs, all of our variables are global.

If you simply evaluate `locals()`, you'll see the same thing. However, if you call `locals()` from within the body of a function, you'll be able to see the difference between local and global variables.

The following example shows the creation of a gobal variable `a`, and a global function, `q`. It shows the local namespace in effect while the function is executing. In this local namespace we also have a variable named `a`.

```
>>> a=22.0
>>> globals()
{'__builtins__': <module '__builtin__' (built-in)>, '__name__': '__main__',
'__doc__': None, 'a': 22.0}
>>> def q( x, y ):
...     a = x / y
...     print locals()
...
>>> locals()
{'__builtins__': <module '__builtin__' (built-in)>, '__name__': '__main__',
'q': <function q at 0x76830>, '__doc__': None, 'a': 22.0}
>>> globals()
{'__builtins__': <module '__builtin__' (built-in)>, '__name__': '__main__',
'q': <function q at 0x76830>, '__doc__': None, 'a': 22.0}
>>> q(22.0,7.0)
{'a': 3.1428571428571428, 'y': 7.0, 'x': 22.0}
```

The function `vars()` accepts a parameter which is the name of a specific local context: a module, class, or object. It returns the local variables for that specific context. The local variables are kept in a local variable named `__dict__`. The `vars()` function retrieves this.

The `dir()` function examines the `__dict__` of a specific object to locate all local variables as well as other features of the object.

Assignment statements, as well as **def** and **class** statements, create names in the local dictionary. The **del** statement removes a name from the local dictionary.

Some Consequences. Since each imported module exists in it's own namespace, all functions and classes within that module must have their names qualified by the module name. We saw this when we imported `math` and `random`. To use the `sqrt()` function, we must say '`math.sqrt`', providing the module name that is used to resolve the name `sqrt()`.

This module namespace assures that everything in a module is kept separate from other modules. It makes our programs clear by qualifying the name with the module that defined the name.

The module namespace also allow a module to have relatively global variables. A module, for example, can have variables that are created when the module is imported. In a sense these are global to all the functions and classes in the module. However, because they are only known within the module's namespace, they won't conflict with variables in our program or other modules.

Having to qualify names within a module can become annoying when we are making heavy use of a module. Python has ways to put elements of a module into the global namespace. We'll look at these in *Components, Modules and Packages*.

11.2 The global Statement

The suite of statements in a function definition executes with a local namespace that is different from the global namespace. This means that all variables created within a function are local to that function. When the suite finishes, these working variables are discarded.

The overall Python session works in the global namespace. Every other context (e.g. within a function's suite) is a distinct local namespace. Python offers us the **global** statement to change the namespace search rule.

```
global name
```

The **global** statement tells Python that the following names are part of the global namespace, not the local namespace.

The following example shows two functions that share a global variable.

```
ratePerHour= 45.50
def cost( hours ):
    global ratePerHour
    return hours * ratePerHour
def laborMaterials( hours, materials ):
    return cost(hours) + materials
```

Warning: Global Warning
The **global** statement has a consequence of tightly coupling pieces of software. This can lead to difficulty in maintenance and enhancement of the program. Classes and modules provide better ways to assemble complex programs.
As a general policy, we discourage use of the **global** statement.

11.3 Call By Value and Call By Reference

Beginning programmers can skip this section. This is a digression for experienced C and C++ programmers.

Most programming languages have a formal mechanism for determining if a parameter receives a copy of the argument (*call by value*) or a reference to the argument object (*call by name* or *call by reference.*)

The distinction is important in languages with "primitive" types: data which is not a formal object. These primitive types can be efficiently passed by value, where ordinary objects are more efficiently passed by reference.

Additionally, this allows a languge like C or C++ to use a reference to a variable as input to a function and have the function update the variable without an obvious assignment statement.

Bad News. The following scenario is entirely hypothetical for Python programmers, but a very real problem for C and C++ programmers. Imagine we have a function `to2()` , with this kind of definition in C.

```
int to2( int *a ) {
    /* set parameter a's value to 2 */
    *a= 2;
    return 0;
}
```

This function changes the value of the variable `a` to 2. This would be termed a *side-effect* because it is in addition to any value the function might return normally.

When we do the following in C

```
int x= 27;
int z= to2( &x );
printf( "x=%i, z=%i", x, z );
```

We get the unpleasant side-effect that our function `to2()` has changed the argument variable, `x`, and the variable wasn't in an **assignment** statement! We merely called a function, using `x` as an argument.

In C, the **&** operator is a hint that a variable might be changed. Further, the function definition *should* contain the keyword **const** when the reference is properly read-only. However, these are burdens placed on the programmer to assure that the program compiles correctly.

Python Rules. In Python, the arguments to a function are always objects, never references to variables.

Consider this Python version of the `to2()` function:

```
def to2( a )
    a = 2
    return 0

x = 27
z = to2( x )
print "x=%d, z=%d" % ( x, z )
```

The variable `x` is a reference to an integer object with a value of 27. The parameter variable (`a`) in the `to2()` function is a reference to the same object, and `a` is local to the function's scope. The original variable, `x`, cannot be changed by the function, and the original argument object, the integer 27, is immutable, and can't be changed either.

If an argument value is a mutable object, the parameter is a reference to that object, and the function has access to methods of that object. The methods of the object can be called, but the original object cannot be replaced with a new object.

We'll look at mutable objects in *Data Structures*. For now, all the objects we've used (strings and numbers) are immutable and cannot be changed.

The Python rules also mean that, in general, all variable updates must be done explicitly via an **assignment** statement. This makes variable changes perfectly clear.

11.4 Function Objects

One interesting consequence of the Python world-view is that a function is an object of the class `function`, a subclass of `callable`. The common feature that all `callable` objects share is that they have a very simple interface: they can be called. Other `callable` objects include the built-in functions, generator functions (which have the **yield** statement instead of the **return** statement) and things called *lambdas*.

Sometimes we don't want to call and evaluate a function. Sometimes we want to do other things to or with a function. For example, the various factory functions (`int()`, `long()`, `float()`, `complex()`) can be used with the `isinstance()` function instead of being called to create a new object.

For example, '`isinstance(2,int)`' has a value of `True`. It uses the `int()` function, but doesn't apply the `int()` function.

A function object is created with the **def** statement. Primarily, we want to evaluate the function objects we create. However, because a function is an object, it has attributes, and it can be manipulated to a limited extent.

From a syntax point of view, a name followed by '`()`' is a function call. You can think of the '`()`' as the "call" operator: they require evaluation of the arguments, then they apply the function.

```
name ( arguments )
```

There are a number of manipulations that you might want to do with a function object.

Call The Function. By far, the most common use for a function object is to call it. When we follow a function name with '`()`', we are calling the function: evaluating the arguments, and applying the function. Calling the function is the most common manipulation.

Alias The Function. This is dangerous, because it can make a program obscure. However, it can also simplify the evoluation and enhancement of software. Here's a scenario.

Imagine that the first version of our program had two functions named `rollDie()` and `rollDice()`. The definitions might look like the following.

```
def rollDie():
    return random.randrange(1,7)
def rollDice():
    return random.randrange(1,7) + random.randrange(1,7)
```

When we wanted to expand our program to handle five-dice games, we realized we could generalize the `rollDice()` function to cover both cases.

```
def rollNDice( n=2 ):
    t= 0
    for d in range(n):
        t += random.randrange( 1, 7 )
    return t
```

It is important to remove the duplicated algorithm in all three versions of our dice rolling function. Since `rollDie()` and `rollDice()` are just special cases of `rollNDice()`.

We can replace our original two functions with something like the following.

```
def rollDie():
    return rollNDice( 1 )
def rollDice():
    return rollNDice()
```

However, we have an alternative.

This revised definition of `rollDice()` is really just an another name for the `rollNDice()`. Because a function is an object assigned to a variable, we can have multiple variables assigned to the function. Here's how we create an alias to a function.

```
def rollDie():
    return rollNDice( 1 )

rollDice = rollNDice
```

> **Warning:** Function Alias Confusion
> Function alias definitions helps maintaining compatibility between old and new releases of software. It is not something that should be done as a general practice; we need to be careful providing multiple names for a given function. This can be a simplification. It can also be a big performance improvement for certain types of functions that are heavily used deep within nested loops.

Function Attributes. A function object has a number of attributes. We can interrogate those attributes, and to a limited extend, we can change some of these attributes. For more information, see section 3.2 of the *Python Language Reference* and section 2.3.9.3 of the *Python Library Reference*.

func_doc

___doc___ Docstring from the first line of the function's body.

func_name

___name___ Function name from the **def** statement.

___module___ Name of the module in which the function name was defined.

func_defaults Tuple with default values to be assigned to each argument that has a default value. This is a subset of the parameters, starting with the first parameter that has a default value.

func_code The actual code object that is the suite of statements in the body of this function.

func_globals The dictionary that defines the global namespace for the module that defines this function. This is `m.__dict__` of the module which defined this function.

func_dict

___dict___ The dictionary that defines the local namespace for the attributes of this function.

You can set and get your own function attributes, also. Here's an example

```
def rollDie():
    return random.randrange(1,7)
rollDie.version= "1.0"
rollDie.authoor= "sfl"
```

Part III

Data Structures

The Data View

Computer programs are built with two essential features: data and processing. We started with processing elements of Python. We're about to start looking at data structures.

In *Language Basics*, we introduced almost all of the procedural elements of the Python language. We started with expressions, looking at the various operators and data types available. We described fourteen of the approximately 24 statements that make up the Python language.

- **Expression Statement**. For example, a function evaluation where there is no return value. Examples include the `print()` function.
- **import**. Used to include a module into another module or program.
- **print**. Used to provide visible output. This is being replaced by the `print()` function.
- **assignment**. This includes the simple and augmented assignment statements. This is how you create variables.
- **del**. Used (rarely) to remove a variable, function, module or other object.
- **if**. Used to conditionally perform suites of statements. This includes **elif** and **else** statements.
- **pass**. This does nothing, but is a necessary syntactic placeholder for an **if** or **while** suite that is empty.
- **assert**. Used to confirm the program is in the expected state.
- **for** and **while**. Perform suites of statements using a sequence of values or while a condition is held true.
- **break** and **continue**. Helpful statements for short-cutting loop execution.
- **def**. Used to define a new function.
- **return**. Used to exit a function. Provides the return value from the function.
- **global**. Used adjust the scoping rules, allowing local access to global names. We discourage its use in *The global Statement*.

The Other Side of the Coin. The next chapters focus on adding various data types to the basic Python language. The subject of data representation and data structures is possibly the most profound part of computer programming. Most of the *killer applications* – email, the world wide web, relational databases – are basically programs to create, read and transmit complex data structures.

We will make extensive use of the object classes that are built-in to Python. This experience will help us design our own object classes in *Data + Processing = Objects*.

We'll work our way through the following data structures.

- **Sequences**. In *Sequences: Strings, Tuples and Lists* we'll extend our knowledge of data types to include an overview various kinds of sequences: strings, tuples and lists. Sequences are collections of objects accessed by their numeric position within the collection.
  - In *Strings* we describe the `string` subclass of sequence. The exercises include some challenging string manipulations.
  - We describe fixed-length sequences, called '`tuple`' s in *Tuples*.
  - In *Lists* we describe the variable-length sequence, called a '`list`'. This '`list`' sequence is one of the powerful features that sets Python apart from other programming languages. The exercises at the end of the '`list`' section include both simple and relatively sophisticated problems.
- **Mappings**. In *Mappings and Dictionaries* we describe mappings and dictionary objects, called `dict`. We'll show how dictionaries are part of some advanced techniques for handling arguments to functions. Mappings are collections of value objects that are accessed by key objects.

- **Sets**. We'll cover `set` objects in *Sets*. Sets are simple collections of unique objects with no additional kind of access.
- **Exceptions**. We'll cover `exception` objects in *Exceptions*. We'll also show the exception handling statements, including **try**, **except**, **finally** and **raise** statements. Exceptions are both simple data objects and events that control the execution of our programs.
- **Iterables**. The **yield** statement is a variation on **return** that simplifies certain kinds of generator algorithms that process or create create *iterable* data structures. We can iterate through almost any kind of data collection. We can also define our own unique or specialized iterations. We'll cover this in *Iterators and Generators*.
- **Files**. The subject of files is so vast, that we'll introduce file objects in *Files*. The **with** statement is particularly helpful when working with files.

  Files are so centrally important that we'll return files in *Components, Modules and Packages*. We'll look at several of the file-related modules in *File Handling Modules* as well as *File Formats: CSV, Tab, XML, Logs and Others*..

In *Functional Programming with Collections* we describe more advanced sequence techniques, including multi-dimensional processing, additional sequence-processing functions, and sorting.

Deferred Topics. There are a few topics that need to be deferred until later.

- **try**. We'll look at exceptions in *Exceptions*. This will include the **except**, **finally** and **raise** statements, also.
- **yield**. We'll look at Generator Functions in *Iterators and Generators*.
- **class**. We'll cover this in it's own part, *Classes*.
- **with**. We'll look at Context Managers in *Managing Contexts: the with Statement*.
- **import**. We'll revisit import in detail in *Components, Modules and Packages*.
- **exec**. Additionally, we'll cover the **exec** statement in *The exec Statement*.

CHAPTER

TWELVE

SEQUENCES: STRINGS, TUPLES AND LISTS

The Common Features of Sequences

Before digging into the details, we'll introduce the common features of three of the data types that are containers for sequences of values.

In *Sequence Semantics* we will provide an overview of the semantics of sequences. We describes the common features of the sequences in *Overview of Sequences*.

The sequence is central to programming and central to Python. A number of statements and functions we have covered have sequence-related features that we have glossed over, danced around, and generally avoided.

We'll revisit a number of functions and statements we covered in previous sections, and add the power of sequences to them. In particular, the **for** statement is something we glossed over in *Iterative Processing: For All and There Exists*.

In the chapters that follow we'll look at *Strings*, *Tuples* and *Lists* in detail. In *Mappings and Dictionaries* , we'll introduce another structured data type for manipulating mappings between keys and values.

12.1 Sequence Semantics

A *sequence* is a container of objects which are kept in a specific order. We can identify the individual objects in a sequence by their position or index. Positions are numbered from zero in Python; the element at index zero is the first element.

We call these *containers* because they are a single object which contains (or collects) any number of other objects. The "any number" clause means that they can contain zero other objects, meaning that an empty container is just as valid as a container with one or thousands of objects.

Important: Other Languages

In some programming languages, they use words like "vector" or "array" to refer to sequential containers. For example, in C or Java, the primitive array has a statically allocated number of positions. In Java, a reference outside that specific number of positions raises an exception. In C, however, a reference outside the defined positions of an array is an error that may never be detected. Really.

There are four commonly-used subspecies of sequence containers.

- String, called `str`. A container of single-byte ASCII characters.
- Unicode String, `unicode`. A container of multi-byte Unicode (or Universal Character Set) characters.

- `tuple`. A container of anything with a fixed number of elements.
- `list`. A container of anything with a dynamic number of elements.

Important: Python 3

This mix of types will change slightly.

The String and Unicode types will merge into the `str` type. This will represent text.

A new container, the "byte array" will be introduced, named `bytes`. This will represent binary data.

`tuple` and `list` won't change.

When we create a `tuple` or `string` , we've created an *immutable*, or static object. We can examine the object, looking at specific characters or items. We can't change the object. This means that we can't put additional data on the end of a `string`. What we can do, however, is create a new `string` that is the concatenation of the two original `string` objects.

When we create a `list`, on the other hand, we've created a *mutable* object. A `list` can have additional objects appended to it or inserted in it. Objects can be removed from a `list`, also. A `list` can grow and shrink; the order of the objects in the `list` can be changed without creating a new `list` object.

One other note on `string`. While `string` are sequences of characters, there is no separate character data type. A character is simply a `string` of length one. This relieves programmers from the C or Java burden of remembering which quotes to use for single characters as distinct from multi-character `string`. It also eliminates any problems when dealing with Unicode multi-byte characters.

12.2 Overview of Sequences

All the varieties of sequences (`string`, `tuple` and `list`) have some common characteristics. We'll identify the common features first, and then move on to cover these in detail for each individual type of sequence. This section is a road-map for the following three sections that cover `string`, `tuple` and '`list`' in detail.

Literal Values. Each sequence type has a literal representation. The details will be covered in separate sections, but the basics are these:

- `string` uses quotes: `"string"`.
- `tuple` uses '`()`': `(1,'b',3.1)`.
- `list` uses '`[]`': `[1,'b',3.1]`.

Operations. Sequences have three common operations: '`+`' will concatenate sequences to make longer sequences. '`*`' is used with a number and a sequence to repeat the sequence several times. Finally, the '`[ ]`' operator is used to select elements from a sequence.

The '`[ ]`' operator can extract a single item, or a subset of items by slicing. There are two forms of '`[]`'.

- The single item format is *sequence* [*index*]. Items are numbered from 0.
- The slice format is *sequence* [*start* `:` *end*]. Items from *start* to *end* -1 are chosen to create a new sequence; it will be a slice of the original sequence. There will be $end - start$ items in the resulting sequence.

Positions can be numbered from the end of the `string` as well as the beginning. Position -1 is the last item of the sequence, -2 is the next-to-last item.

Here's how it works: each item has a positive number position that identifies the item in the sequence. We'll also show the negative position numbers for each item in the sequence. For this example, we're looking at a four-element sequence like the `tuple` '`(3.14159,"two words",2048,(1+2j))`' .

forward position	0	1	2	3
reverse position	-4	-3	-2	-1
item	3.14159	“two words”	2048	(1+2j)

Why do we have two different ways of identifying each position in the sequence? If you want, you can think of it as a handy short-hand. The last item in any sequence, `S` can be identified by the formula ‘`S[ len(S)-1 ]`’ . For example, if we have a sequence with 4 elements, the last item is in position 3. Rather than write ‘`S[ len(S)-1 ]`’, Python lets us simplify this to ‘`S[-1]`’ .

You can see how this works with the following example.

```
>>> a=(3.14159,"two words",2048,(1+2j))
>>> a[0]
3.1415899999999999
>>> a[-3]
'two words'
>>> a[2]
2048
>>> a[-1]
(1+2j)
```

Built-in Functions. `len()`, `max()` and `min()` apply to all varieties of sequences. We’ll provide the definitions here and refer to them in various class definitions.

len(*sized_collection*)
: Return the number of items of the collection. This can be any kind of sized collection. All sequences and mappings are subclasses of `collections.Sized` and provide a length.

  Here are some examples.

  ```
  >>> len("Wednesday")
  9
  >>> len( (1,1,2,3) )
  4
  ```

max(*iterable_collection*)
: Returns the largest value in the iterable collection. All sequences and mappings are subclasses of `collections.Iterable`; the `max()` function can iterate over elements and locate the largest.

  ```
  >>> max( (1,2,3) )
  3
  >>> max('abstractly')
  'y'
  ```

  Note that `max()` can also work with a number of individual arguments instead of a single iterable collection argument value. We looked a this in *Collection Functions*.

min(*iterable_collection*)
: Returns the smallest value in the iterable collection. All sequences and mappings are subclasses of `collections.Iterable`; the `max()` function can iterate over elements and locate the smallest.

  ```
  >>> min( (10,11,2) )
  2
  >>> min( ('10','11','2') )
  '10'
  ```

  Note that strings are compared alphabetically. The `min()` (and `max()` function can’t determine that these are supposed to be evaluated as numbers.)

`sum`(*iterable_collection, [start=0]*)
Return the sum of the items in the iterable collection. All sequences and mappings are subclasses of `collections.Iterable`.

If `start` is provided, this is the initial value for the sum, otherwise `0` is used.

If the values being summed are not all numeric values, this will raise a `TypeError` exception.

```
>>> sum( (1,1,2,3,5,8) )
20
>>> sum( (), 3 )
3
>>> sum( (1,2,'not good') )
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unsupported operand type(s) for +: 'int' and 'str'
```

`any`(*iterable_collection*)
Return `True` if there exists an item in the iterable collection which is `True`. All sequences and mappings are subclasses of `collections.Iterable`.

`all`(*iterable_collection*)
Return `True` if all items in the iterable collection are `True`. All sequences and mappings are subclasses of `collections.Iterable`.

`enumerate`(*iterable_collection*)
Iterates through the iterable collection returning 2-tuples of '`( index, item )`'.

```
>>> for position, item in enumerate( ('word',3.1415629,(2+3j) ) ):
...     print position, item
...
0 word
1 3.1415629
2 (2+3j)
```

`sorted`(*sequence, [key=None], [reverse=False]*)
This returns an iterator that steps through the elements of the iterable container in ascending order.

If the `reverse` keyword parameter is provided and set to `True`, the container is iterated in descending order.

The `key` parameter is used when the items in the container aren't simply sorted using the default comparison operators. The *key* function must return the fields to be compared selected from the underlying objects in the tuple.

We'll look at this in detail in *Functional Programming with Collections*.

`reversed`(*sequence*)
This returns an iterator that steps through the elements in the iterable container in reverse order.

```
>>> tuple( reversed( (9,1,8,2,7,3) ) )
(3, 7, 2, 8, 1, 9)
```

Comparisons. The standard comparisons ('`<`', '`<=`', '`>`', '`<=`', '`==`', '`!=`') apply to sequences. These all work by doing item-by-item comparison within the two sequences. The item-by-item rule results in `strings` being sorted alphabetically, and `tuples` and '`list`'s sorted in a way that is similar to `strings`.

There are two additional comparisons: **in** and **not in**. These check to see if a single value occurs in the sequence. The **in** operator returns a `True` if the item is found, `False` if the item is not found. The **not in** operator returns `True` if the item is not found in the sequence.

Methods. The `string` and `list` classes have method functions that operate on the object's value. For instance '`"abc".upper()`' executes the `upper()` method belonging to the `string` literal `"abc"`. The result is a new string, `'ABC'`. The exact dictionary of methods is unique to each class of sequences.

Statements. The `tuple` and `list` classes are central to certain Python statements, like the **assignment** statement and the **for** statement. These were details that we skipped over in *The Assignment Statement* and *Iterative Processing: For All and There Exists*.

Modules. There is a `string` module with several `string` specific functions. Most of these functions are now member functions of the `string` type. Additionally, this module has a number of constants to define various subsets of the ASCII character set, including digits, printable characters, whitespace characters and others.

Factory Functions. There are also built-in factory (or conversion) functions for the sequence objects. We've looked at some of these already, when we looked at `str()` and `repr()`.

12.3 Exercises

1. **Tuples and Lists**. What is the value in having both immutable sequences (`tuple`) and mutable sequences (`list`)? What are the circumstances under which you would want to change a `string`? What are the problems associated with a `string` that grows in length? How can storage for variable length `string` be managed?
2. **Unicode Strings**. What is the value in making a distinction between Unicode strings and ASCII strings? Does it improve performance to restrict a `string` to single-byte characters? Should all strings simply be Unicode strings to make programs simpler? How should file reading and writing be handled?
3. **Statements and Data Structures**. In order to introduce the **for** statement in *Iterative Processing: For All and There Exists*, we had to dance around the sequence issue. Would it make more sense to introduce the various sequence data structures first, and then describe statements that process the data structure later?

   Something has to be covered first, and is therefore more fundamental. Is the processing statement more fundamental to programming, or is the data structure?

12.4 Style Notes

Try to avoid extraneous spaces in `list` and `tuple` displays. Python programs should be relatively compact. Prose writing typically keeps ()'s close to their contents, and puts spaces after commas, never before them. This should hold true for Python, also.

The preferred formatting for a `list` or `tuple`, then, is '`[1,2,3]`' or '`(1, 2, 3)`'. Spaces are not put after the initial '`[`' or '`(`'. Spaces are not put before '`,`'.

CHAPTER

THIRTEEN

STRINGS

We'll look at the two `string` classes from a number of viewpoints: semantics, literal values, operations, comparison operators, built-in functions, methods and modules. Additionally, we have a digression on the immutability of `string` objects.

13.1 String Semantics

A String (the formal class name is `str`) is an immutable sequence of ASCII characters.

A Unicode String (`unicode`) is an immutable sequence of Unicode characters.

Since a string (either `str` or `unicode`) is a sequence, all of the common operations on sequences apply. We can concatenate string objects together and select characters from a string. When we select a slice from a string, we've extracted a substring.

An individual character is simply a string of length one.

Important: Python 3.0

The Python 2 `str` class, which is limited to single-byte ASCII characters does two separate things: it represents text as well as a collection of bytes.

The text features of `str` gain the features from the Unicode String class, `unicode`. The new `str` class will represent strings of text, irrespective of the underlying encoding. It can be ASCII, UTF-8, UTF-16 or any other encoding.

The "array of bytes" features of the Python 2 `str` class will be moved into a new class, `bytes`. This new class will implement simple sequences of bytes and will support conversion between bytes and strings using encoding and decoding functions.

13.2 String Literal Values

A `str` is a sequence of ASCII characters. The literal value for a `str` is written by surrounding the value with quotes or apostrophes. There are several variations to provide some additional features.

Basic String Strings are enclosed in matching quotes ('`"`') or apostrophes ('`'`'). A string enclosed in quotes ('`"`') can contain apostrophes ('`'`'); similarly, a string enclosed in apostrophes ('`'`') can contains quotes ('`"`'). A basic `str` must be completed on a single line, or continued with a '\' as the very last character of a line.

Examples:

```
"consultive"
'syncopated'
"don't do that"
'"Okay," he said.'
```

Multi-Line String Also called "Triple-Quoted String".

A multi-line `str` is enclosed in triple quotes ('`"""`') or triple apostrophes ('`'''`'). It continues on across line boundaries until the concluding triple-quote or triple-apostrophe.

Examples:

```
"""A very long
string"""

'''SELECT *
FROM THIS, THAT
WHERE THIS.KEY = THAT.FK
AND THIS.CODE = 'Active'
'''
```

Unicode String A Unicode String uses the above quoting rules, but prefaces the quote with ('`u"`'), ('`u'`'), ('`u"""`') or ('`u'''`').

Unicode is the Universal Character Set; each character requires from 1 to 4 bytes of storage. ASCII is a single-byte character set; each of the 256 ASCII characters requires a single byte of storage. Unicode permits any character in any of the languages in common use around the world.

A special '`\uxxxx`' escape sequence is used for Unicode characters that don't happen to occur on your ASCII keyboard.

Examples:

```
u'\u65e5\u672c'
u"All ASCII"
```

Raw String A Raw String uses the above quoting rules, but prefaces the quote with ('`r"`'), ('`r'`'), ('`r"""`') or ('`r'''`').

The backslash characters ('\') are *not* interpreted as escapes by Python, but are left as is. This is handy for Windows files names that contain '\'. It is also handy for regular expressions that make extensive use of backslashes.

Examples:

```
newline_literal= r'\n'
filename= "C:\mumbo\jumbo"
pattern= "(\*\S+\*)"
```

The `newline_literal` is a two character string, not the newline character.

Outside of raw strings, non-printing characters and Unicode characters that aren't found on your keyboard are created using *escapes*. A table of escapes is provided below. These are Python representations for unprintable ASCII characters. They're called escapes because the '\' is an escape from the usual meaning of the following character.

Escape	Meaning
\\	Backslash (\)
\'	Apostrophe (')
\"	Quote (")
\a	Audible Signal; the ASCII code called BEL. Some OS's translate this to a screen flash or ignore it completely.
\b	Backspace (ASCII BS)
\f	Formfeed (ASCII FF). On a paper-based printer, this would move to the top of the next page.
\n	Linefeed (ASCII LF), also known as newline. This would move the paper up one line.
\r	Carriage Return (ASCII CR). On a paper based printer, this returned the print carriage to the start of the line.
\t	Horizontal Tab (ASCII TAB)
\ooo	An ASCII character with the given octal value. The *ooo* is any octal number.
\xhh	An ASCII character with the given hexadecimal value. The '`x`' is required. The *hh* is any hex number.

Adjacent Strings. Note that adjacent `string` objects are automatically concatenated to make a single `string`.

'`"ab" "cd" "ef"`' is the same as '`"abcdef"`'.

The most common use for this is the following:

```
msg = "A very long" \
"message, which didn't fit on" \
"one line."
```

Unicode Characters. For Unicode, a special '`\uxxxx`' escape is provided. This requires the four digit Unicode character identification.

For example, "日本" is made up of Unicode characters '`U+65e5`' and '`U+672c`'. In Python, we write this string as '`u'\u65e5\u672c'`'.

There are a variety of Unicode encoding schemes, for example, UTF-8, UTF-16 and LATIN-1. The `codecs` module provides mechanisms for encoding and decoding Unicode Strings.

13.3 String Operations

There are a number of operations on `str` objects, operations which create `str`s and operations which create other objects from `str`s.

There are three operations ('`+`' , '`*`' , '`[ ]`') that work with all sequences (including `str`s) and a unique operation, '`%`', that can be performed only with `str` objects.

The '`+`' operator creates a new `string` as the concatenation of the arguments.

```
>>> "hi " + 'mom'
'hi mom'
```

The '`*`' operator between `str` and numbers (number '`*`' `str` or `str` '`*`' number) creates a new `str` that is a number of repetitions of the input `str`.

```
>>> print 3*"cool!"
cool!cool!cool!
```

The '[ ]' operator can extract a single character or a slice from the `string`. There are two forms: the single-item form and the slice form.

- The single item format is *string* [*index*]. Characters are numbered from 0 to '`len(string)`'. Characters are also numbered in reverse from -'`len(string)`' to -1.
- The slice format is *string* [*start* `:` *end*]. Characters from *start* to *end* -1 are chosen to create a new `str` as a slice of the original `str`; there will be *end* − *start* characters in the resulting `str`.

  If *start* is omitted it is the beginning of the `string` (position 0).

  If *end* is omitted it is the end of the `string` (position -1).

  Yes, you can omit both ('`someString[:]`') to make a copy of a string.

```
>>> s="adenosine"
>>> s[2]
'e'
>>> s[:5]
'adeno'
>>> s[5:]
'sine'
>>> s[-5:]
'osine'
>>> s[:-5]
'aden'
```

The String Formatting Operation, %. The % operator is sometimes called *string interpolation*, since it interpolates literal text and converted values. We prefer to call it string formatting, since that is a more apt description. Much of the formatting is taken straight from the C library's `printf()` function.

This operator has three forms. You can use % with a `str` and value, `str` and a `tuple` as well as `str` and classname:*dict*. We'll cover `tuple` and `dict` in detail later.

The string on the left-hand side of % contains a mixture of *literal text* plus *conversion specifications*. A conversion specification begins with '%'. For example, integers are converted with '`%i`'. Each conversion specification will use a corresponding value from the `tuple`. The first conversion uses the first value of the `tuple`, the second conversion uses the second value from the `tuple`.

For example:

```
import random
d1, d2 = random.randrange(1,6), random.randrange(1,6)
r= "die 1 shows %i, and die 2 shows %i" % ( d1, d2 )
```

The first '`%i`' will convert the value for `d1` to a `string` and insert the value, the second '`%i`' will convert the value for `d2` to a `string`. The % operator returns the new `string` based on the format, with each conversion specification replaced with the appropriate values.

Conversion Specifications. Each conversion specification has from one to four elements, following this pattern: '`%`''.'

```
 [ flags ][ width [ precision ]] code
```

The '`%`' and the final *code* in each conversion specification are required. The other elements are optional.

The optional *flags* element can have any combination of the following values:

'`-`' Left adjust the converted value in a field that has a length given by the *width* element. The default is right adjustment.

'+' Show positive signs (sign will be '+' or '-'). The default is to show negative signs only.

␣(a *space*) Show positive signs with a space (sign will be ␣or '-'). The default is negative signs only.

'#' Use the Python literal rules (0 for octal, 0x for hexadecimal, etc.) The default is decoration-free notation.

'0' Zero-fill the the field that has a length given by the *width* element. The default is to space-fill the field. This doesn't make a lot of sense with the - (left-adjust) flag.

The optional *width* element is a number that specifies the total number of characters for the field, including signs and decimal points. If omitted, the width is just big enough to hold the output number. If a '*' is used instead of a number, an item from the `tuple` of values is used as the width of the field. For example, '`"%*i" % ( 3, d1 )`' uses the value 3 from the `tuple` as the field width and `d1` as the value to convert to a `string`.

The optional *precision* element (which must be preceded by a dot, '.' if it is present) has a few different purposes. For numeric conversions, this is the number of digits to the right of the decimal point. For `string` conversions, this is the maximum number of characters to be printed, longer `string` s will be truncated. If a '*' is used instead of a number, an item from the `tuple` of values is used as the precision of the conversion. For example, '`"%*.*f" % ( 6, 2, avg )`' uses the value 6 from the `tuple` as the field width, the value 2 from the `tuple` as the precision and `avg` as the value.

The standard conversion rules also permit a long or short indicator: '`l`' or '`h`'. These are tolerated by Python so that these formats will be compatible with C, but they have no effect. They reflect internal representation considerations for C programming, not external formatting of the data.

The required one-letter *code* element specifies the conversion to perform. The codes are listed below.

'%' Not a conversion, this creates a '%' in the resulting `str`. Use '`%%`' to put a '%' in the output `str`.

'c' Convert a single-character `str`. This will also convert an integer value to the corresponding ASCII character. For example, '`"%c" % ( 65, )`' results in '`"A"`'.

's' Convert a `str`. This will convert non- `str` objects by implicitly calling the `str()` function.

'r' Call the `repr()` function, and insert that value.

'i' 'd' Convert a numeric value, showing ordinary decimal output. The code i stands for integer, d stands for decimal. They mean the same thing; but it's hard to reach a consensus on which is "correct".

'u' Convert an *unsigned* number. While relevant to C programming, this is the same as the '`i`' or '`d`' format conversion.

'o' Convert a numeric value, showing the octal representation. '`%#0`' gets the Python-style value with a leading zero. This is similar to the `oct()` function.

'x' 'X' Convert a numeric value, showing the hexadecimal representation. '`%#X`' gets the Python-style value with a leading '`0X`'; '`%#x`' gets the Python-style value with a leading '`0x`'. This is similar to the `hex()` function.

'e' 'E' Convert a numeric value, showing scientific notation. '`%e`' produces $\pm d.ddd$ '`e`' $\pm xx$, '`%E`' produces $\pm d.ddd$ '`E`' $\pm xx$.

'f' 'F' Convert a numeric value, using ordinary decimal notation. In case the number is gigantic, this will switch to '`%g`' or '`%G`' notation.

'g' 'G' "Generic" floating-point conversion. For values with an exponent larger than -4, and smaller than the *precision* element, the '`%f`' format will be used. For values with an exponent smaller than -4, or values larger than the *precision* element, the '`%e`' or '`%E`' format will be used.

Here are some examples.

```
"%i: %i win, %i loss, %6.3f" % (count,win,loss,float(win)/loss)
```

This example does four conversions: three simple integer and one floating point that provides a width of 6 and 3 digits of precision. `-0.000` is the expected format. The rest of the `string` is literally included in the output.

```
"Spin %3i: %2i, %s" % (spin,number,color)
```

This example does three conversions: one number is converted into a field with a width of 3, another converted with a width of 2, and a `string` is converted, using as much space as the `string` requires.

```
>>> a=6.02E23
>>> "%e" % a
'6.020000e+23'
>>> "%E" % a
'6.020000E+23'
>>>
```

This example shows simple conversion of a floating-point number to the default scientific notation which has a witdth of 12 and a precision of 6.

13.4 String Comparison Operations

The standard comparisons ('`<`', '`<=`', '`>`', '`>=`', '`==`', '`!=`') apply to `str` objects. These comparisons use the standard character-by-character comparison rules for ASCII or Unicode.

There are two additional comparisons: **in** and **not in**. These check to see if a substring occurs in a longer string. The **in** operator returns a `True` when the substring is found, `False` if the substring is not found. The **not in** operator returns `True` if the substring is not found.

```
>>> 'a' in 'xyzzyabcxyzzy'
True
>>> 'abc' in 'xyzzyabc'
True
```

Don't be fooled by the fact that string representations of integers don't seem to sort properly. String comparison does not magically recornize that the strings are representations of numbers. It's simple "alphabetical order" rules applied to digits.

```
>>> '100' < '25'
True
```

This is true because '`'1' < '2'`'.

13.5 String Statements

The **for** statement will step though all elements of a sequence. In the case of a string, it will step through each character of the string.

For example:

```
for letter in "forestland":
    print letter
```

This will print each letter of the given string.

13.6 String Built-in Functions

The following built-in functions are relevant to `str` manipulation

chr(*i*)
: Return a `str` of one character with ordinal `i`. Note that $0 \leq i < 256$ to be a proper ASCII character.

unichr(*u*)
: Return a Unicode String (`unicode`) of one character with ordinal `u`. $0 \leq u < 65536$.

ord(*c*)
: Return the integer ordinal of a one character `str`. This works for any character, including Unicode characters.

unicode(*string, [encoding], [errors]*)
: Creates a new Unicode object from the given encoded `string`. `encoding` defaults to the current default `string` encoding. `errors` defines the error handling, defaults to 'strict'.

  The `unicode()` function converts the `string` to a specific Unicode external representation. The default `encoding` is 'UTF-8' with 'strict' error handling.

  Choices for `errors` are 'strict', 'replace' and 'ignore'. Strict raises an exception for unrecognized characters, replace substitutes the Unicode replacement character ('`\uFFFD`') and ignore skips over invalid characters.

  The `codecs` and `unicodedata` modules provide more functions for working with Unicode.

```
>>> unicode("hi mom","UTF-16")
u'\u6968\u6d20\u6d6f'
>>> unicode("hi mom","UTF-8")
u'hi mom'
```

Important: Python 3

The `ord()`, `chr()`, `unichr()` and `unicode()` functions will be simplified in Python 3.

Python 3 no longer separates ASCII from Unicode strings. These functions will all implicitly work with Unicode strings. Note that the UTF-8 encoding of Unicode overlaps with ASCII, so this simplification to use Unicode will not significantly disrupt programs that work ASCII files.

Several important functions were defined earlier in *String Conversion Functions*.

- `repr()`. Returns a canonical `string` representation of the object. For most object types, '`eval(repr(object)) == object`'.

  For simple numeric types, the result of `repr()` isn't very interesting. For more complex, types, however, it often reveals details of their structure.

```
>>> a="""a very
... long string
... in multiple lines
... """
>>> repr(a)
"'a very \\nlong string \\nin multiple lines\\n'"
```

  This representation shows the newline characters ('`\n`') embedded within the triple-quoted string.

  Important: Python 3

  The "reverse quotes" ('`a`') work like '`repr(a)`'. The reverse quote syntax is rarely used, and will be dropped in Python 3.

- `str()`. Return a nice `string` representation of the object. If the argument is a `string`, the return value is the same object.

```
>>> a= str(355.0/113.0)
>>> a
'3.14159292035'
>>> len(a)
13
```

Some other functions which apply to strings as well as other sequence objects.

- `len()`. For strings, this function returns the number of characters.

```
>>> len("abcdefg")
7
>>> len(r"\n")
2
>>> len("\n")
1
```

- `max()`. For strings, this function returns the maximum character.
- `min()`. For strings, this function returns the minimum character.
- `sorted()`. Iterate through the string's characters in sorted order. This expands the string into an explicit list of individual characters.

```
>>> sorted( "malapertly" )
['a', 'a', 'e', 'l', 'l', 'm', 'p', 'r', 't', 'y']
>>> "".join( sorted( "malapertly" ) )
'aaellmprty'
```

- `reversed()`. Iterate through the string's characters in reverse order. This creates an iterator. The iterator can be used with a variety of functions or statements.

```
>>> reversed( "malapertly" )
<reversed object at 0x600230>
>>> "".join( reversed( "malapertly" )  )
'yltrepalam'
```

13.7 String Methods

A `string` object has a number of method functions. These can be grouped arbitrarily into transformations, which create new `string` s from old, and information, which returns a fact about a `string`.

The following *string* transformation functions create a new `string` object from an existing *string*.

`capitalize()`
: Create a copy of the *string* with only its first character capitalized.

`center(`*width*`)`
: Create a copy of the *string* centered in a string of length `width`. Padding is done using spaces.

`encode(`*encoding, [errors]*`)`
: Return an encoded version of *string*. Default `encoding` is the current default string encoding. `errors` may be given to set a different error handling scheme. Default is 'strict' meaning that encoding errors raise a `ValueError`. Other possible values are 'ignore' and 'replace'.

`expandtabs`(*[tabsize]*)
Return a copy of *string* where all tab characters are expanded using spaces. If `tabsize` is not given, a tab size of 8 characters is assumed.

`join`(*sequence*)
Return a string which is the concatenation of the `string`s in the `sequence`. Each separator between elements is a copy of the given *string* object.

`ljust`(*width*)
Return a copy of *string* left justified in a string of length `width`. Padding is done using spaces.

`lower`()
Return a copy of *string* converted to lowercase.

`lstrip`()
Return a copy of *string* with leading whitespace removed.

`replace`(*old, new, [maxsplit]*)
Return a copy of *string* with all occurrences of substring `old` replaced by `new`. If the optional argument `maxsplit` is given, only the first `maxsplit` occurrences are replaced.

`rjust`(*width*)
Return a copy of *string* right justified in a string of length `width`. Padding is done using spaces.

`rstrip`()
Return a copy of *string* with trailing whitespace removed.

`strip`()
Return a copy of *string* with leading and trailing whitespace removed.

`swapcase`()
Return a copy of *string* with uppercase characters converted to lowercase and vice versa.

`title`()
Return a copy of *string* with words starting with uppercase characters, all remaining characters in lowercase.

`translate`(*table, [deletechars]*)
Return a copy of the *string*, where all characters occurring in the optional argument `deletechars` are removed, and the remaining characters have been mapped through the given translation `table`. The table must be a `string` of length 256, providing a translation for each 1-byte ASCII character.

The translation tables are built using the `string.maketrans()` function in the `string` module.

`upper`()
Return a copy of *string* converted to uppercase.

The following accessor methods provide information about a *string*.

`count`(*sub, [start], [end]*)
Return the number of occurrences of substring `sub` in *string*. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`endswith`(*suffix, [start], [end]*)
Return `True` if *string* ends with the specified `suffix`, otherwise return `False`. The suffix can be a single string or a sequence of individual strings. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`find`(*sub, [start], [end]*)
Return the lowest index in *string* where substring `sub` is found. Return -1 if the substring is not found. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`index`(*sub, [start], [end]*)
Return the lowest index in *string* where substring `sub` is found. Raise `ValueError` if the substring is not found. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`isalnum`()
Return `True` if all characters in *string* are alphanumeric and there is at least one character in *string*; `False` otherwise.

`isalpha`()
Return `True` if all characters in *string* are alphabetic and there is at least one character in *string*; `False` otherwise.

`isdigit`()
Return `True` if all characters in *string* are digits and there is at least one character in *string*; `False` otherwise.

`islower`()
Return `True` if all characters in *string* are lowercase and there is at least one cased character in *string*; `False` otherwise.

`isspace`()
Return `True` if all characters in *string* are whitespace and there is at least one character in *string*, `False` otherwise.

`istitle`()
Return `True` if *string* is *titlecased*. Uppercase characters may only follow uncased characters (whitespace, punctuation, etc.) and lowercase characters only cased ones, `False` otherwise.

`isupper`()
Return `True` if all characters in *string* are uppercase and there is at least one cased character in *string*; `False` otherwise.

`rfind`(*sub, [start], [end]*)
Return the highest index in *string* where substring `sub` is found. Return -1 if the substring is not found. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`rindex`(*sub, [start], [end]*)
Return the highest index in *string* where substring `sub` is found. Raise `ValueError` if the substring is not found.. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

`startswith`(*sub, [start], [end]*)
Return `True` if *string* starts with the specified `prefix`, otherwise return `False`. The prefix can be a single string or a sequence of individual strings. If `start` or `end` are present, these have the same meanings as a slice '`string[start:end]`'.

The following generators create another kind of object, usually a sequence, from a *string*.

`partition`(*separator*)
Return three values: the text prior to the first occurance of `separator` in *string*, the `sep` as the delimiter, and the text after the first occurance of the separator. If the separator doesn't occur, all of the input string is in the first element of the 3-tuple; the other two elements are empty strings.

`split`(*separator, [maxsplit]*)
Return a `list` of the words in the *string*, using `separator` as the delimiter. If `maxsplit` is given, at most `maxsplit` splits are done. If `separator` is not specified, any whitespace characater is a separator.

`splitlines`(*keepends*)
Return a `list` of the lines in *string*, breaking at line boundaries. Line breaks are not included in the resulting `list` unless `keepends` is given and set to `True`.

13.8 String Modules

There is an older module named `string`. Almost all of the functions in this module are directly available as methods of the `string` type. The one remaining function of value is the `maketrans()` function, which creates a translation table to be used by the `translate()` method of a `string`.

`maketrans`(*from, to*)

Return a translation table (a `string` 256 characters long) suitable for use in `str.translate()`. The `from` and `to` parameters must be strings of the same length. The table will assure that each character in `from` is mapped to the character in the same position in `to`.

The following example shows how to make and then apply a translation table.

```
>>> import string
>>> t= string.maketrans("aeiou","xxxxx")
>>> phrase= "now is the time for all good men to come to the aid of their party"

>>> phrase.translate( t )
'nxw xs thx txmx fxr xll gxxd mxn tx cxmx tx thx xxd xf thxxr pxrty'
```

The `codecs` module takes a different approach and has a number of built-in translations.

More importantly, this module contains a number of definitions of the characters in the ASCII character set. These definitions serve as a central, formal repository for facts about the character set. Note that there are general definitions, applicable to Unicode character setts, different from the ASCII definitions.

ascii_letters The set of all letters, essentially a union of `ascii_lowercase` and `ascii_uppercase`.

ascii_lowercase The lowercase letters in the ASCII character set: `'abcdefghijklmnopqrstuvwxyz'`

ascii_uppercase The uppercase letters in the ASCII character set: `'ABCDEFGHIJKLMNOPQRSTUVWXYZ'`

digits The digits used to make decimal numbers: `'0123456789'`

hexdigits The digits used to make hexadecimal numbers: `'0123456789abcdefABCDEF'`

letters This is the set of all letters, a union of `lowercase` and `uppercase`, which depends on the setting of the locale on your system.

lowercase This is the set of lowercase letters, and depends on the setting of the locale on your system.

octdigits The digits used to make octal numbers: `'01234567'`

printable All printable characters in the character set. This is a union of digits, letters, punctuation and whitespace.

punctuation All punctuation in the ASCII character set, this is `!"#$%&'()*+,-./:;<=>?@[\]^_`{|}~`

uppercase This is the set of uppercase letters, and depends on the setting of the locale on your system.

whitespace A collection of characters that cause spacing to happen. For ASCII this is `'\t\n\x0b\x0c\r'`

13.9 String Exercises

1. **Check Amount Writing**.

   Translate a number into the English phrase.

   This example algorithm fragment is only to get you started. This shows how to pick off the digits from the right end of a number and assemble a resulting string from the left end of the string.

   Note that the right-most two digits have special names, requiring some additional cases above and beyond the simplistic loop shown below. For example, 291 is "two hundred ninety one", where 29 is "twenty nine". The word for "2" changes, depending on the context.

   As a practical matter, you should analyze the number by taking off three digits at a time, the expression '`(number % 1000)`' does this. You would then format the three digit number with words like "million", "thousand", etc.

English Words For An Amount, *n*

   (a) **Initialization**.

   Set *result* ← ""

   Set *tc* ← 0. This is the "tens counter" that shows what position we're examining.

   (b) **Loop**. While $n > 0$.

      i. **Get Right Digit**. Set *digit* ← $n\%10$, the remainder when divided by 10.

      ii. **Make Phrase**. Translate `digit` to a string from "zero" to "nine". Translate `tc` to a string from "" to "thousand". This is tricky because the "teens" are special, where the "hundreds" and "thousands" are pretty simple.

      iii. **Assemble Result**. Prepend `digit` string and `tc` string to the left end of the `result` string.

      iv. **Next Digit**. $n \leftarrow \lfloor n \div 10 \rfloor$. Be sure to use the '`//`' integer division operator, or you'll get floating-point results.

      Increment `tc` by 1.

   (c) **Result**. Return `result` as the English translation of *n*.

2. **Roman Numerals**.

   This is similar to translating numbers to English. Instead we will translate them to Roman Numerals.

   The Algorithm is similar to Check Amount Writing (above). You will pick off successive digits, using '`%10`' and '`/10`' to gather the digits from right to left.

   The rules for Roman Numerals involve using four pairs of symbols for ones and five, tens and fifties, hundreds and five hundreds. An additional symbol for thousands covers all the relevant bases.

   When a number is followed by the same or smaller number, it means addition. "II" is two 1's = 2. "VI" is 5 + 1 = 6.

   When one number is followed by a larger number, it means subtraction. "IX" is 1 before 10 = 9. "IIX" isn't allowed, this would be "VIII".

   For numbers from 1 to 9, the symbols are "I" and "V", and the coding works like this.

   (a) "I"

   (b) "II"

(c) "III"

(d) "IV"

(e) "V"

(f) "VI"

(g) "VII"

(h) "VIII"

(i) "IX"

The same rules work for numbers from 10 to 90, using "X" and "L". For numbers from 100 to 900, using the symbols "C" and "D". For numbers between 1000 and 4000, using "M".

Here are some examples. 1994 = MCMXCIV, 1956 = MCMLVI, 3888= MMMDCCCLXXXVIII

3. **Word Lengths**.

   Analyze the following block of text. You'll want to break into into words on whitespace boundaries. Then you'll need to discard all punctuation from before, after or within a word.

   What's left will be a sequence of words composed of ASCII letters. Compute the length of each word, and produce the sequence of digits. (no word is 10 or more letters long.)

   Compare the sequence of word lenghts with the value of '`math.pi`'.

```
Poe, E.
Near a Raven

Midnights so dreary, tired and weary,
Silently pondering volumes extolling all by-now obsolete lore.
During my rather long nap - the weirdest tap!
An ominous vibrating sound disturbing my chamber's antedoor.
"This", I whispered quietly, "I ignore".
```

   This is based on http://www.cadaeic.net/cadenza.htm.

13.10 Digression on Immutability of Strings

In *Strings* and *Tuples* we noted that `string` and `tuple` objects are immutable. They cannot be changed once they are created. Programmers experienced in other languages sometimes find this to be an odd restriction.

Two common questions that arise are how to expand a `string` and how to remove characters from a `string`.

Generally, we don't expand or contract a `string`, we create a new `string` that is the concatenation of the original `string` objects. For example:

```
>>> a="abc"
>>> a=a+"def"
>>> a
'abcdef'
```

In effect, Python gives us `string` objects of arbitrary size. It does this by dynamically creating a new `string` instead of modifying an existing `string`.

Some programmers who have extensive experience in other languages will ask if creating a new `string` from the original `string` is the most efficient way to accomplish this. Or they suggest that it would be

"simpler" to allow a mutable `string` for this kind of concatenation. The short answer is that Python's storage management makes this use of immutable `string` the simplest and most efficient.

Responses to the immutability of `tuple` and mutability of `list` vary, including some of the following frequently asked questions.

Since a `list` does everything a `tuple` does and is mutable, why bother with `tuple`?

Immutable `tuple` objects are more efficient than variable-length `list` objects for some operations. Once the `tuple` is created, it can only be examined. When it is no longer referenced, the normal Python garbage collection will release the storage for the `tuple`.

Most importantly, a tuple can be reliably hashed to a single value. This makes it a usable key for a mapping.

Many applications rely on fixed-length `tuple`s. A program that works with coordinate geometry in two dimensions may use 2-tuples to represent (x, y) coordinate pairs. Another example might be a program that works with colors as 3-tuples, (r, g, b), of red, green and blue levels. A variable-length `list` is not appropriate for these kinds of fixed-length tuple.

Wouldn't it be "more efficient" to allow mutable `string` s?

There are a number of axes for efficiency: the two most common are time and memory use.

A mutable `string` could use less memory. However, this is only true in the benign special case where we are only replacing or shrinking the `string` within a fixed-size buffer. If the `string` expands beyond the size of the buffer the program must either crash with an exception, or it must switch to dynamic memory allocation. Python simply uses dynamic memory allocation from the start. C programs often have serious security problems created by attempting to access memory outside of a `string` buffer. Python avoids this problem by using dynamic allocation of immutable `string` objects.

Processing a mutable `string` could use less time. In the cases of changing a `string` in place or removing characters from a `string`, a fixed-length buffer would require somewhat less memory management overhead. Rather than indict Python for offering immutable `string`, this leads to some productive thinking about `string` processing in general.

In text-intensive applications we may want to avoid creating separate `string` objects. Instead, we may want to create a single `string` object – the input buffer – and work with slices of that buffer. Rather than create `string`, we can create `slice` objects that describe starting and ending offsets within the one-and-only input buffer.

If we then need to manipulate these slices of the input buffer, we can create new `string` objects only as needed. In this case, our application program is designed for efficiency. We use the Python `string` objects when we want flexibility and simplicity.

CHAPTER

FOURTEEN

TUPLES

We'll look at `tuple` from a number of viewpoints: semantics, literal values, operations, comparison operators, statements, built-in functions and methods.

Additionally, we have a digression on the Σ operator in *Digression on The Sigma Operator*.

14.1 Tuple Semantics

A `tuple` is a container for a fixed sequence of data objects. The name comes from the Latin suffix for multiples: dou*ble*, tri*ple*, quadr*uple*, quin*tuple*.

Mathematicians commonly consider *ordered pairs*; for instance, most analytical geometry is done with Cartesian coordinates (x, y). An ordered pair can be generalized as a 2-tuple.

An essential ingredient here is that a `tuple` has a fixed and known number of elements. A 3-dimensional point is a 3-tuple. An CMYK color code is a 4-tuple. The size of the `tuple` can't change without fundamentally redefining the problem we're solving.

A `tuple` is an immutable sequence of Python objects. Since it is a sequence, all of the common operations to sequences apply. Since it is immutable, it cannot be changed. Two common questions that arise are how to expand a `tuple` and how to remove objects from a `tuple`.

When someone asks about changing an element inside a `tuple`, either adding, removing or updating, we have to remind them that the `list`, covered in *Lists*, is for dynamic sequences of elements. A `tuple` is generally applied when the number of elements is fixed by the nature of the problem.

This `tuple` processing even pervades the way functions are defined. We can have positional parameters collected into a `tuple`, something we'll cover in *Advanced Parameter Handling For Functions*.

14.2 Tuple Literal Values

A `tuple` literal is created by surrounding objects with '`()`' and separating the items with commas ('`,`'). An empty `tuple` is simple '`()`'.

An interesting question is how Python tells an expression from a 1-tuple. A 1-element `tuple` has a single comma; for example, '`(1,)`'. An expression lacks the comma: `(1)`. A pleasant consequence of this is that an extra comma at the end of every `tuple` is legal; for example, '`(9, 10, 56, )`'.

Examples:

```
xy= (2, 3)
personal= ('Hannah',14,5*12+6)
singleton= ("hello",)
```

xy A 2-tuple with integers.

personal A 3-tuple with a string and two integers

singleton A 1-tuple with a string. The trailing '`,`' assures that his is a tuple, not an expression.

The elements of a `tuple` do not have to be the same type. A `tuple` can be a mixture of any Python data types, including other `tuple`s.

14.3 Tuple Operations

There are three standard sequence operations ('`+`', '`*`', '`[]`') that can be performed with `tuple`s as well as other sequences.

The '`+`' operator creates a new `tuple` as the concatenation of the arguments. Here's an example.

```
>>> ("chapter",8) + ("strings","tuples","lists")
('chapter', 8, 'strings', 'tuples', 'lists')
```

The '`*`' operator between `tuple` and number (number '`*`' `tuple` or `tuple` '`*`' number) creates a new `tuple` that is a number of repetitions of the input `tuple`.

```
>>> 2*(3,"blind","mice")
(3, 'blind', 'mice', 3, 'blind', 'mice')
```

The '`[]`' operator selects an item or a slice from the `tuple`.

There are two forms: the single-item form and the slice form.

- The single item format is *tuple* [*index*]. Items are numbered from 0 to '`len(tuple)`'. Items are also numbered in reverse from -'`len(tuple)`' to -1.
- The slice format is *tuple* [*start* `:` *end*]. Items from *start* to *end* -1 are chosen to create a new `tuple` as a slice of the original `tuple`; there will be *end* − *start* items in the resulting `tuple`.

  If *start* is omitted it is the beginning of the `tuple` (position 0).

  If *end* is omitted it is the end of the `tuple` (position -1).

  Yes, you can omit both ('`someTuple[:]`') to make a copy of a tuple. This is a *shallow copy*: the original objects are now members of two distinct tuples.

```
>>> t=( (2,3), (2,"hi"), (3,"mom"), 2+3j,    6.02E23 )
>>> t[2]
(3, 'mom')
>>> t[:3]
((2, 3), (2, 'hi'), (3, 'mom'))
>>> t[3:]
((2+3j), 6.02e+23)
>>> t[-1]
6.02e+23
>>> t[-3:]
((3, 'mom'), (2+3j), 6.02e+23)
```

14.4 Tuple Comparison Operations

The standard comparisons ('<', '<=', '>', '>=', '==', '!=', **in**, **not in**) work exactly the same among `tuple` objects as they do among `string` and other sequences. The `tuple` pbjects are compared element by element. If the corresponding elements are the same type, ordinary comparison rules are used. If the corresponding elements are different types, the type names are compared, since there is almost no other rational basis for comparison.

```
>>> a = (1, 2, 3, 4, 5)
>>> b = (9, 8, 7, 6, 5)
>>> a < b
True
>>> 3 in a
True
>>> 3 in b
False
```

Here's a longer example.

redblack.py

```
#!/usr/bin/env python
import random
n= random.randrange(38)
if n == 0:
    print '0', 'green'
elif n == 37:
    print  '00', 'green'
elif n in ( 1,3,5,7,9, 12,14,16,18, 19,21,23,25,27, 30,32,34,36 ):
    print n, 'red'
else:
    print n, 'black'
```

1. We import `random`.
2. We create a random number, `n` in the range 0 to 37.
3. We check for 0 and 37 as special cases of single and double zero.
4. If the number is in the `tuple` of red spaces on the roulette layout, this is printed.
5. If none of the other rules are true, the number is in one of the black spaces.

14.5 Tuple Statements

There are a number of statements that have specific features related to `tuple` objects.

The Assignment Statement. There is a variation on the **assignment** statement called a **multiple-assignment** statement that works nicely with `tuple`s. We looked at this in *Multiple Assignment Statement*. Multiple variables are set by decomposing the items in the `tuple`.

For example:

```
>>> x, y = (1, 2)
>>> x
1
>>> y
2
```

An essential ingredient here is that a `tuple` has a fixed and known number of elements. For example a 2-dimensional geometric point might have a `tuple` with x and y. A 3-dimensional point might be a `tuple` with x, y, and z.

This works well because the right side of the assignment statement is fully evaluated before the assignments are performed. This allows things like swapping the values in two variables with '`x,y=y,x`'.

The for Statement. The **for** statement will step though all elements of a sequence.

For example:

```
s= 0
for i in ( 1,3,5,7,9, 12,14,16,18, 19,21,23,25,27, 30,32,34,36 ):
    s += i
print "total",s
```

This will step through each number in the given tuple.

There are three built-in functions that will transform a tuple into another sequence. The `enumerate()`, `sorted()` and `reversed()` functions will provide the items of the tuple with their index, in sorted order or in reverse order.

14.6 Tuple Built-in Functions

The `tuple()` function creates a tuple out of another sequence object.

tuple(*sequence*)
: Create a tuple from another sequence. This will convert `list` or `str` to a `tuple`.

Functions which apply to tuples, but are defined elsewhere.

- `len()`. For tuples, this function returns the number of items.

  ```
  >>> len( (1,1,2,3) )
  4
  >>> len( () )
  0
  ```

- `max()`. For tuples, this function returns the maximum item.

  ```
  >>> max( (1,9973,2) )
  9973
  ```

- `min()`. For tuples, this function returns the minimum item.
- `sum()`. For tuples, this function sums the individual items.

  ```
  >>> sum( (1,9973,2) )
  9976
  ```

- `any()`. For tuples, Return `True` if there exists any item which is `True`.

```
>>> any( (0,None,False) )
False
>>> any( (0,None,False,42) )
True
>>> any( (1,True) )
True
```

- `all()`. For tuples, Return `True` if all items are `True`.

  ```
  >>> all( (0,None,False,42) )
  False
  >>> all( (1,True) )
  True
  ```

- `enumerate()`. Iterate through the tuple returning 2-tuples of '`( index, item )`'.

  In effect, this function "enumerates" all the items in a sequence: it provides a number and each element of the original *sequence* in a 2-tuple.

  ```
  for i, x in someTuple:
      print "position", i, " has value ", x
  ```

  Consider the following.

  ```
  >>> a = ( 3.1415926, "Words", (2+3j) )
  >>> tuple( enumerate( a ) )
  ((0, 3.1415926000000001), (1, 'Words'), (2, (2+3j)))
  ```

  We created a `tuple` from the enumeration. This shows that each item of the enumeration is a 2-tuple with the index number and an item from the original tuple.

- `sorted()`. Iterate through the tuple in sorted order.

  ```
  >>> tuple( sorted( (9,1,8,2,7,3) ))
  (1, 2, 3, 7, 8, 9)
  >>> tuple( sorted( (9,1,8,2,7,3), reverse=True ))
  (9, 8, 7, 3, 2, 1)
  ```

- `reversed()`. Iterate through the tuple in reverse order.

  ```
  >>> tuple( reversed( (9,1,8,2,7,3) ) )
  (3, 7, 2, 8, 1, 9)
  ```

The following function returns a tuple.

divmod(*x, y) -> (div, mod*)
: Return a 2-tuple with '`((x-x%y)/y, x%y)`'. The return values have the invariant: $div \times y + mod = x$. This is the quotient and the remainder in division.

  The `divmod()` functions is often combined with multiple assignment. For example:

  ```
  >>> q,r = divmod(355,113)
  >>> q
  3
  >>> r
  16
  ```

```
>>> q*113+r
355
```

14.7 Tuple Exercises

These exercises implement some basic statistical algorithms. For some background on the Sigma operator, Σ, see *Digression on The Sigma Operator*.

1. **Blocks of Stock**. A block of stock as a number of attributes, including a purchase date, a purchase price, a number of shares, and a ticker symbol. We can record these pieces of information in a `tuple` for each block of stock and do a number of simple operations on the blocks. Let's dream that we have the following portfolio.

Purchase Date	Purchase Price	Shares	Symbol	:Current Price"
25 Jan 2001	43.50	25	CAT	92.45
25 Jan 2001	42.80	50	DD	51.19
25 Jan 2001	42.10	75	EK	34.87
25 Jan 2001	37.58	100	GM	37.58

We can represent each block of stock as a 5-tuple with purchase date, purchase price, shares, ticker symbol and current price.

```
portfolio= [ ( "25-Jan-2001", 43.50, 25, 'CAT', 92.45 ),
( "25-Jan-2001", 42.80, 50, 'DD', 51.19 ),
( "25-Jan-2001", 42.10, 75, 'EK', 34.87 ),
( "25-Jan-2001", 37.58, 100, 'GM', 37.58 )
]
```

Develop a function that examines each block, multiplies shares by purchase price and determines the total purchase price of the portfolio.

Develop a second function that examines each block, multiplies shares by purchase price and shares by current price to determine the total amount gained or lost.

2. **Mean**. Computing the mean of a `list` of values is relatively simple. The mean is the sum of the values divided by the number of values in the `list` . Since the statistical formula is so closely related to the actual loop, we'll provide the formula, followed by an overview of the code.

$$\mu_x = \frac{\sum\limits_{0 \le i < n} x_i}{n}$$

[The cryptic-looking μ_x is a short-hand for "mean of variable x".]

The definition of the Σ mathematical operator leads us to the following method for computing the mean:

Computing Mean

(a) **Initialize**. Set sum, s, to zero

(b) **Reduce**. For each value, i, in the range 0 to the number of values in the list, n:

Set $s \leftarrow s + x_i$.

(c) **Result**. Return $s \div n$.

3. **Standard Deviation**. The standard deviation can be done a few ways, but we'll use the formula shown below. This computes a deviation measurement as the square of the difference between each sample and the mean. The sum of these measurements is then divided by the number of values times the number of degrees of freedom to get a standardized deviation measurement. Again, the formula summarizes the loop, so we'll show the formula followed by an overview of the code.

$$\sigma_x = \sqrt{\frac{\sum\limits_{0 \le i < n} (x_i - \mu_x)^2}{n-1}}$$

[The cryptic-looking σ_x is short-hand for "standard deviation of variable x".]

The definition of the Σ mathematical operator leads us to the following method for computing the standard deviation:

Computing Standard Deviation

(a) **Initialize**. Compute the mean, m.

Initialize sum, s, to zero.

(b) **Reduce**. For each value, x_i in the list:

Compute the difference from the mean, $d \leftarrow x_i - \mu_x$.

Set $s \leftarrow s + d^2$.

(c) **Variance**. Compute the variance as $\frac{s}{n-1}$. The $n-1$. factor reflects the statistical notion of "degrees of freedom", which is beyond the scope of this book.

(d) **Standard Deviation**. Return the square root of the variance.

The `math` module contains the `math.sqrt()` funtion. For some additional information, see *The math Module*.

14.8 Digression on The Sigma Operator

For those programmers new to statistics, this section provides background on the Sigma operator, Σ.

The usual presentation of the summation operator looks like this.

$$\sum_{i=1}^{n} f(i)$$

The Σ operator has three parts to it. Below it is a bound variable, i and the starting value for the range, written as $i = 1$. Above it is the ending value for the range, usually something like n. To the right is some function to execute for each value of the bound variable. In this case, a generic function, $f(i)$. This is read as "sum f (i) for i in the range 1 to n".

This common definition of Σ uses a closed range; one that includes the end values of 1 and n. This, however, is not a helpful definition for software. It is slightly simpler to define Σ to start with zero and use a half-open interval. It still exactly n elements, including 0 and n-1; mathematically, $0 \le i < n$.

For software design purposes, we prefer the following notation, but it is not often used. Since most statistical and mathematical texts use 1-based indexing, some care is required when translating formulae to

programming languages that use 0-based indexing.

$$\sum_{0 \le i < n} f(i)$$

This shows the bound variable (i) and the range below the operator. It shows the function to execute on the right of the operator.

Statistical Algorithms. Our two statistical algorithms have a form more like the following. In this we are applying some function, f, to each value, x_i of an array.

$$\sum_{0 \le i < n} f(x_i)$$

When computing the mean, there the function applied to each value does nothing. When computing standard deviation, the function applied involves subtracting and multiplying.

We can transform this definition directly into a **for** loop that sets the bound variable to all of the values in the range, and does some processing on each value of the sequence of values.

This is the Python implemention of Σ. This computes two values, the sum, `sum`, and the number of elements, `n` .

Python Sigma Iteration

```
sum= 0
for x_i in aSequence:
    fx_i = some processing of x_i
    sum += fx_i
n= len(aSequence)
```

1. Execute the body of the loop for all values of `x_i` in the sequence `aSequence`. The sequence can be a tuple, list or other sequential container.
2. For simple mean calculation, the `fx_i` statement does nothing. For standard deviation, however, this statement computes the measure of deviation from the average.
3. We sum the `x_i` values for a mean calculation. We sum `fx_i` values for a standard deviation calculation.

CHAPTER

FIFTEEN

LISTS

We'll look at `list` from a number of viewpoints: semantics, literal values, operations, comparison operators, statements, built-in functions and methods.

15.1 List Semantics

A `list` is a container for variable length sequence of Python objects. A `list` is mutable, which means that items within the `list` can be changed. Also, items can be added to the `list` or removed from the `list`.

Since a `list` is a sequence, all of the common operations to sequences apply.

Sometimes we'll see a `list` with a fixed number of elements, like a two-dimensional point with two elements, x and y. A fixed-length `list` may not be the right choice; a `tuple`, covered in *Tuples* is usually better for static sequences of elements.

A great deal of Python's internals are `list` -based. The **for** statement, in particular, expects a sequence, and we often create a `list` by using the `range()` function. When we split a `string` using the `split()` method, we get a `list` of substrings.

15.2 List Literal Values

A `list` literal is created by surrounding objects with '`[]`' and separating the items with commas ('`,`'). A `list` can be created, expanded and reduced. An empty `list` is simply '`[]`'. As with `tuple`, an extra comma at the end of the `list` is gracefully ignored.

Examples:

```
myList = [ 2, 3, 4, 9, 10, 11, 12 ]
history = [ ]
```

The elements of a `list` do not have to be the same type. A `list` can be a mixture of any Python data types, including `list`s, `tuple`s, `string`s and numeric types.

A `list` permits a sophisticated kind of display called a *comprehension*. We'll revisit this in some depth in *List Comprehensions*. As a teaser, consider the following:

```
>>> [ 2*i+1 for i in range(6) ]
[1, 3, 5, 7, 9, 11]
```

This statement creates a `list` using a list comprehension. A comprehension starts with a candidate `list` ('`range(6)`', in this example) and derives the `list` values from the candidate `list` (using '`2*i+1`' in this example). A great deal of power is available in comprehensions, but we'll save the details for a later section.

15.3 List Operations

The three standard sequence operations ('`+`', '`*`', '`[]`') can be performed with `list`, as well as other sequences like `tuple` and `string`.

The '`+`' operator creates a new `list` as the concatenation of the arguments.

```
>>> ["field"] + [2, 3, 4] + [9, 10, 11, 12]
['field', 2, 3, 4, 9, 10, 11, 12]
```

The '`*`' operator between `list` and numbers (number '`*`' `list` or `list` '`*`' number) creates a new `list` that is a number of repetitions of the input `list`.

```
>>> 2*["pass","don't","pass"]
['pass', "don't", 'pass', 'pass', "don't", 'pass']
```

The '`[]`' operator selects an character or a slice from the `list`. There are two forms: the single-item form and the slice form.

- The single item format is *list* [*index*]. Items are numbered from 0 to '`len(list)`'. Items are also numbered in reverse from -'`len(list)`' to -1.
- The slice format is *list* [*start* `:` *end*]. Items from *start* to *end* -1 are chosen to create a new `list` as a slice of the original `list`; there will be *end* − *start* items in the resulting `list`.

  If *start* is omitted it is the beginning of the `list` (position 0).

  If *end* is omitted it is the end of the `list` (position -1).

  Yes, you can omit both ('`someList[:]`') to make a copy of a list. This is a *shallow copy*: the original objects are now members of two distinct lists.

In the following example, we've constructed a `list` where each element is a `tuple`. Each `tuple` could be a pair of dice.

```
>>> l=[(6, 2), (5, 4), (2, 2), (1, 3), (6, 5), (1, 4)]
>>> l[2]
(2, 2)
>>> l[:3]
[(6, 2), (5, 4), (2, 2)]
>>> l[3:]
[(1, 3), (6, 5), (1, 4)]
>>> l[-1]
(1, 4)
>>> l[-3:]
[(1, 3), (6, 5), (1, 4)]
```

15.4 List Comparison Operations

The standard comparisons ('`<`', '`<=`', '`>`', '`>=`', '`==`', '`!=`', **in**, **not in**) work exactly the same among `list`, `tuple` and `string` sequences. The `list` items are compared element by element. If the corresponding

elements are the same type, ordinary comparison rules are used. If the corresponding elements are different types, the type names are compared, since there is no other rational basis for comparison.

```
d1= random.randrange(6)+1
d2= random.randrange(6)+1
if d1+d2 in [2, 12] + [3, 4, 9, 10, 11]:
    print "field bet wins on ", d1+d2
else:
    print "field bet loses on ", d1+d2
```

This will create two random numbers, simulating a roll of dice. If the number is in the `list` of field bets, this is printed. Note that we assemble the final `list` of field bets from two other `list` objects. In a larger application program, we might separate the different winner `list` instances based on different payout odds.

15.5 List Statements

There are a number of statements that have specific features related to `list` objects.

The Assignment Statement. The variation on the **assignment** statement called **multiple-assignment** statement also works with `list`s. We looked at this in *Multiple Assignment Statement*. Multiple variables are set by decomposing the items in the `list`.

```
>>> x, y = [ 1, "hi" ]
>>> x
1
>>> y
'hi'
```

This will only work of the `list` has a fixed and known number of elements. This is more typical when working with a `tuple`, which is immutable, rather than a `list`, which can vary in length.

The for Statement. The **for** statement will step though all elements of a sequence.

```
s= 0
for i in [2,3,5,7,11,13,17,19]:
    s += i
print "total",s
```

When we introduced the **for** statement in *Iterative Processing: The for Statement*, we showed the `range()` function; this function creates a `list`. We can also create a `list` with a literal or comprehension. We've looked at simple literals above. We'll look at comprehensions below.

The del Statement. The **del** statement removes items from a `list`. For example

```
>>> i = range(10)
>>> del i[0], i[2], i[4], i[6]
>>> i
[1, 2, 4, 5, 7, 8]
```

This example reveals how the **del** statement works.

The `i` variable starts as the `list` `[0, 1, 2, 3, 4, 5, 6, 7, 8, 9 ]`.

1. Remove '`i[0]`' and the variable is `[1, 2, 3, 4, 5, 6, 7, 8, 9]`.
2. Remove '`i[2]`' (the value 3) from this new `list` , and get `[1, 2, 4, 5, 6, 7, 8, 9]`.

3. Remove '`i[4]`' (the value 6) from this new `list` and get `[1, 2, 4, 5, 7, 8, 9]`.
4. Finally, remove '`i[6]`' and get `[1, 2, 4, 5, 7, 8]`.

15.6 List Built-in Functions

The `list()` function creates a list out of another sequence object.

`list`(*sequence*)
Create a list from another sequence. This will convert `tuple` or `str` to a `list`.

Functions which apply to tuples, but are defined elsewhere.

- `len()`. For lists, this function returns the number of items.

```
>>> len( [1,1,2,3] )
4
>>> len( [] )
0
```

- `max()`. For lists, this function returns the maximum item.

```
>>> max( [1,9973,2] )
9973
```

- `min()`. For lists, this function returns the minimum item.
- `sum()`. For lists, this function sums the individual items.

```
>>> sum( [1,9973,2] )
9976
```

- `any()`. For lists, Return `True` if there exists any item which is `True`.

```
>>> any( [0,None,False] )
False
>>> any( [0,None,False,42] )
True
>>> any( [1,True] )
True
```

- `all()`. For lists, Return `True` if all items are `True`.

```
>>> all( [0,None,False,42] )
False
>>> all( [1,True] )
True
```

- `enumerate()`. Iterate through the list returning 2-tuples of '`( index, item )`'.

  In effect, this function "enumerates" all the items in a sequence: it provides a number and each element of the original *sequence* in a 2-tuple.

```
for i, x in someList:
    print "position", i, " has value ", x
```

  Consider the following list of tuples.

```
>>> a = [ ("pi",3.1415946),("e",2.718281828),("mol",6.02E23) ]
>>> list( enumerate( a ) )
[(0, ('pi', 3.1415945999999999)), (1, ('e', 2.7182818279999998)
02e+23))]
>>> for i, t in enumerate( a ):
...     print "item",i,"is",t
...
item 0 is ('pi', 3.1415945999999999)
item 1 is ('e', 2.7182818279999998)
item 2 is ('mol', 6.02e+23)
```

- `sorted()`. Iterate through the list in sorted order.

```
>>> list( sorted( [9,1,8,2,7,3] ))
[1, 2, 3, 7, 8, 9]
>>> tuple( sorted( [9,1,8,2,7,3], reverse=True ))
[9, 8, 7, 3, 2, 1]
```

- `reversed()`. Iterate through the list in reverse order.

```
>>> tuple( reversed( [9,1,8,2,7,3] ) )
[3, 7, 2, 8, 1, 9]
```

The following function returns a list.

range(*[start], stop, [step]*)
: The arguments must be plain integers. If the `step` argument is omitted, it defaults to 1. If the `start` argument is omitted, it defaults to 0. `step` must not be zero (or else `ValueError` is raised).

  The full form returns a `list` of plain integers [*start*, $start + step$, $start + 2 \times step$, ...].

  If `step` is positive, the last element is the largest $start + i \times step < stop$; ; if `step` is negative, the last element is the largest $start + i \times step > stop$.

15.7 List Methods

A `list` object has a number of member methods. These can be grouped arbitrarily into mutators, which change the `list`, transformers which create something new from the `list`, and and accessors, which returns a fact about a `list`.

The following `list` mutators update a `list` object. Generally, these do not return a value.

In the case of the `pop()` method, it both returns information as well as mutates the `list`.

append(*object*)
: Update *list* by appending `object` to end of the `list`.

extend(*list*)
: Extend *list* by appending `list` elements. Note the difference from `append()` , which treats the argument as a single `list` object.

insert(*index, object*)
: Update `list` *l* by inserting `object` before position `index`. If index is greater than '`len(list)`', the object is simply appended. If index is less than zero, the object is prepended.

`pop`(*[index=-1]*)
: Remove and return item at `index` (default last, -1) in *list*. An exception is raised if the *list* is already empty.

`remove`(*value*)
: Remove first occurrence of `value` from *list*. An exception is raised if the value is not in the `list`.

`reverse`()
: Reverse the items of the *list*. This is done "in place", it does not create a new `list`. There is no return value.

`sort`(*[key], [reverse=False]*)
: Sort the items of the *list*. This is done "in place", it does not create a new `list`.

  If the `reverse` keyword parameter is provided and set to `True`, the tuple is sorted into descending order.

  The `key` parameter is used when the items in the tuple aren't simply sorted using the default comparison operators. The *key* function must return the fields to be compared selected from the underlying items in the tuple.

  We'll look at this in detail in *Functional Programming with Collections*.

The following accessor methods provide information about a `list`.

`count`(*value*)
: Return number of occurrences of `value` in *list*.

`index`(*value*)
: Return index of first occurrence of `value` in *list*.

Stacks and Queues. The `list.append()` and `list.pop()` functions can be used to create a standard push-down *stack*, or last-in-first-out (LIFO) `list`. The `append()` method places an item at the end of the `list` (or top of the stack), where the `pop()` method can remove it and return it.

```
>>> stack = []
>>> stack.append(1)
>>> stack.append( "word" )
>>> stack.append( ("a","2-tuple") )
>>> stack.pop()
('a', '2-tuple')
>>> stack.pop()
'word'
>>> stack.pop()
1
>>> len(stack)
0
>>> stack.pop()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: pop from empty list
```

The `list.append()` and `list.pop()` functions can be used to create a standard *queue*, or first-in-first-out (FIFO) `list`. The `append()` method places an item at the end of the queue. A call to '`pop(0)`' removes the first item from the queue and returns it.

```
>>> queue = []
>>> queue.append( 1 )
>>> queue.append( "word" )
>>> queue.append( ("a","2-tuple") )
```

```
>>> queue.pop(0)
1
>>> queue.pop(0)
'word'
>>> queue.pop(0)
('a', '2-tuple')
>>> len(queue)
0
>>> queue.pop(0)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
IndexError: pop from empty list
```

15.8 Using Lists as Function Parameter Defaults

It's very, very important to note that default values must be immutable objects. Recall that numbers, strings, `None`, and `tuple` objects are immutable.

We note that lists as well as sets and dictionaries are mutable, and cannot be used as default values for function parameters.

Consider the following example of what not to do.

```
>>> def append2( someList=[] ):
...     someList.append(2)
...     return someList
...
>>> looks_good= []
>>> append2(looks_good)
[2]
>>> append2(looks_good)
[2, 2]
>>> looks_good
[2, 2]
>>>
>>>
>>> not_good= append2()
>>> not_good
[2]
>>> worse= append2()
>>> worse
[2, 2]
>>> not_good
[2, 2]
```

1. We defined a function which has a default value that's a mutable object. This is simple a bad programming practice in Python.
2. We used this function with a list object, `looks_good`. The function updated the list object as expected.
3. We used the function's default value to create `not_good`. The function appended to an empty list and returned this new list object.

   It turns out that the function updated the mutable default value, also.
4. When we use the function's default value again, with `worse`, the function uses the updated default value and updates it again.

Both `not_good` and `worse` are references to the same mutable object that is being updated.

To avoid this, do not use mutable values as defaults. Do this instead.

```
def append2( someList=None ):
    if someList is None:
        someList= []
    someList.append(2)
    return someList
```

This creates a fresh new mutable object as needed.

15.9 List Exercises

1. **Accumulating Distinct Values**. This uses the *Bounded Linear Search* algorithm to locate duplicate values in a sequence. This is a powerful technique to eliminate sorting from a wide variety of summary-type reports. Failure to use this algorithm leads to excessive processing in many types of applications.

Distinct Values of a Sequence, `seq`

(a) **Initialize Distinct Values**. Set $dv \leftarrow$ list().

(b) **Loop**. For each value, v, in *seq*.

We'll use the Bounded Linear Search to see if v occurs in dv.

i. **Initialize**. Set $i \leftarrow 0$.

Append v to the list dv.

ii. **Search**. while $dv[i] \neq v$: increment i.

At this point $dv[i] = v$. The question is whether $i = \text{len}(dv)$ or not.

iii. **New Value?**. if $i = \text{len}(dv)$: v is distinct.

iv. **Existing Value?**. if $i \neq \text{len}(dv)$: v is a duplicate of $dv[i]$.

Delete $dv[-1]$, the value we added.

(c) **Result**. Return array dv, which has distinct values from *seq*.

You may also notice that this fancy Bounded Linear Search is suspiciously similar to the `index()` method function of a list. Rewrite this using '`uniq.index`' instead of the Bounded Linear Search in step 2.

When we look the `set` collection, you'll see another way to tackle this problem.

2. **Binary Search**. This is not as universally useful as the Bounded Linear Search (above) because it requires the data be sorted.

Binary Search a sorted Sequence, *seq*, for a target value, *tgt*

(a) **Initialize**. $l, h \leftarrow 0, \text{len}(seq)$.

$m \leftarrow (l + h) \div 2$. This is the midpoint of the sorted sequence.

(b) **Divide and Conquer**. While $l + 1 < h$ **and** $seq[m] \neq tgt$.

If $tgt < seq[m]$: $h \leftarrow m$. Move h to the midpoint.

If $tgt > seq[m]$: $l \leftarrow m + 1$. Move l to the midpoint.

$m \leftarrow (l + h) \div 2$. Compute a midpoint of the new, smaller sequence.

(c) **Result**. If $tgt = seq[m]$: return m

If $tgt \neq seq[m]$: return `-1` as a code for "not found".

3. **Quicksort**. The super-fast sort routine

As a series of loops it is rather complex. As a recursion it is quite short. This is the same basic algorithm in the C libraries.

Quicksort proceeds by partitioning the `list` into two regions: one has all of the high values, the other has all the low values. Each of these regions is then individually sorted into order using the quicksort algorithm. This means the each region will be subdivided and sorted.

For now, we'll sort an array of simple numbers. Later, we can generalize this to sort generic objects.

Quicksort a List, *a* between elements *lo* and *hi*

(a) **Partition**

i. **Initialize**. $ls, hs \leftarrow lo, hi$. Setup for partitioning between ls and hs.

$middle \leftarrow (ls + hs) \div 2$.

ii. **Swap To Partition**. while $ls < hs$:

If $a[ls].key \leq a[middle].key$: increment ls by 1. Move the low boundary of the partitioning.

If $a[ls].key > a[middle].key$: swap the values $a[ls] \leftrightarrows a[middle]$.

If $a[hs].key \geq a[middle].key$: decrement hs by 1. Move the high boundary of the partitioning.

If $a[hs].key < a[middle].key$:, swap the values $a[hs] \leftrightarrows a[middle]$.

(b) **Quicksort Each Partition**.

QuickSort(a , lo, $middle$)

QuickSort(a , $middle$+1, hi)

4. **Recursive Search**. This is also a binary search: it works using a design called "divide and conquer". Rather than search the whole `list`, we divide it in half and search just half the `list`. This version, however is defined with a recusive function instead of a loop. This can often be faster than the looping version shown above.

Recursive Search a List, *seq* for a target, *tgt*, in the region between elements *lo* and *hi*.

(a) **Empty Region?** If $lo + 1 \geq hi$: return -1 as a code for "not found".

(b) **Middle Element**. $m \leftarrow (lo + hi) \div 2$.

(c) **Found?** If $seq[m] = tgt$: return m.

(d) **Lower Half?** If $seq[m] < tgt$: return recursiveSearch (*seq*, *tgt*, *lo*, *m*)

(e) **Upper Half?** If $seq[m] > tgt$: return recursiveSearch(*seq*, *tgt*, *m*+1, *hi*)

5. **Sieve of Eratosthenes**. This is an algorithm which locates prime numbers. A prime number can only be divided evenly by 1 and itself. We locate primes by making a table of all numbers, and then crossing out the numbers which are multiples of other numbers. What is left must be prime.

Sieve of Eratosthenes

(a) **Initialize**. Create a list, *prime* of 5000 booleans, all `True`, initially.

$p \leftarrow 2$.

(b) **Iterate**. While $2 \leq p < 5000$.

i. **Find Next Prime**. While **not** $prime[p]$ **and** $2 \leq p < 5000$:

Increment p by 1.

ii. **Remove Multiples**. At this point, p is prime.

Set $k \leftarrow p + p$.

while $k < 5000$.

$prime[k] \leftarrow False$.

Increment k by p.

iii. **Next p**. Increment p by 1.

(c) **Report**. At this point, for all p, if *prime* [p] is true, p is prime.

while $2 \leq p < 5000$:

if $prime[p]$: print p

The reporting step is a "filter" operation. We're creating a list from a source range and a filter rule. This is ideal for a list comprehension. We'll look at these in *List Comprehensions*.

Formally, we can say that the primes are the set of values defined by $primes = \{p|_{0 \leq p < 5000}$ **if** $prime_p\}$. This formalism looks a little bit like a list comprehension.

6. **Polynomial Arithmetic**. We can represent numbers as polynomials. We can represent polynomials as arrays of their coefficients. This is covered in detail in [Knuth73], section 2.2.4 algorithms A and M.

Example: $4x^3 + 3x + 1$ has the following coefficients: '`( 4, 0, 3, 1 )`'.

The polynomial $2x^2 - 3x - 4$ is represented as '`( 2, -3, -4 )`'.

The sum of these is $4x^3 + 2x^2 - 3$; '`( 4, 2, 0, -3 )`'.

The product these is $8x^5 - 12x^4 - 10x^3 - 7x^2 - 15x - 4$; '`( 8, -12, -10, -7, -15, -4 )`'.

You can apply this to large decimal numbers. In this case, x is 10, and the coefficients must all be between 0 and x-1. For example, $1987 = 1x^3 + 9x^2 + 8x + 7$, when $x = 10$.

Add Polynomials, *p*, *q*

(a) **Result Size**. $r_{sz} \leftarrow$ the larger of len(p) and len(q).

(b) **Pad P?** If len(p) $< r_{sz}$:

Set *p1* to a tuple of $r_{sz} - \text{len}(p)$ zeros + p.

Else: Set *p1* to p.

(c) **Pad Q?** If $\text{len}(q) < r_{sz}$:

Set *q1* t a tuple of $r_{sz} - \text{len}(q)$ zeroes + q.

Else, Set *q1* to q.

(d) **Add**. Add matching elements from *p1* and *q1* to create result, r.

(e) **Result**. Return r as the sum of p and q.

Multiply Polynomials, *x*, *y*

(a) **Result Size**. $r_{sz} \leftarrow \text{len}(x) + \text{len}(y)$.

Initialize the result list, r, to all zeros, with a size of r_{sz}.

(b) **For all elements of x**. while $0 \leq i < \text{len}(x)$:

For all elements of y. while $0 \leq j < \text{len}(y)$:

Set $r[i+j] = r[i+j] + x[i] \times y[j]$.

(c) **Result**. Return a tuple made from r as the product of x and y.

7. **Random Number Evaluation**. Before using a new random number generator, it is wise to evaluate the degree of randomness in the numbers produced. A variety of clever algorithms look for certain types of expected distributions of numbers, pairs, triples, etc. This is one of many random number tests.

Use `random.random()` to generate an array of random samples. These numbers will be uniform over the interval 0..1

Distribution test of a sequence of random samples, *U*

(a) **Initialize**. Initialize *count* to a list of 10 zeros.

(b) **Examine Samples**. For each sample value, v, in the original set of 1000 random samples, U.

i. **Coerce Into Range**. Set $x \leftarrow \lfloor v \times 10 \rfloor$. Multiply by 10 and truncate and integer to get a a new value in the range 0 to 9.

ii. **Count**. Increment *count* $[x]$ by 1.

(c) **Report**. We expect each count to be 1/10th of our available samples. We need to display the actual count and the % of the total. We also need to calculate the difference between the actual count and the expected count, and display this.

8. **Dutch National Flag**. A challenging problem, one of the hardest in this set. This is from Edsger Dijkstra's book, *A Discipline of Programming* [Dijkstra76].

Imagine a board with a row of holes filled with red, white, and blue pegs. Develop an algorithm which will swap pegs to make three bands of red, white, and blue (like the Dutch flag). You must also satisfy this additional constraint: each peg must be examined exactly once.

Without the additional constraint, this is a relatively simple sorting problem. The additional constraint requires that instead of a simple sort which passes over the data several times, we need a more clever sort.

Hint: You will need four partitions in the array. Initially, every peg is in the "Unknown" partition. The other three partitions ("Red", "White" and "Blue") are empty. As the algorithm proceeds, pegs are swapped into the Red, White or Blue partition from the Unknown partition. When you are done, the unknown partition is reduced to zero elements, and the other three partitions have known numbers of elements.

CHAPTER

SIXTEEN

MAPPINGS AND DICTIONARIES

Many algorithms need to map a key to a data value. This kind of mapping is supported by the Python dictionary, `dict`. We'll look at dictionaries from a number of viewpoints: semantics, literal values, operations, comparison operators, statements, built-in functions and methods.

We are then in a position to look at two applications of the dictionary. We'll look at how Python uses dictionaries along with sequences to handle arbitrary connections of parameters to functions in *Advanced Parameter Handling For Functions*. This is a very sophisticated set of tools that let us define functions that are very flexible and easy to use.

16.1 Dictionary Semantics

A dictionary, called a `dict`, maps a *key* to a *value*. The key can be any type of Python object that computes a consistent hash value. The value referenced by the key can be any type of Python object.

There is a subtle terminology issue here. Python has provisions for creating a variety of different types of mappings. Only one type of mapping comes built-in; that type is the `dict`. The terms are almost interchangeable. However, you may develop or download other types of mappings, so we'll be careful to focus on the `dict` class.

Working with a `dict` is similar to working with a sequence. Items are inserted into the `dict`, found in the `dict` and removed from the `dict`. A `dict` object has member methods that return a sequence of keys, or values, or (*key* , *value*) `tuple`s suitable for use in a **for** statement.

Unlike a sequence, a `dict` does not preserve order. Instead of order, a `dict` uses a *hashing* algorithm to identify each item's place in the `dict` with a rapid calculation of the key's hash value. The built-in function, `hash()` is used to do this calculation. Items in the `dict` are inserted in an position related to their key's apparently random hash values.

Some Alternate Terminology. A `dict` can be thought of as a container of (*key* : *value*) pairs. This can be a helpful way to imagine the information in a mapping. Each pair in the list is the mapping from a key to an associated value.

A `dict` can be called an associative array. Ordinary arrays, typified by sequences, use a numeric index, but a `dict`'s index is made up of the key objects. Each key is associated with (or "mapped to") the appropriate value.

Some Consequences. Each key object has a hash value, which is used to place the value in the `dict`. Consequently, the keys must have consistent hash values; they must be immutable objects. You can't use `list`, `dict` or `set` objects as keys. You can use `tuple`, `string` and `frozenset` objects, since they are immutable. Additionally, when we get to class definitions (in *Classes*), we can make arrangements for our objects to return an immutable hash value.

A common programming need is a heterogeneous container of data. Database records are an example. A record in a database might have a boat's name (as a `string`), the length overall (as a number) and an inventory of sails (a `list` of `string`s). Often a record like this will have each element (known as a *field*) identified by name.

A C or C++ '`struct`' accomplishes this. This kind of named collection of data elements may be better handled with a class (someting we'll cover in *Classes*) or a named tuple (see `collections`). However, a mapping is also useful for managing this kind of heterogeneous data with named fields.

Note that many languages make record definitions a statically-defined container of named fields. A Python `dict` is dynamic, allowing us to add field names at run-time.

A common alternative to hashing is using some kind of ordered structure to maintain the keys. This might be a tree or list, which would lead to other kinds of mappings. For example, there is an ordered dictionary, in the Python `collections` module.

16.2 Dictionary Literal Values

A `dict` literal is created by surrounding a key-value list with '`{}`'; a key is separated from its value with '`:`', and the '`key : value`' pairs are separated with commas ('`,`'). An empty `dict` is simply '`{}`'. As with `list` and `tuple`, an extra '`,`' inside the '`{}`' is tolerated.

Examples:

```
diceRoll = { (1,1): "snake eyes", (6,6): "box cars" }
myBoat = { "NAME":"KaDiMa", "LOA":18, "SAILS":["main","jib","spinnaker"] }
theBets = { }
```

diceRoll This is a `dict` with two elements. One element has a key of a `tuple` `(1,1)` and a value of a `string`, `"snake eyes"`. The other element has a key of a `tuple` `(6,6)` and a value of a `string` `"box cars"`.

myBoat This variable is a `dict` with three elements. One element has a key of the `string` `"NAME"` and a value of the `string` `"KaDiMa"`. Another element has a key of the `string` `"LOA"` and a value of the integer `18`. The third element has a key of the `string` `"SAILS"` and the value of a `list` `["main", "jib", "spinnaker"]`.

theBets An empty `dict`.

The values and keys in a `dict` do not have to be the same type. Keys must be a type that can produce a hash value. Since `list` s and `dict` objects are mutable, they are not permitted as keys. All other non-mutable types (especially `string`, `frozenset` and `tuple`) are legal keys.

16.3 Dictionary Operations

A `dict` only permits a single operation: '`[]`'. This is used to add, change or retrieve items from the `dict`. The slicing operations that apply to sequences don't apply to a `dict`.

Examples of `dict` operations.

```
>>> d= {}
>>> d[2] = [ (1,1) ]
>>> d[3] = [ (1,2), (2,1) ]
>>> d
{2: [(1, 1)], 3: [(1, 2), (2, 1)]}
```

```
>>> d[2]
[(1, 1)]
>>> d["2 or 3"] = d[2] + d[3]
>>> d
{'2 or 3': [(1, 1), (1, 2), (2, 1)], 2: [(1, 1)], 3: [(1, 2), (2, 1)]}
```

1. This example starts by creating an empty `dict`, `d`.
2. Into '`d[2]`' we insert a `list` with a single `tuple`.
3. Into '`d[3]`' we insert a `list` with two `tuple`s.
4. When the entire `dict` is printed it shows the two key:value pairs, one with a key of 2 and another with a key of 3.
5. The entry with a key of the `string` `"2 or 3"` has a value which is computed from the values of '`d[2] + d[3]`'. Since these two entries are `list`s, the `list`s can be combined with the `+` operator. The resulting expression is stored into the `dict`.
6. When we print `d`, we see that there are three key:value pairs: one with a key of 3, one with a key of 2 and one with a key of `"2 or 3"` .

This ability to use any object as a key is a powerful feature, and can eliminate some needlessly complex programming that might be done in other languages.

Here are some other examples of picking elements out of a `dict`.

```
>>> myBoat = { "NAME":"KaDiMa", "LOA":18,
...       "SAILS":["main","jib","spinnaker"] }
>>> myBoat["NAME"]
'KaDiMa'
>>> myBoat["SAILS"].remove("spinnaker")
>>> myBoat
{'LOA': 18, 'NAME': 'KaDiMa', 'SAILS': ['main', 'jib']}
```

String Formatting with Dictionaries. The `string` formatting operator, `%`, can be applied between `str` and `dict` as well as `str` and sequence. When this operator was introduced in *Strings*, the format specifications were applied to a `tuple` or other sequence. When used with a `dict`, each format specification is given an additional option that specifies which `dict` element to use. The general format for each conversion specification is:

```
%( element ) [ flags ][
width [ . precision ]] code
```

The *flags*, *width*, *precision* and *code* elements are defined in *Strings*. The *element* field must be enclosed in ()'s; this is the key to be selected from the `dict`.

For example:

```
print "%(NAME)s, %(LOA)d" % myBoat
```

This will find '`myBoat[NAME]`' and use '`%s`' formatting; it will find '`myBoat[LOA]`' and use '`%d`' number formatting.

16.4 Dictionary Comparison Operations

Some of the standard comparisons ('<' , '<=' , '>' , '>=', '==' , '!=') don't have a lot of meaning between two dictionaries. Since there may be no common keys, nor even a common data type for keys, dictionaries are simply compared by length. The `dict` with fewer elements is considered less than a `dict` with more elements.

The membership comparisons (**in**, **not in**) apply to the keys of the dictionary.

```
>>> colors = { "blue": (0x30,0x30,0xff), "green": (0x30,0xff,0x97),
... "red": (0xff,0x30,0x97), "yellow": (0xff,0xff,0x30) }
>>> "blue" in colors
True
>>> (0x30,0x30,0xff) in colors
False
>>> "orange" not in colors
True
```

16.5 Dictionary Statements

There are a number of statements that have specific features related to `dict` objects.

The for Statement. The **for** statement iterates through the keys of the dictionary.

```
>>> colors = { "blue": (0x30,0x30,0xff), "green": (0x30,0xff,0x97),
... "red": (0xff,0x30,0x97), "yellow": (0xff,0xff,0x30) }
>>> for c in colors:
...     print c, colors[c]
```

It's common to use some slightly different techniques for iterating through the elements of a `dict`.

- The key:value pairs. We can use the `items()` method to iterate through the sequence of 2-tuples that contain each key and the associated value.

  ```
  for key, value in someDictionary.items():
      # process key and value
  ```

- The values. We can use the `values()` method to iterate through the sequence of values in the dictionary.

  ```
  for value in someDictionary.values():
      # process the value
  ```

  Note that we can't easily determine the associated key. A dictionary only goes one way: from key to value.

- The keys. We can use the `keys()` method to iterate through the sequence of keys. This is what happens when we simply use the dictionary object in the **for** statement.

Here's an example of using the key:value pairs.

```
>>> myBoat = { "NAME":"KaDiMa", "LOA":18,
...     "SAILS":["main","jib","spinnaker"] }
>>> for key, value in myBoat.items():
...     print key, "=", value
...
```

```
LOA = 18
NAME = KaDiMa
SAILS = ['main', 'jib', 'spinnaker']
```

The del Statement. The **del** statement removes items from a `dict` . For example

```
>>> i = { "two":2, "three":3, "quatro":4 }
>>> del i["quatro"]
>>> i
{'two': 2, 'three': 3}
```

In this example, we use the key to remove the item from the `dict`.

The member function, `pop()`, does this also.

```
>>> i = { "two":2, "three":3, "quatro":4 }
>>> i.pop("quatro")
4
>>> i
{'two': 2, 'three': 3}
```

16.6 Dictionary Built-in Functions

Here are the built-in functions that deal with dictionaries.

dict(*[values], [key=value...]*)
Creates a new dictionary. If a positional parameter, `values` is provided, each element must be a 2-tuple. The `values` pairs are used to populate the dictionary; the first element of each pair is the key and the second element is the value.

Note that the `zip()` function produces a `list` of 2-tuples from two parallel `lists`.

If any keyword parameters are provided, each keyword becomes a key in the dictionary and the keyword argument becomes the value for that key.

```
>>> dict( [('first',0), ('second',1),('third',2)] )
{'second': 1, 'third': 2, 'first': 0}
>>> dict( zip(['fourth','fifth','sixth'],[3,4,5]) )
{'sixth': 5, 'fifth': 4, 'fourth': 3}
>>> dict( seventh=7, eighth=8, ninth=9 )
{'seventh': 7, 'eighth': 8, 'ninth': 9}
```

Functions which apply to dicts, but are defined elsewhere.

- `len()`. For dicts, this function returns the number of items.

```
>>> len( {1:'first',2:'second',3:'third'} )
3
>>> len( {} )
0
```

- `max()`. For dicts, this function returns the maximum key.

```
>>> max( {1:'first',2:'second',3:'third'} )
3
```

- `min()`. For dicts, this function returns the minimum key.
- `sum()`. For dicts, this function sums the keys.

```
>>> sum( {1:'first',2:'second',3:'third'} )
6
```

- `any()`. Equivalent to '`any( dictionary.keys() )`'. Return `True` if any key in the dictionary are `True`, or equivalent to `True`. This is almost always true except for empty dictionaries or a peculiar dictionary with keys of `0`, `False`, `None`, etc.
- `all()`. Equivalent to '`all( dictionary.keys() )`'. Return `True` if all keys in the dictionary are `True`, or equivalent to `True`.

```
>>> all( {1:'first',2:'second',3:'third'} )
True
>>> all( {1:'first',2:'second',None:'error'} )
False
```

- `enumerate()`. Iterate through the dictionary returning 2-tuples of '`( index, key )`'. This iterates through the key values. Since dictionaries have no explicit ordering to their keys, this enumeration is in an arbitrary order.
- `sorted()`. Iterate through the dictionary keys in sorted order. The keys are actually a list, and this returns a list of the sorted keys.

```
>>> sorted( { "two":2, "three":3, "quatro":4 } )
['quatro', 'three', 'two']
```

16.7 Dictionary Methods

A `dict` object has a number of member methods. Many of these maintain the values in a `dict` . Others retrieve parts of the `dict` as a sequence, for use in a **for** statement.

The following mutator functions update a `dict` object. Most of these do not return a value. The `dict.pop()` and `dict.setdefault()` methods both update the dictionary *and* return values.

`clear()`
: Remove all items from the *dict*.

`pop`(*key, [default]*)
: Remove the given key from the *dict*, returning the associated value. If the key does not exist, return the default value provided. If the key does not exist and no default value exists, raise a `KeyError` exception.

`setdefault`(*key, [default]*)
: If the `key` is in the dictionary, return the associated value. If the `key` is not in the dictionary, set the given `default` as the value and return this value. If `default` is not given, it defaults to `None`.

`update`(*new, [key=value...]*)
: Merge values from the new `new` into the original *dict*, adding or replacing as needed.

  It is equivalent to the following Python statement. '`for k in new.keys(): d[k]= new[k]`'

  If any keyword parameters are provided, each keyword becomes a key in the dictionary and the keyword argument becomes the value for that key.

```
>>> x= dict( seventh=7, eighth=8, ninth=9 )
>>> x
{'seventh': 7, 'eighth': 8, 'ninth': 9}
>>> x.update( first=1 )
>>> x
{'seventh': 7, 'eighth': 8, 'ninth': 9, 'first': 1}
```

The following transformer function transforms a dictionary into another object.

`copy()`
: Copy the `dict` to make a new `dict`. This is a *shallow copy*. All objects in the new `dict` are references to the same objects as the original `dict`.

The following accessor methods provide information about a `dict`.

`get(`*key, [default]*`)`
: Get the item with the given `key`, similar to '`dict[key]`'. If the key is not present and `default` is given, supply `default` instead. If the key is not present and no default is given, raise the `KeyError` exception.

`items()`
: Return all of the items in the `dict` as a sequence of (key,value) 2-tuples. Note that these are returned in no particular order.

`keys()`
: Return all of the keys in the `dict` as a sequence of keys. Note that these are returned in no particular order.

`values()`
: Return all the values from the `dict` as a sequence. Note that these are returned in no particular order.

16.8 Using Dictionaries as Function Parameter Defaults

It's very, very important to note that default values must be immutable objects. Recall that numbers, strings, `None`, and `tuple` objects are immutable.

We note that dictionaries as well as sets and lists are mutable, and cannot be used as default values for function parameters.

Consider the following example of what not to do.

```
>>> def default2( someDict={} ):
...     someDict['default']= 2
...     return someDict
...
>>> looks_good= {}
>>> default2(looks_good)
{'default': 2}
>>> default2(looks_good)
{'default': 2}
>>> looks_good
{'default': 2}
>>>
>>>
>>> not_good= default2()
>>> not_good
{'default': 2}
>>> worse= default2()
```

```
>>> worse
{'default': 2}
>>> not_good
{'default': 2}
>>>
>>> not_good['surprise']= 'what?'
>>> not_good
{'default': 2, 'surprise': 'what?'}
>>> worse
{'default': 2, 'surprise': 'what?'}
```

1. We defined a function which has a default value that's a mutable object. This is simple a bad programming practice in Python.
2. We used this function with a dictionary object, `looks_good`. The function updated the dictionary object as expected.
3. We used the function's default value to create `not_good`. The function inserted a value into an empty dictionary and returned this new dictionary object.

   It turns out that the function updated the mutable default value, also.
4. When we use the function's default value again, with `worse`, the function uses the updated default value and updates it again.

   Both `not_good` and `worse` are references to the same mutable object that is being updated.

To avoid this, do not use mutable values as defaults. Do this instead.

```
def default2( someDict=None ):
    if someDict is None:
        someDict= {}
    someDict['default']= 2
    return someDict
```

This creates a fresh new mutable object as needed.

16.9 Dictionary Exercises

1. **Word Frequencies**. Update the exercise in *Accumulating Unique Values* to count each occurance of the values in `aSequence`. Change the result from a simple sequence to a `dict`. The `dict` key is the value from `aSequence`. The `dict` value is the count of the number of occurances.

   If this is done correctly, the input sequence can be words, numbers or any other immutable Python object, suitable for a `dict` key.

   For example, the program could accept a line of input, discarding punctuation and breaking them into words in space boundaries. The basic `string` operations should make it possible to create a simple sequence of words.

   Iterate through this sequence, placing the words into a `dict`. The first time a word is seen, the frequency is 1. Each time the word is seen again, increment the frequency. Produce a frequency table.

   To alphabetize the frequency table, extract just the keys. A sequence can be sorted (see section 6.2). This sorted sequence of keys can be used to extract the counts from the `dict`.
2. **Stock Reports**. A block of publicly traded stock has a variety of attributes, we'll look at a few of them. A stock has a ticker symbol and a company name. Create a simple `dict` with ticker symbols and company names.

For example:

```
stockDict = { 'GM': 'General Motors',
 'CAT':'Caterpillar', 'EK':"Eastman Kodak" }
```

Create a simple `list` of blocks of stock. These could be `tuple` s with ticker symbols, prices, dates and number of shares. For example:

```
purchases = [ ( 'GE', 100, '10-sep-2001', 48 ),
 ( 'CAT', 100, '1-apr-1999', 24 ),
 ( 'GE', 200, '1-jul-1999', 56 ) ]
```

Create a purchase history report that computes the full purchase price (shares times dollars) for each block of stock and uses the stockDict to look up the full company name. This is the basic relational database join algorithm between two tables.

Create a second purchase summary that which accumulates total investment by ticker symbol. In the above sample data, there are two blocks of GE. These can easily be combined by creating a `dict` where the key is the ticker and the value is the `list` of blocks purchased. The program makes one pass through the data to create the `dict`. A pass through the `dict` can then create a report showing each ticker symbol and all blocks of stock.

3. **Date Decoder**. A date of the form '`8-MAR-85`' includes the name of the month, which must be translated to a number. Create a `dict` suitable for decoding month names to numbers. Create a function which uses `string` operations to split the date into 3 items using the "-" character. Translate the month, correct the year to include all of the digits.

   The function will accept a date in the "dd-MMM-yy" format and respond with a `tuple` of (y , m, d).

4. **Dice Odds**. There are 36 possible combinations of two dice. A simple pair of loops over range(6)+1 will enumerate all combinations. The sum of the two dice is more interesting than the actual combination. Create a `dict` of all combinations, using the sum of the two dice as the key.

   Each value in the `dict` should be a `list` of `tuple` s; each `tuple` has the value of two dice. The general outline is something like the following:

Enumerate Dice Combinations

Initialize. $combos \leftarrow dict()$

For all d1. Iterate with $1 \leq d_1 < 7$.

For all d2. Iterate with $1 \leq d_2 < 7$.

Create a Tuple. $t \leftarrow (d_1, d_2)$.

In the Dictionary. Is $d_1 + d_2$ a key in *combos*?

Append. Append the tuple, t to the value for item $d_1 + d_2$ in *combos*.

Not In the Dictionary. If $d_1 + d_2$ is not a key in *combos*, then

Insert. Add a new element $d_1 + d_2$ to the *combos*; the value is a 1-element list of the tuple, t.

Report. Display the resulting dictionary.

16.10 Advanced Parameter Handling For Functions

In *More Function Definition Features* we hinted that Python functions can handle a variable number of argument values in addition to supporting optional argument values.

When we define a function, we can have optional parameters. We define a fixed number of parameters, but some (or all) can be omitted because we provided default values for them. This allows us to provide too few positional argument values.

If we provide too many positional argument values to a function, however, Python raises an exception. It turns out that we can also handle this.

Consider the following example. We defined a function of three positional parameters, and then evaluated it with more than three argument values.

```
>>> def avg(a,b,c): return (a+b+c)/3.0
...
>>> avg(10,11,12)
11.0
>>> avg(10,11,12,13)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: avg() takes exactly 3 arguments (4 given)
```

First, we'll look at handling an unlimited number of positional values. Then we'll look at handling an unlimited number of keyword values.

16.10.1 Unlimited Number of Positional Argument Values

Python lets us define a function that handles an unknown and unlimited number of argument values. Examples of built-in functions with a unlimited number of argument values are `max()` and `min()`.

Rather than have Python raise an exception for extra argument values, we can request the additional positional argument values be collected into a `tuple`. To do this, we provide a final parameter definition of the form * *extras*. The * indicates that this parameter variable is the place to capture the extra argument values. The variable, here called *extras*, will receive a sequence with all of the extra positional argument values.

You can only provide one such variable (if you provided two, how could Python decide which of these two got the extra argument values?) You must provide this variable after the ordinary positional parameters in the function definition.

The following function accepts an unlimited number of positional arguments; it collects these in a single `tuple` parameter, `args`.

```
def myMax( *args ):
    max= args[0]
    for a in args[1:]:
        if a > max: max= a
    return max
```

Here's another example. In this case we have a fixed parameter in the first position and all the extra parameters collected into a `tuple` called `vals`.

```
def printf( format, *vals ):
    print format % vals
```

This should look familiar to C programmers. Now we can write the following, which may help ease the transition from C to Python.

```
printf( "%s = %d", "some string", 2 )
printf( "%s, %s, %d %d", "thing1", "thing2", 3, 22 )
```

16.10.2 Unlimited Number of Keyword Argument Values

In addition to collecting extra positional argument values into a single parameter, Python can also collect extra keyword argument values into a `dict`.

If you want a container of keyword arguments, you provide a parameter of the form ** *extras*. Your variable, here called *extras*, will receive a `dict` with all of the keyword parameters.

The following function accepts any number of keyword arguments; they are collected into a single parameter.

```
def rtd( **args ):
    if "rate" in args and "time" in args:
        args['distance'] = args['rate']*args['time']
    elif "rate" in args and "distance" in args:
        args['time']= args['distance']/args['rate']
    elif "time" in args and "distance" in args:
        args['rate']= args['distance']/args['time']
    else:
        raise Exception( "%r does not compute" % ( args, ) )
    return args
```

Here's two examples of using this `rtd()` function.

```
>>> rtd( rate=60.0, time= .75 )
{'distance': 45.0, 'rate': 60.0, 'time': 0.75}
>>> rtd( distance=173, time=2+50/60.0 )
{'distance': 173, 'rate': 61.058823529411761, 'time': 2.8333333333333335}
```

The keyword arguments are collected into a `dict`, named `args`. We check for combinations of "rate", "time" and "distance" in the `args` dictionary. For each combination, we can solve for the remaining value and update the `dict` by insert the additional key and value into the `dict`.

16.10.3 Evaluation with a Container Instead of Individual Argument Values

When evaluating a function, we can provide a sequence instead of providing individual positional parameters.

We do this with a special version of the * operator when evaluating a function. Here's an example of forcing a 3- `tuple` to be assigned to three positional parameters.

```
>>> def avg3( a, b, c ):
...     return (a+b+c)/3.0
...
>>> data= ( 4, 3, 2 )
>>> avg3( *data )
3.0
```

In this example, we told Python to assign each element of our 3-tuple named `data`, to a separate parameter variables of the function `avg3()`.

As with the * operator, we can use ** to make a `dict` become a series of keyword parameters to a function.

```
>>> d={ 'a':5, 'b':6, 'c':9 }
>>> avg3( **d )
6.666666666666667
```

In this example, we told Python to assign each element of the `dict`, `d` , to specific keyword parameters of our function.

We can mix and match this with ordinary parameter assignment, also. Here's an example.

```
>>> avg3( 2, b=3, **{'c':4} )
3.0
```

Here we've called our function with three argument values. The parameter `a` will get its value from a simple positional parameter. The parameter `b` will get its value from a keyword argument. The parameter `c` will get its value from having the `dict` `{'c':4}` turned into keyword parameter assignment.

We'll make more use of this in *Inheritance* .

CHAPTER

SEVENTEEN

SETS

Many algorithms need to work with simple containers of data values, irrespective of order or any key. This is a simple set of objects, which is supported by the Python set container. We'll look at Sets from a number of viewpoints: semantics, literal values, operations, comparison operators, statements, built-in functions and methods.

17.1 Set Semantics

A `set` is, perhaps the simplest possible container, since it contains objects in no particular order with no particular identification. Objects stand for themselves. With a sequence, objects are identified by position. With a mapping, objects are identified by some key. With a `set`, objects stand for themselves.

Since each object stands for itself; elements of a `set` cannot be duplicated. A `list` or `tuple`, for example, can have any number of duplicate objects. For example, the `tuple ( 1, 1, 2, 3 )` has four elements, which includes two copies of the integer `1`; if we create a `set` from this `tuple`, the `set` will only have three elements.

A `set` has large number of operations for unions, intersections, and differences. A common need is to examine a `set` to see if a particular object is a member of that `set`, or if one `set` is contained within another `set`.

A `set` is mutable, which means that it cannot be used as a key for a `dict` (see *Mappings and Dictionaries* for more information.) In order to use a `set` as a `dict` key, we can create a `frozenset`, which is an immutable copy of a `set`. This allows us to accumulate a `set` of values to create a `dict` key.

17.2 Set Literal Values

There are no literal values for `set` objects. A `set` value is created by using the `set()` or `frozenset()` factory functions. These can be applied to any *iterable* container, which includes any sequence, the keys of a `dict`, or even a file.

We'll return to the general notion of "iterable" when we look at the **yield** statement in *Iterators and Generators*.

`set`(*iterable*)
: Transforms the given iterable (sequence, file, `frozenset` or `set`) into a `set`.

```
>>> set( ("hello", "world", "of", "words", "of", "world") )
set(['world', 'hello', 'words', 'of'])
```

Note that we provided a six-tuple sequence to the `set()` function, and we got a `set` with the four unique objects. The `set` is shown as a `list` literal, to remind us that a `set` is mutable.

You cannot provide a list of argument values to the `set()` function. You must provide an iterable object (usually a tuple).

Trying '`set( "one", "two", "three" )`' will result in an `TypeError` because you provided three arguments. You must provide a single argument which is iterable. All sequences are iterable, so a sequence literal is the easiest to provide.

`set`(*iterable*)
Transforms the given iterable (sequence, file or `set`) into an immutable `frozenset`.

17.3 Set Operations

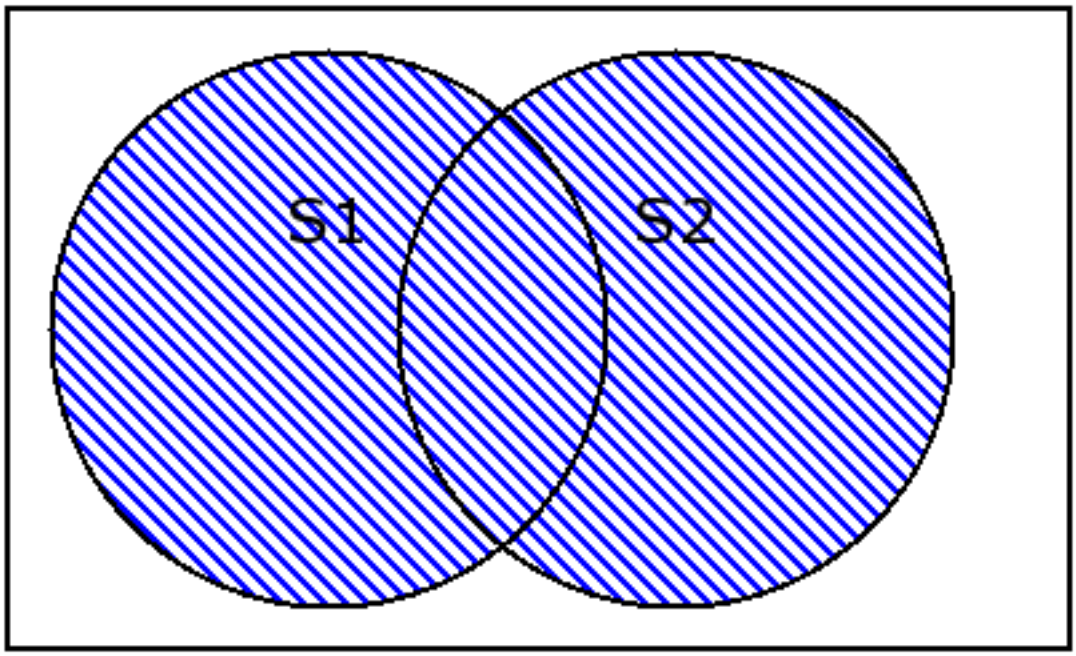
There are a large number of `set` operations, including union ('`|`'), intersection ('`&`'), difference ('`-`'), and symmetric difference ('`^`'). These are unusual operations, so we'll look at them in some detail. In addition to the operator notation, there are also method functions which do the same things. We'll look at the method function versions below.

We'll use the following two `set` objects to show these operators.

```
>>> fib=set( (1,1,2,3,5,8,13) )
>>> prime=set( (2,3,5,7,11,13) )
```

Union. '`|`'. The resulting `set` has elements from both source `set`s. An element is in the result if it is one `set` *or* the other.

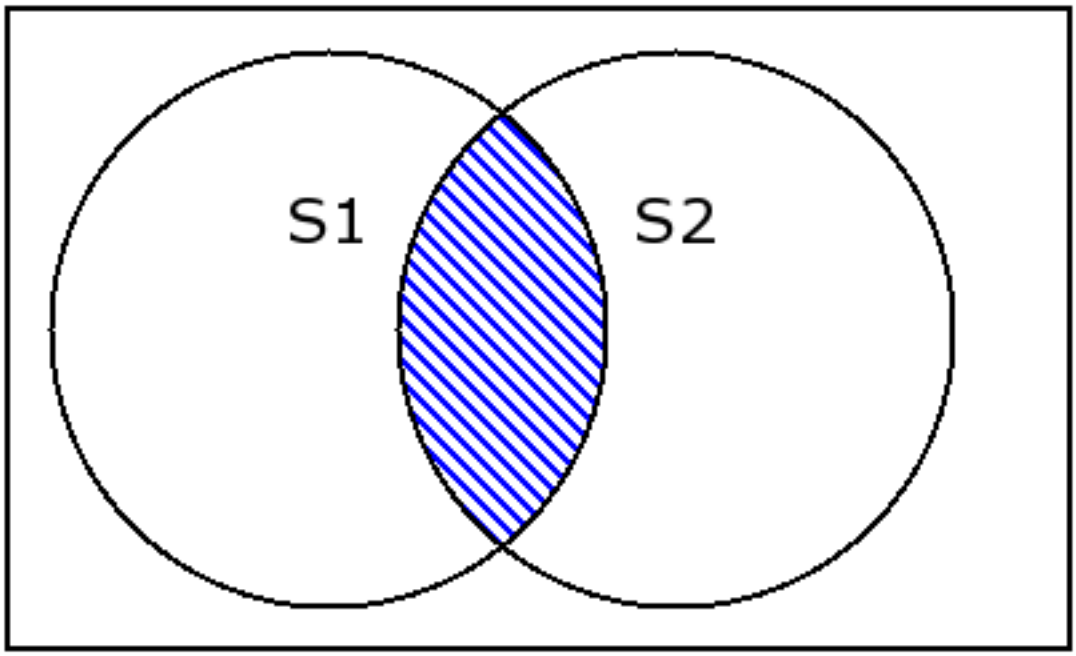
```
>>> fib | prime
set([1, 2, 3, 5, 7, 8, 11, 13])
```



$$S1 \cup S2 = \{e | e \in S1 \text{ or } e \in S2\}$$

Intersection. '`&`'. The resulting `set` has elements that are common to both source `set`s. An element is in the result if it is in one `set` *and* the other.

```
>>> fib & prime
set([2, 3, 5, 13])
```



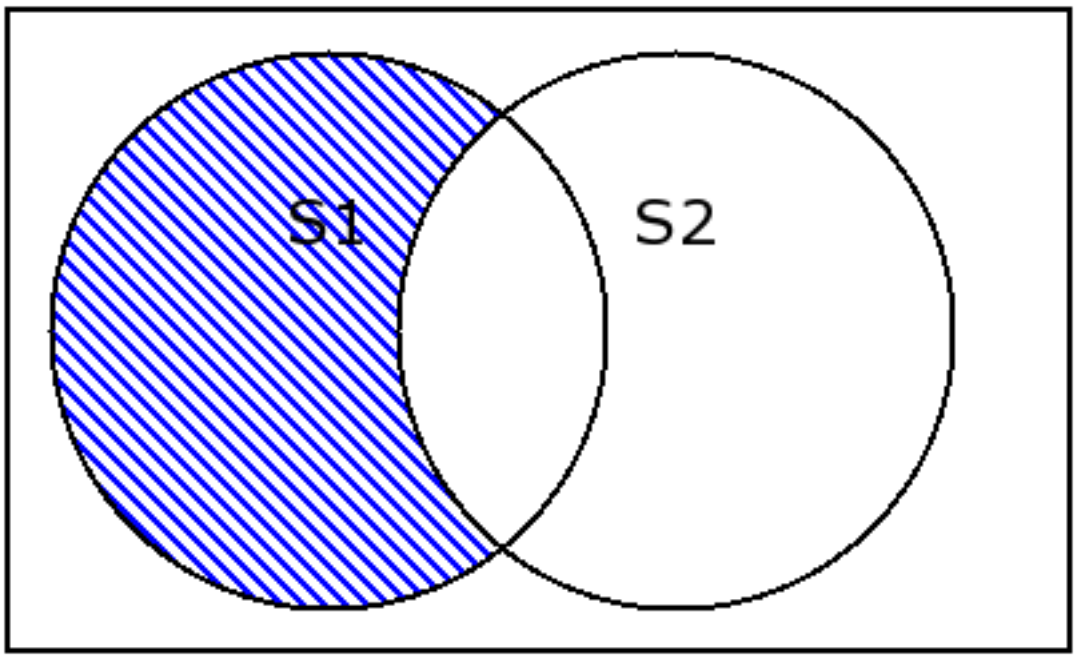
$$S1 \cap S2 = \{e | e \in S1 \text{ and } e \in S2\}$$

Difference. '`-`'. The resulting `set` has elements of the left-hand `set` with all elements from the right-hand `set` removed. An element will be in the result if it is in the left-hand `set` and not in the right-hand `set`.

```
>>> fib - prime
set([8, 1])
>>> prime - fib
set([11, 7])
```

$$S1 - S2 = \{e | e \in S1 \text{ and } e \notin S2\}$$
$$S2 - S1 = \{e | e \notin S1 \text{ and } e \in S2\}$$

Symmetric Difference. '`^`'. The resulting `set` has elements which are unique to each `set`. An element will be in the result `set` if either it is in the left-hand `set` and not in the right-hand `set` or it is in the right-hand `set` and not in the left-hand `set`. Whew!




```
>>> fib ^ prime
set([1, 7, 8, 11])
```

$$S1 \ominus S2 = \{e | e \in S1 \text{ xor } e \in S2\}$$

17.4 Set Comparison Operators

Therer are a number of `set` comparisons. All of the standard comparisons ('<', '<=', '>', '>=', '==', '!=', **in**, **not in**) work with `set`s, but the interpretation of the operators is based on `set` theory. The various operations from set theory are the subset and proper subset relationships.

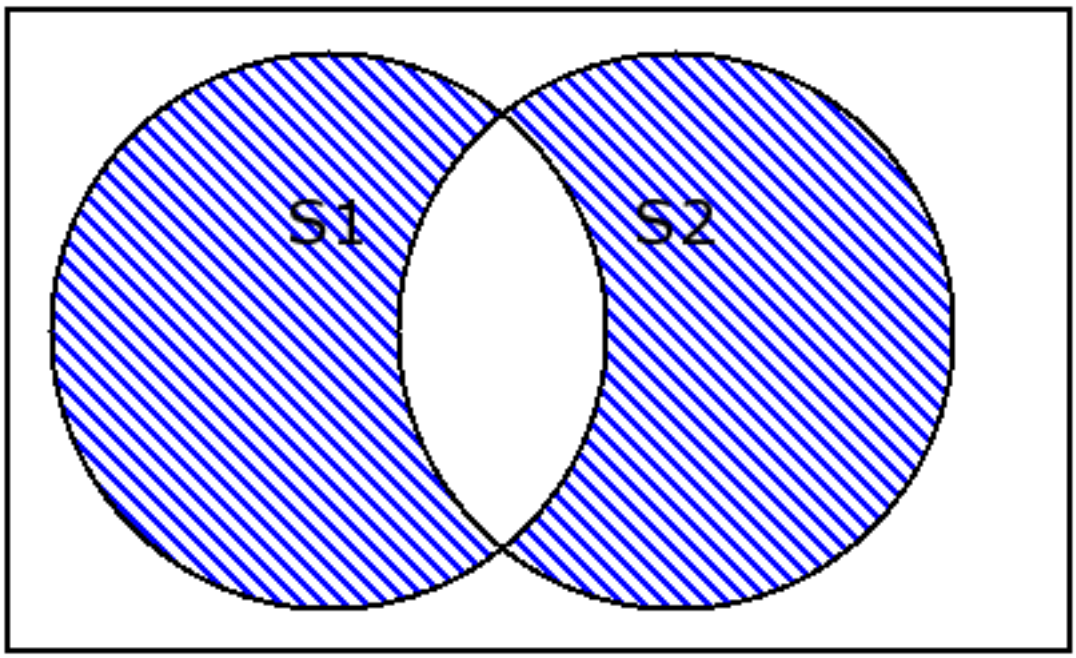
The various comparison mathematical operations of $\subset$, $\subseteq$, $\supset$, $\supseteq$ are implemented by '<', '<=', '>', '>='.

In the following example, the `set` `craps` is all of the ways we can roll craps on a come out roll. Also, we've defined `three` to hold both of the dice rolls that total 3. When we compare `three` with `craps`, we see the expected relationships: `three` is a subset `craps` as well as a proper subset of `craps`.

```
>>> craps= set( [ (1,1), (2,1), (1,2), (6,6) ] )
>>> three = set( [ (1,2), (2,1) ] )
>>> three < craps
True
>>> three <= craps
True
```

The **in** and **not in** operators implement that $\in$ and $\notin$ relationships.

In the following example, the `set` `craps` is all of the ways we can roll craps on a come out roll. We've modeled a throw of the dice as a 2-tuple. We can now test a specific throw to see if it is craps.




```
>>> craps= set( [ (1,1), (2,1), (1,2), (6,6) ] )
>>> (1,2) in craps
True
>>> (3,4) in craps
False
```

17.5 Set Statements

The **for** statement works directly with `set` objects, because they are iterable. A `set` is not a sequence, but it is like a sequence because we can iterate through the elements using a **for** statement.

Here we create three `set` objects: `even`, `odd`, and `zero` to reflect some standard outcomes in Roulette. The union of all three `set`s is the complete `set` of possible spins. We can iterate through this resulting `set`.

```
>>> even= set( range(2,38,2) )
>>> odd= set( range(1,37,2) )
>>> zero= set( (0,'00') )
>>> for n in even|odd|zero:
        print n
```

17.6 Set Built-in Functions

A number of built-in functions create or process `set` objects.

The `set()` and `frozenset()` were described above, under Set Literal Values.

Functions which apply to sets, but are defined elsewhere.

- `len()`. For sets, this function returns the number of items.

```
>>> len( set( [1,1,2,3] ) )
3
>>> len( set() )
0
```

  Note that sets do not include duplicates, that's why the length in the first example is not 4.

- `max()`. For sets, this function returns the maximum item.

```
>>> max( set( [1,1,2,3,5,8] ) )
8
```

- `min()`. For sets, this function returns the minimum item.
- `sum()`. For sets, this function sums the items.

```
>>> sum( set( [1,1,2,3,5,8] ) )
19
```

  Note that sets do not include duplicates, that's why the sum is not 20.

- `any()`. For sets, Return `True` if there exists any item which is `True`.

```
>>> set( [0, None, False] )
set([0, None])
>>> any( _ )
False
>>> any( set( [0,None,False,42] ) )
True
```

  Note that `False` and `0` have the same value when constructing a set, and are duplicates.

- `all()`. For sets, Return `True` if all items are `True`.

```
>>> all( set( [0,None,False,42] ) )
False
>>> all( set( [1,True] ) )
True
```

- `enumerate()`. Iterate through the set returning 2-tuples of '`( index, item )`'. Since sets have no explicit ordering to their items, this enumeration is in an arbitrary order.
- `sorted()`. Iterate through the set elements in sorted order. This returns a set of elements.

```
>>> sorted( set( [1,1,2,3,5,8] ) )
[1, 2, 3, 5, 8]
```

17.7 Set Methods

A `set` object has a number of member methods.

The following mutators update a `set` object. Note that most of these methods don't return a value. The exception is pop.

`clear()`
Remove all items from the *set*.

`pop()`
Remove an arbitrary object from the *set*, returning the object. If the `set` was already empty, this will raise a `KeyError` exception.

`add(`*new*`)`
Adds element `new` to the *set*. If the object is already in the *set*, nothing happens.

`remove(`*old*`)`
Removes element `old` from the *set* . If the object `old` is not in the *set* , this will raise a `KeyError` exception.

`discard()`
Same a `set.remove()`.

`update(`*new*`)`
Merge values from the `new` `set` into the original *set*, adding elements as needed.

It is equivalent to the following Python statement. '`s |= new`'.

`intersection_update(`*new*`)`
Update *set* to have the intersection of *set* and `new`. In effect, this discards elements from *set*, keeping only elements which are common to `new` and *set*

It is equivalent to the following Python statement. '`s &= new`'.

`difference_update(`*new*`)`
Update *set* to have the difference between *set* and `new`. In effect, this discards elements from *set* which are also in `new`.

It is equivalent to the following Python statement. '`s -= new`'.

`symmetric_difference_update(`*new*`)`
Update *set* to have the symmetric difference between *set* and `new`. In effect, this both discards elements from *s* which are common with `new` and also inserts elements into *s* which are unique to `new`.

It is equivalent to the following Python statement. '`s ^= new`'.

The following transformers built a new object from one or more `set`s.

`copy()`
Copy the `set` to make a new `set`. This is a *shallow copy*. All objects in the new `set` are references to the same objects as the original `set`.

`union(`*new*`)`
If `new` is a proper `set`, return '`set | new`'. If `new` is a sequence or other iterable, make a new `set` from the value of `new`, then return the union, '`set | new`'. This does not update the original *set*.

```
>>> prime.union( (1, 2, 3, 4, 5) )
set([1, 2, 3, 4, 5, 7, 11, 13])
```

`intersection(`*new*`)`
If `new` is a proper `set`, return '`set & new`'. If `new` is a sequence or other iterable, make a new `set` from the value of `new`, then return the intersection, '`set & new`'. This does not update *set*.

`difference(`*new*`)`
If `new` is a proper `set`, return '`set - new`'. If `new` is a sequence or other iterable, make a new `set` from the value of `new`, then return the difference, '`set - new`'. This does not update *set*.

`symmetric_difference`(*new*)
: If `new` is a proper `set`, return '`s ^ new`'. If `new` is a sequence or other iterable, make a new `set` from the value of `new`, then return the symmetric difference, '`sset ^ new`'. This does not update *s* .

The following accessor methods provide information about a `set`.

`issubset`(*other*)
: If *set* is a subset of `other`, return `True`, otherwise return `False`. Essentially, this is '`set <= other`' .

`issuperset`(*other*)
: If *set* is a superset of `other`, return `True` , otherwise return `False`. Essentially, this is '`set >= other`'.

17.8 Using Sets as Function Parameter Defaults

It's very, very important to note that default values must be immutable objects. Recall that numbers, strings, `None`, and `tuple` objects are immutable.

We note that sets as well as dictionaries and lists are mutable, and cannot be used as default values for function parameters.

Consider the following example of what not to do.

```
>>> def default2( someSet=set() ):
...     someSet.add(2)
...     return someSet
...
>>> looks_good= set()
>>> default2( looks_good )
set([2])
>>> looks_good
set([2])
>>>
>>>
>>> not_good= default2()
>>> not_good
set([2])
>>> worse= default2()
>>> worse
set([2])
>>>
>>> not_good.add(3)
>>> not_good
set([2, 3])
>>> worse
set([2, 3])
```

1. We defined a function which has a default value that's a mutable object. This is simple a bad programming practice in Python.
2. We used this function with a set object, `looks_good`. The function updated the set object as expected.
3. We used the function's default value to create `not_good`. The function inserted a value into an empty set and returned this new set object.

   It turns out that the function updated the mutable default value, also.
4. When we use the function's default value again, with `worse`, the function uses the updated default value and updates it again.

Both `not_good` and `worse` are references to the same mutable object that is being updated.

To avoid this, do not use mutable values as defaults. Do this instead.

```
def default2( someSet=None ):
    if someSet is None:
        someSet= {}
    someSet.add( 2 )
    return someSet
```

This creates a fresh new mutable object as needed.

17.9 Set Exercises

1. **Dice Rolls**. In Craps, each roll of the dice belongs to one of several `set` s of rolls that are used to resolve bets. There are only 36 possible dice rolls, but it's annoying to define the various `set` s manually. Here's a multi-step procedure that produces the various `set` s of dice rolls around which you can define the game of craps.

   First, create a sequence with 13 empty `set` s, call it `dice`. Something like '`[ set() ]*13`' doesn't work because it makes 13 copies of a single `set` object. You'll need to use a for statement to evaluate the `set` constructor function 13 different times. What is the first index of this sequence? What is the last entry in this sequence?

   Second, write two, nested, for-loops to iterate through all 36 combinations of dice, creating 2- `tuple` s. The 36 2-tuple s will begin with `(1,1)` and end with `(6,6)`. The sum of the two elements is an index into `dice`. We want to add each 2- `tuple` to the appropriate `set` in the `dice` sequence.

   When you're done, you should see results like the following:

   ```
   >>> dice[7]
   set([(5, 2), (6, 1), (1, 6), (4, 3), (2, 5), (3, 4)])
   ```

   Now you can define the various rules as `set`s built from other `set`s.

   lose On the first roll, you lose if you roll 2, 3 or 12. This is the `set` '`dice[2] | dice[3] | dice[12]`'. The game is over.

   win On the first roll, you win if you roll 7 or 11. The game is over. This is '`dice[7] | dice[11]`'.

   point On the first roll, any other result (4, 5, 6, 8, 9, or 10) establishes a point. The game runs until you roll the point or a seven.

   craps Once a point is established, you win if you roll the point's number. You lose if you roll a 7.

   Once you have these three `set`s defined, you can simulate the first roll of a craps game with a relatively elegant-looking program. You can generate two random numbers to create a 2-tuple. You can then check to see if the 2-tuple is in the `lose` or `win` `set`s.

   If the come-out roll is in the `point` `set`, then the sum of the 2-tuple will let you pick a `set` from the dice sequence. For example, if the come-out roll is `(2,2)`, the sum is 4, and you'd assign '`dice[4]`' to the variable `point`; this is the `set` of winners for the rest of the game. The `set` of losers for the rest of the game is always the `craps` `set`.

The rest of the game is a simple loop, like the come-out roll loop, which uses two random numbers to create a 2- tuple. If the number is in the point set, the game is a winner. If the number is in the craps set, the game is a loser, otherwise it continues.

2. **Roulette Results**. In Roulette, each spin of the wheel has a number of attributes like even-ness, low-ness, red-ness, etc. You can bet on any of these attributes. If the attribte on which you placed bet is in the set of attributes for the number, you win.

   We'll look at a few simple attributes: red-black, even-odd, and high-low. The even-odd and high-low attributes are easy to compute. The red-black attribute is based on a fixed set of values.

   ```
   redNumbers= set( [1,3,5,7,9,12,14,16,18,19,21,23,25,27,30,32,34,36] )
   ```

   We have to distinguish between 0 and 00, which makes some of this decision-making rather complex. We can, for example, use ordinary integers for the numbers 0 to 36, and append the string "00" to this set of numbers. For example, '`set( range(37) ) | set( ['00'] )`'. This set is the entire Roulette wheel, we can call it wheel.

   We can define a number of set s that stand for bets: red, black, even, odd, high and low. We can iterate though the values of wheel, and decide which set s that value belongs to.

   - If the spin is non-zero and '`spin % 2 == 0`', add the spin to the even set.
   - If the spin is non-zero and '`spin % 2 != 0`', add the spin to the odd set.
   - If the spin is non-zero and it's in the redNumbers set, add the spin to the red set.
   - If the spin is non-zero and it's not in the redNumbers set, add the value to the black set.
   - If the spin is non-zero and '`spin <= 18`', add the value to the low set.
   - If the spin is non-zero and '`spin > 18`', add the value to the high set.

   Once you have these six sets defined, you can use them to simulate Roulette. Each round involves picking a random spin with something like '`random.choice( list(wheel) )`'. You can then see which set the spin belongs to. If the spin belongs to a set on which you've bet, the spin is a winner, otherwise it's a loser.

   These six sets all pay 2:1. There are a some set s which pay 3:1, including the 1-12, 13-24, 25 to 36 ranges, as well as the three columns, spin % 3 == 0, spin % 3 == 1 and spin % 3 == 2. There are still more bets on the Roulette table, but the set s of spins for those bets are rather complex to define.

3. **Sieve of Eratosthenes**. Look at *Sieve of Eratosthenes*. We created a list of candidate prime numbers, using a sequence with 5000 boolean flags. We can, without too much work, simplify this to use a set instead of a list.

Sieve of Eratosthenes - Set Version

(a) **Initialize**

Create a set, prime which has integers between 2 and 5000.

Set $p \leftarrow 2$

(b) **Iterate**. While $2 \leq p < 5000$:

Find Next Prime. while not $prime_p$ and $2 \leq p < 5000$:

Increment p by 1.

Remove Multiples. At this point, p is prime.

Set $k \leftarrow p + p$

while $k < 5000$:

Remove `k` from the `set` `prime`

Set $k \leftarrow k + p$

Next `p`. Increment `p` by 1.

(c) **Report**.

At this point, the `set` `prime` has the prime numbers. We can return the `set`.

In the **Find Next Prime** step, you're really looking for the minimum in the `prime` set which is greater than or equal to `p`.

In the **Remove Multiples** step, you can create the `set` of multiples, and use `difference_update()` to remove the multiples from `prime`.

You can, also, use the `range()` function to create multiples of `p`, and create a `set` from this sequence of multiples.

CHAPTER

EIGHTEEN

EXCEPTIONS

The try, except, finally and raise statements

A well-written program should produce valuable results even when exceptional conditions occur. A program depends on numerous resources: memory, files, other packages, input-output devices, to name a few. Sometimes it is best to treat a problem with any of these resources as an exception, which interrupts the normal sequential flow of the program.

In *Exception Semantics* we introduce the semantics of exceptions. We'll show the basic exception-handling features of Python in *Basic Exception Handling* and the way exceptions are raised by a program in *Raising Exceptions*.

We'll look at a detailed example in *An Exceptional Example*. In *Complete Exception Handling and The finally Clause*, we cover some additional syntax that's sometimes necessary. In *Exception Functions*, we'll look at a few standard library functions that apply to exceptions.

We descibe most of the built-in exceptions in *Built-in Exceptions*. In addition to exercises in *Exception Exercises*, we also include style notes in *Style Notes* and a digression on problems that can be caused by poor use of exceptions in *A Digression*.

18.1 Exception Semantics

An *exception* is an event that interrupts the ordinary sequential processing of a program. When an exception is *raised*, Python will *handle* it immediately. Python does this by examining **except** clauses associated with **try** statements to locate a suite of statements that can process the exception. If there is no **except** clause to handle the exception, the program stops running, and a message is displayed on the standard error file.

An exception has two sides: the dynamic change to the sequence of execution and an object that contains information about the exceptional situation. The dynamic change is initiated by the **raise** statement, and can finish with the handlers that process the raised exception. If no handler matches the exception, the program's execution effectively stops at the point of the **raise**.

In addition to the dynamic side of an exception, an object is created by the **raise** statement; this is used to carry any information associated with the exception.

Consequences. The use of exceptions has two important consequences.

First, we need to clarify where exceptions can be raised. Since various places in a program will raise exceptions, and these can be hidden deep within a function or class, their presence should be announced by specifying the possible exceptions in the docstring.

Second, multiple parts of a program will have handlers to cope with various exceptions. These handlers should handle just the meaningful exceptions. Some exceptions (like `RuntimeError` or `MemoryError`) generally can't

be handled within a program; when these exceptions are raised, the program is so badly broken that there is no real recovery.

Exceptions are a powerful tool for dealing with rare, atypical conditions. Generally, exceptions should be considered as different from the expected or ordinary conditions that a program handles. For example, if a program accepts input from a person, exception processing is not appropriate for validating their inputs. There's nothing rare or uncommon about a person making mistakes while attempting to enter numbers or dates. On the other hand, an unexpected disconnection from a network service is a good candidate for an exception; this is a rare and atypical situation. Examples of good exceptions are those which are raised in response to problems with physical resources like files and networks.

Python has a large number of built-in exceptions, and a programmer can create new exceptions. Generally, it is better to create new exceptions rather than attempt to stretch or bend the meaning of existing exceptions.

18.2 Basic Exception Handling

Exception handling is done with the **try** statement. The **try** statement encapsulates several pieces of information. Primarily, it contains a suite of statements and a group of exception-handling clauses. Each exception-handling clause names a class of exceptions and provides a suite of statements to execute in response to that exception.

The basic form of a **try** statement looks like this:

```
try:
    suite

except exception 〈 , target 〉 :
    suite

except:
    suite
```

Each *suite* is an indented block of statements. Any statement is allowed in the suite. While this means that you can have nested **try** statements, that is rarely necessary, since you can have an unlimited number of **except** clauses on a single **try** statement.

If any of the statements in the **try** suite raise an exception, each of the **except** clauses are examined to locate a clause that matches the exception raised. If no statement in the **try** suite raises an exception, the **except** clauses are silently ignored.

The first form of the **except** clause provides a specific exception class which is used for matching any exception which might be raised. If a `target` variable name is provided, this variable will have the exception object assigned to it.

The second form of the **except** clause is the "catch-all" version. This will match all exceptions. If used, this must be provided last, since it will always match the raised exception.

We'll look at the additional **finally** clause in a later sections.

Important: Python 3

The **except** statement can't easily handle a list of exception classes. The Python 2 syntax for this is confusing because it requires some additional '`()`' around the list of exceptions.

```
except ( exception, ... )  〈 , target 〉 :
```

The Python 3 syntax wil be slightly simpler. Using the keyword **as** will remove the need for the additional '`()`' around the list of exceptions.

```
except exception, ...  as target
```

Overall Processing. The structure of the complete **try** statement summarizes the philosophy of exceptions. First, try the suite of statements, expecting them work. In the unlikely event that an exception is raised, find an exception clause and execute that exception clause suite to recover from or work around the exceptional situation.

Except clauses include some combination of error reporting, recovery or work-around. For example, a recovery-oriented except clause could delete useless files. A work-around exception clause could returning a complex result for square root of a negative number.

First Example. Here's the first of several related examples. This will handle two kinds of exceptions, `ZeroDivisionError` and `ValueError`.

exception1.py

```
def avg( someList ):
    """Raises TypeError or ZeroDivisionError exceptions."""
    sum= 0
    for v in someList:
        sum = sum + v
    return float(sum)/len(someList)
def avgReport( someList ):
    try:
        m= avg(someList)
        print "Average+15%=", m*1.15
    except TypeError, ex:
        print "TypeError:", ex
    except ZeroDivisionError, ex:
        print "ZeroDivisionError:", ex
```

This example shows the `avgReport()` function; it contains a **try** clause that evaluates the `avg()` function. We expect that there will be a `ZeroDivisionError` exception if an empty list is provided to `avg()`. Also, a `TypeError` exception will be raised if the list has any non-numeric value. Otherwise, it prints the average of the values in the list.

In the **try** suite, we print the average. For certain kinds of inappropriate input, we will print the exceptions which were raised.

This design is generally how exception processing is handled. We have a relatively simple, clear function which attempts to do the job in a simple and clear way. We have a application-specific process which handles exceptions in a way that's appropriate to the overall application.

Nested :command:'try' Statements. In more complex programs, you may have many function definitions. If more than one function has a **try** statement, the nested function evaluations will effectively nest the **try** statements inside each other.

This example shows a function `solve()`, which calls another function, `quad()`. Both of these functions have a **try** statement. An exception raised by `quad()` could wind up in an exception handler in `solve()`.

exception2.py

```
def sum( someList ):
    """Raises TypeError"""
    sum= 0
    for v in someList:
        sum = sum + v
    return sum
def avg( someList ):
    """Raises TypeError or ZeroDivisionError exceptions."""
    try:
        s= sum(someList)
        return float(s)/len(someList)
    except TypeError, ex:
        return "Non-Numeric Data"
def avgReport( someList ):
    try:
        m= avg(someList)
        print "Average+15%=", m*1.15
    except TypeError, ex:
        print "TypeError: ", ex
    except ZeroDivisionError, ex:
        print "ZeroDivisionError: ", ex
```

In this example, we have the same `avgReport()` function, which uses `avg()` to compute an average of a list. We've rewritten the `avg()` function to depend on a `sum()` function. Both `avgReport()` and `avg()` contain **try** statements. This creates a nested context for evaluation of exceptions.

Specifically, when the function sum is being evaluated, an exception will be examined by `avg()` first, then examined by `avgReport()`. For example, if `sum()` raises a `TypeError` exception, it will be handled by `avg()`; the `avgReport()` function will not see the `TypeError` exception.

Function Design. Note that this example has a subtle bug that illustrates an important point regarding function design. We introduced the bug when we defined `avg()` to return either an answer or an error status code in the form of a `string`. Generally, things are more complex when we try to mix return of valid results and return of error codes.

Status codes are the only way to report errors in languages that lack exceptions. C, for example, makes heavy use of status codes. The POSIX standard API definitions for operating system services are oriented toward C. A program making OS requests must examing the results to see if it is a proper values or an indication that an error occurred. Python, however, doesn't have this limitation. Consequently many of the OS functions available in Python modules will raise exceptions rather than mix proper return values with status code values.

In our case, our design for `avg()` attepts to return either a valid numeric result or a string result. To be correct we would have to do two kinds of error checking in `avgReport()`. We would have to handle any exceptions and we would also have to examine the results of `avg()` to see if they are an error value or a proper answer.

Rather than return status codes, a better design is to simply use exceptions for all kinds of errors. IStatus codes have no real purposes in well-designed programs. In the next section, we'll look at how to define and raise our own exceptions.

18.3 Raising Exceptions

The **raise** statement does two things: it creates an `exception` object, and immediately leaves the expected program execution sequence to search the enclosing **try** statements for a matching **except** clause. The effect of a **raise** statement is to either divert execution in a matching **except** suite, or to stop the program because no matching **except** suite was found to handle the exception.

The `Exception` object created by **raise** can contain a message string that provides a meaningful error message. In addition to the string, it is relatively simple to attach additional attributes to the exception.

Here are the two forms for the **raise** satement.

```
raise exceptionClass , value
```

```
raise exception
```

The first form of the **raise** statement uses an exception class name. The optional parameter is the additional value that will be contained in the exception. Generally, this is a `string` with a message, however any object can be provided.

Here's an example of the **raise** statement.

```
raise ValueError, "oh dear me"
```

This statement raises the built-in exception `ValueError` with an amplifying `string` of `"oh dear me"`. The amplifying string in this example, one might argue, is of no use to anybody. This is an important consideration in exception design. When using a built-in exception, be sure that the arguments provided pinpoint the error condition.

The second form of the raise statement uses an object constructor to create the `Exception` object.

```
raise ValueError( "oh dear me" )
```

Here's a variation on the second form in which additional attributes are provided for the exception.

```
ex= MyNewError( "oh dear me" )
ex.myCode= 42
ex.myType= "O+"
raise ex
```

In this case a handler can make use of the message, as well as the two additional attributes, `myCode` and `myType`.

Defining Your Own Exception. You will rarely have a need to raise a built-in exception. Most often, you will need to define an exception which is unique to your application.

We'll cover this in more detail as part of the object oriented programming features of Python, in *Classes* . Here's the short version of how to create your own unique exception class.

```
class MyError( Exception ): pass
```

This single statement defines a subclass of `Exception` named `MyError`. You can then raise `MyError` in a **raise** statement and check for `MyError` in **except** clauses.

Here's an example of defining a unique exception and raising this exception with an amplifying `string`.

quadratic.py

```
import math
class QuadError( Exception ): pass
def quad(a,b,c):
    if a == 0:
        ex= QuadError( "Not Quadratic" )
        ex.coef= ( a, b, c )
        raise ex
    if b*b-4*a*c < 0:
        ex= QuadError( "No Real Roots" )
        ex.coef= ( a, b, c )
        raise ex
    x1= (-b+math.sqrt(b*b-4*a*c))/(2*a)
    x2= (-b-math.sqrt(b*b-4*a*c))/(2*a)
    return (x1,x2)
```

Additional raise Statements. Exceptions can be raised anywhere, including in an **except** clause of a **try** statement. We'll look at two examples of re-raising an exception.

We can use the simple **raise** statement in an **except** clause. This re-raises the original exception. We can use this to do standardized error handling. For example, we might write an error message to a log file, or we might have a standardized exception clean-up process.

```
try:
     attempt something risky
except Exception, ex:
    log_the_error( ex )
    raise
```

This shows how we might write the exception to a standard log in the function `log_the_error()` and then re-raise the original exception again. This allows the overall application to choose whether to stop running gracefully or handle the exception.

The other common technique is to transform Python errors into our application's unique errors. Here's an example that logs an error and transforms the built-in `FloatingPointError` into our application-specific error, `MyError`.

```
class MyError( Exception ): pass

try:
     attempt something risky
except FloatingPointError, e:
    do something locally, perhaps to clean up
    raise MyError("something risky failed: %s" % ( e, ) )
```

This allows us to have more consistent error messages, or to hide implementation details.

18.4 An Exceptional Example

The following example uses a uniquely named exception to indicate that the user wishes to quit rather than supply input. We'll define our own exception, and define function which rewrites a built-in exception to be our own exception.

We'll define a function, `ckyorn()`, which does a "Check for Y or N". This function has two parameters, `prompt` and `help`, that are used to prompt the user and print help if the user requests it. In this case, the return value is always a "Y" or "N". A request for help ("?") is handled automatically. A request to quit is treated as an exception, and leaves the normal execution flow. This function will accept "Q" or end-of-file (usually `ctrl-D`, but also `ctrl-Z` on Windows) as the quit signal.

interaction.py

```
class UserQuit( Exception ): pass
def ckyorn( prompt, help="" ):
    ok= 0
    while not ok:
        try:
            a=raw_input( prompt + " [y,n,q,?]: " )
        except EOFError:
            raise UserQuit
        if a.upper() in [ 'Y', 'N', 'YES', 'NO' ]: ok= 1
        if a.upper() in [ 'Q', 'QUIT' ]:
            raise UserQuit
        if a.upper() in [ '?' ]:
            print help
    return a.upper()[0]
```

We can use this function as shown in the following example.

```
import interaction
answer= interaction.ckyorn(
    help= "Enter Y if finished entering data",
    prompt= "All done?")
```

This function transforms an `EOFError` into a `UserQuit` exception, and also transforms a user entry of "Q" or "q" into this same exception. In a longer program, this exception permits a short-circuit of all further processing, omitting some potentially complex **if** statements.

Details of the `ckyorn()` Function Our function uses a loop that will terminate when we have successfully interpreted an answer from the user. We may get a request for help or perhaps some uninterpretable input from the user. We will continue our loop until we get something meaningful. The post condition will be that the variable `ok` is set to True and the answer, `a` is one of `("Y", "y", "N", "n")`.

Within the loop, we surround our `raw_input()` function with a **try** suite. This allows us to process any kind of input, including user inputs that raise exceptions. The most common example is the user entering the end-of-file character on their keyboard.

We handle the built-in `EOFError` by raising our `UserQuit` exception. When we get end-of-file from the user, we need to tidy up and exit the program promptly.

If no exception was raised, we examine the input character to see if we can interpret it. Note that if the user enters 'Q' or 'QUIT', we treat this exactly like as an end-of-file; we raise the `UserQuit` exception so that the program can tidy up and exit quickly.

We return a single-character result only for ordinary, valid user inputs. A user request to quit is considered extraordinary, and we raise an exception for that.

18.5 Complete Exception Handling and The finally Clause

A common use case is to have some final processing that must occur irrespective of any exceptions that may arise. The situation usually arises when an external resource has been acquired and must be released. For example, a file must be closed, irrespective of any errors that occur while attempting to read it.

With some care, we can be sure that all exception clauses do the correct final processing. However, this may lead to a some redundant programming. The **finally** clause saves us the effort of trying to carefully repeat the same statement(s) in a number of **except** clauses. This final step will be performed before the try block is finished, either normally or by any exception.

The complete form of a **try** statement looks like this:

```
try:
    suite


except exception , target :
    suite


except:
    suite


finally: suite
```

Each *suite* is an indented block of statements. Any statement is allowed in the suite. While this means that you can have nested **try** statements, that is rarely necessary, since you can have an unlimited number of **except** clauses.

The **finally** clause is always executed. This includes all three possible cases: if the try block finishes with no exceptions; if an exception is raised and handled; and if an exception is raised but not handled. This last case means that every nested try statement with a **finally** clause will have that **finally** clause executed.

Use a **finally** clause to close files, release locks, close database connections, write final log messages, and other kinds of final operations. In the following example, we use the **finally** clause to write a final log message.

```
def avgReport( someList ):
    try:
        print "Start avgReport"
        m= avg(someList)
        print "Average+15%=", m*1.15
    except TypeError, ex:
        print "TypeError: ", ex
    except ZeroDivisionError, ex:
        print "ZeroDivisionError: ", ex
    finally:
        print "Finish avgReport"
```

18.6 Exception Functions

The `sys` module provides one function that provides the details of the exception that was raised. Programs with exception handling will occasionally use this function.

The sys.exc_info() function returns a 3- tuple with the exception, the exception's parameter, and a traceback object that pinpoints the line of Python that raised the exception. This can be used something like the following not-very-good example.

exception2.py

```
import sys
import math
a= 2
b= 2
c= 1
try:
    x1= (-b+math.sqrt(b*b-4*a*c))/(2*a)
    x2= (-b-math.sqrt(b*b-4*a*c))/(2*a)
    print x1, x2
except:
    e,p,t= sys.exc_info()
    print e,p
```

This uses **multiple assignment** to capture the three elements of the sys.exc_info() tuple , the exception itself in e, the parameter in p and a Python traceback object in t.

This "catch-all" exception handler in this example is a bad policy. It may catch exceptions which are better left uncaught. We'll look at these kinds of exceptions in *Built-in Exceptions*. For example, a RuntimeError is something you should not bother catching.

18.7 Exception Attributes

Exceptions have one interesting attribute. In the following example, we'll assume we have an exception object named *e*. This would happen inside an **except** clause that looked like 'except SomeException, e:'.

Traditionally, exceptions had a message attribute as well as an args attribute. These were used inconsistently.

When you create a new Exception instance, the argument values provided are loaded into the args attribute. If you provide a single value, this will also be available as message; this is a property name that references 'args[0]'.

Here's an example where we provided multiple values as part of our Exception.

```
>>> a=Exception(1,2,3)
>>> a.args
(1, 2, 3)
>>> a.message
__main__:1: DeprecationWarning: BaseException.message has been deprecated as of
Python 2.6
''
```

Here's an example where we provided a single value as part of our Exception; in this case, the message attribute is made available.

```
>>> b=Exception("Oh dear")
>>> b.message
'Oh dear'
```

```
>>> b.args
('Oh dear',)
```

18.8 Built-in Exceptions

The following exceptions are part of the Python environment. There are three broad categories of exceptions.

- Non-error Exceptions. These are exceptions that define events and change the sequence of execution.
- Run-time Errors. These exceptions can occur in the normal course of events, and indicate typical program problems.
- Internal or Unrecoverable Errors. These exceptions occur when compiling the Python program or are part of the internals of the Python interpreter; there isn't much recovery possible, since it isn't clear that our program can even continue to operate. Problems with the Python source are rarely seen by application programs, since the program isn't actually running.

Here are the non-error exceptions. Generally, you will never have a handler for these, nor will you ever raise them with a **raise** statement.

exception `StopIteration`
This is raised by an iterator when there is no next value. The **for** statement handles this to end an iteration loop cleanly.

exception `GeneratorExit`
This is raised when a generator is closed by having the `close()` method evaluated.

exception `KeyboardInterrupt`
This is raised when a user hits `ctrl-C` to send an interrupt signal to the Python interpreter. Generally, this is not caught in application programs because it's the only way to stop a program that is misbehaving.

exception `SystemExit`
This exception is raised by the `sys.exit()` function. Generally, this is not caught in application programs; this is used to force a program to exit.

Here are the errors which can be meaningfully handled when a program runs.

exception `AssertionError`
Assertion failed. See the **assert** statement for more information in *The assert Statement*

exception `AttributeError`
Attribute not found in an object.

exception `EOFError`
Read beyond end of file.

exception `FloatingPointError`
Floating point operation failed.

exception `IOError`
I/O operation failed.

exception `IndexError`
Sequence index out of range.

exception `KeyError`
Mapping key not found.

exception `OSError`
OS system call failed.

exception `OverflowError`
Result too large to be represented.

exception `TypeError`
Inappropriate argument type.

exception `UnicodeError`
Unicode related error.

exception `ValueError`
Inappropriate argument value (of correct type).

exception `ZeroDivisionError`
Second argument to a division or modulo operation was zero.

The following errors indicate serious problems with the Python interepreter. Generally, you can't do anything if these errors should be raised.

exception `MemoryError`
Out of memory.

exception `RuntimeError`
Unspecified run-time error.

exception `SystemError`
Internal error in the Python interpreter.

The following exceptions are more typically returned at compile time, or indicate an extremely serious error in the basic construction of the program. While these exceptional conditions are a necessary part of the Python implementation, there's little reason for a program to handle these errors.

exception `ImportError`
Import can't find module, or can't find name in module.

exception `IndentationError`
Improper indentation.

exception `NameError`
Name not found globally.

exception `NotImplementedError`
Method or function hasn't been implemented yet.

exception `SyntaxError`
Invalid syntax.

exception `TabError`
Improper mixture of spaces and tabs.

exception `UnboundLocalError`
Local name referenced but not bound to a value.

The following exceptions are part of the implementation of exception objects. Normally, these never occur directly. These are generic categories of exceptions. When you use one of these names in a **catch** clause, a number of more more specialized exceptions will match these.

exception `Exception`
Common base class for all user-defined exceptions.

exception StandardError
Base class for all standard Python errors. Non-error exceptions (StopIteration, GeneratorExit, KeyboardInterrupt and SystemExit) are not subclasses of StandardError.

exception ArithmeticError
Base class for arithmetic errors. This is the generic exception class that includes OverflowError, ZeroDivisionError, and FloatingPointError.

exception EnvironmentError
Base class for errors that are input-output or operating system related. This is the generic exception class that includes IOError and OSError.

exception LookupError
Base class for lookup errors in sequences or mappings, it includes IndexError and KeyError.

18.9 Exception Exercises

1. **Input Helpers**. There are a number of common character-mode input operations that can benefit from using exceptions to simplify error handling. All of these input operations are based around a loop that examines the results of raw_input and converts this to expected Python data.

   All of these functions should accept a prompt, a default value and a help text. Some of these have additional parameters to qualify the list of valid responses.

   All of these functions construct a prompt of the form:

   ```
   your prompt [ valid input hints ,?,q]:
   ```

   If the user enters a ?, the help text is displayed. If the user enters a q, an exception is raised that indicates that the user quit. Similarly, if the KeyboardInterrupt or any end-of-file exception is received, a user quit exception is raised from the exception handler.

   Most of these functions have a similar algorithm.

User Input Function

(a) **Construct Prompt**. Construct the prompt with the hints for valid values, plus '?' and 'q'.

(b) **While Not Valid Input**. Loop until the user enters valid input.

Try the following suite of operations.

Prompt and Read. Use raw_input() to prompt for and read a reply from the user.

Help?. If the user entered "?", provide the help message.

Quit?. If the user entered "q" or "Q", raise a UserQuit exception.

Other. Try the following suite of operations

Convert. Attempt any conversion. Some inputs will involve numeric, or date-time conversions.

Validate. If necessary, do any validation checks checks. For some prompts, there will be a fixed list of valid answers. There may be a numeric range or a date range. For other prompts, there is no checking required.

If the input passes the validation, break out of the loop. This is our hoped-for answer.

In the event of an exception, the user input was invalid.

Nothing?. If the user entered nothing, and there is a default value, return the default value.

In the event of any other exceptions, this function should generally raise a `UserQuit` exception.

(c) **Result**. Return the validated user input.

Functions to implement

ckdate Prompts for and validates a date. The basic version would require dates have a specific format, for example mm/dd/yy. A more advanced version would accept a `string` to specify the format for the input. Much of this date validation is available in the `time` module, which will be covered in *Dates and Times: the time and datetime Modules*. This function not return bad dates or other invalid input.

ckint Display a prompt; verify and return an integer value

ckitem Build a menu; prompt for and return a menu item. A menu is a numbered list of alternative values, the user selects a value by entering the number. The function should accept a sequence of valid values, generate the numbers and return the actual menu item `string`. An additional help prompt of `"??"` should be accepted, this writes the help message and redisplays the menu.

ckkeywd Prompts for and validates a keyword from a list of keywords. This is similar to the menu, but the prompt is simply the list of keywords without numbers being added.

ckpath Display a prompt; verify and return a pathname. This can use the os.path module for information on construction of valid paths. This should use fstat to check the user input to confirm that it actually exists.

ckrange Prompts for and validates an integer in a given range. The range is given as separate values for the lowest allowed and highest allowed value. If either is not given, then that limit doesn't apply. For instance, if only a lowest value is given, the valid input is greater than or equal to the lowest value. If only a highest value is given, the input must be less than or equal to the highest value.

ckstr Display a prompt; verify and return a `string` answer. This is similar to the basic `raw_input()`, except that it provides a simple help feature and raises exceptions when the user wants to quit.

cktime Display a prompt; verify and return a time of day. This is similar to ckdate; a more advanced version would use the time module to validate inputs. The basic version can simply accept a '`hh:mm:ss`' time `string` and validate it as a legal time.

ckyorn Prompts for and validates yes/no. This is similar to ckkeywd, except that it tolerates a number of variations on yes (YES, y, Y) and a number of variations on no (NO, n, N). It returns the canonical forms: Y or N irrespective of the input actually given.

18.10 Style Notes

Built-in exceptions are all named with a leading upper-case letter. This makes them consistent with class names, which also begin with a leading upper-case letter.

Most modules or classes will have a single built-in exception, often called `Error`. This exception will be imported from a module, and can then be qualified by the module name. Modules and module qualification is covered in *Components, Modules and Packages*. It is not typical to have a complex hierarchy of exceptional conditions defined by a module.

18.11 A Digression

Readers with experience in other programming languages may equate an exception with a kind of **goto** statement. It changes the normal course of execution to a (possibly hard to find) exception-handling suite. This is a correct description of the construct, which leads to some difficult decision-making.

Some exception-causing conditions are actually predictable states of the program. The notable exclusions are I/O Error, Memory Error and OS Error. These three depend on resources outside the direct control of the running program and Python interpreter. Exceptions like Zero Division Error or Value Error can be checked with simple, clear **if** statements. Exceptions like Attribute Error or Not Implemented Error should never occur in a program that is reasonably well written and tested.

Relying on exceptions for garden-variety errors – those that are easily spotted with careful design or testing – is often a sign of shoddy programming. The usual story is that the programmer received the exception during testing and simply added the exception processing **try** statement to work around the problem; the programmer made no effort to determine the actual cause or remediation for the exception.

In their defense, exceptions can simplify complex nested **if** statements. They can provide a clear "escape" from complex logic when an exceptional condition makes all of the complexity moot. Exceptions should be used sparingly, and only when they clarify or simplify exposition of the algorithm. A programmer should not expect the reader to search all over the program source for the relevant exception-handling clause.

Future examples, which use I/O and OS calls, will benefit from simple exception handling. However, exception laden programs are a problem to interpret. Exception clauses are relatively expensive, measured by the time spent to understand their intent.

CHAPTER

NINETEEN

ITERATORS AND GENERATORS

The yield Statement

We've made extensive use of the relationship between the **for** statement and various kinds of *iterable* containers without looking too closely at how this really works.

In this chapter, we'll look at the semantics of iterators in *Iterator Semantics*; this includes their close relationshp to an iterable container, and the **for** statement. We can then look at the semantics of generator functions in *Generator Function Semantics*, and talk about the syntax for defining a generator function in *Defining a Generator Function*.

We'll look at other built-in functions we use with iterators in *Generator Functions*.

We'll review statements related to the use of iterators in *Generator Statements*.

We'll provide more places where iterators are used in *Iterators Everywhere*, as well as an in-depth example in *Generator Function Example*.

When we see how to define our own classes of objects, we'll look at creating our own iterators in *Creating or Extending Data Types*.

19.1 Iterator Semantics

The easiest way to define an iterator (and the closely-related concept of generator function) is to look at the **for** statement. The **for** statement makes use of a large number of iterator features. This statement is the core use case for iterators, and we'll use it to understand the interface an iterator must provide.

Let's look at the following snippet of code.

```
for i in ( 1, 2, 3, 4, 5 ):
    print i
```

Under the hood, the **for** statement engages in the following sequence of interactions with an iterable object (the `tuple (1,2,3,4,5)`).

1. The **for** statement requests an iterator from the object. The **for** statement does this by evaluating the `iter()` function on the object in the **in** clause.

   The working definition of *iterable* is that the object responds to the `iter()` function by returning an iterator. All of the common containers (`str`, `list`, `tuple`, `dict`, `set`) will respond to the `iter()` function by returning an iterator over the items in the container. A `dict` iterator will yield the keys in the mapping.

2. The **for** statement uses the `next()` function to evaluate the the iterator's `next()` method and assigns the resulting object to the target variable. In this case, the variable `i` is assigned to each object.
3. The **for** statement evaluates the suite of statements. In this case, the suite is just a **print** statement.
4. The **for** statement continues steps 2 and 3 until an exception is raised.

   If the exception is a `StopIteration`, this is handled to indicate that the loop has finished normally.

The **for** statement is one side of the interface; the other side is the iterator object itself. From the above scenario, we can see that an iterator must define a `__next__()` method that the **for** statement can use. This method does one of two things.

- Returns the next item from a sequence (or other container) or
- Raises the `StopIteration` exception.

To do this, an iterator must also maintain some kind of internal state to know which item in the sequence will be delivered next.

When we describe a container as iterable, we mean that it responds to the built-in `iter()` function by returning an iterator object that can be used by the **for** statement. All of the sequence containers return iterators; `set`, `dict` and files also return iterators. In the case of a `dict`, the iterator returns the `dict` keys in no particular order.

Iterators in Python. As noted above, all of the containers we've seen so far have the iterable interface. This means that the container will return an iterator object that will visit all the elements (or keys) in the container.

It turns out that there are many other uses of iterators in Python. Many of the functions we've looked at work with iterators.

We'll return to this in *Iterators Everywhere*.

Defining Our Own Iterators. There are two ways to define our own iterators. We can create an object that has the iterator interface, or we can define a generator function. Under the hood, a generator function will have the iterator interface, but we're saved from having to create a class with all the right method function names.

We'll look at Generator Functions in *Generator Function Semantics*.

We'll look at defining an Iterator class in *Data + Processing = Objects*.

19.2 Generator Function Semantics

A generator function is a function that can be used by the **for** statement as if it were an iterator. A generator looks like a conventional function, with one important difference: a generator includes the **yield** statement.

The essential relationship between a generator function and the **for** statement is the following.

1. The **for** statement calls the generator. The generator begins execution and executes statements in the suite up to the first **yield** statement. The **yield** creates the initial value for the **for** statement to assign.
2. The **for** statement applies the built-in `next()` function to the generator function's hidden `next()` method. The value that was returned by the **yield** statement is assigned to the target variable.
3. The **for** statement evaluates it's suite of statements.
4. The **for** statement applies the built-in `next()` function to the generator function's hidden `next()` method. The generator resumes execution after the **yield** statement. When the generator function gets to another **yield** statement, this value creates a value for the **for** statement.

5. The **for** statement continues steps 3 and 4 until the generator executes a **return** statement (or runs past the end of it's suite). Either situation will raise the `StopIteration` exception.

   When a `StopIteration` is raised, it is handled by the **for** statement as a normal termination of the loop.

What we Provide. Generator function definition is similar to function definition (see *Functions*). We provide three pieces of information: the name of the generator, a list of zero or more parameters, and a suite of statements that yields the output values. The suite of statements must include at least one **yield** statement.

We evaluate a generator in a **for** statement by following the function's name with '`()`' enclosing any argument values. The Python interpreter evaluates the argument values, then applies the generator. This will start execution of the the generator's suite.

Once the generator has started, the generator and the **for** statement pass control back and forth. The generator will yield objects and the **for** statement consumes those objects.

This back-and-forth between the **for** statement and the generator means that the generator's local variables are all preserved. In other words, a generator function has a peer relationship with the **for** statement; it's local variables are kept when it yields a value. The **for** suite and the generator suite could be called *coroutines*.

Example: Using a Generator to Consolidate Information. Lexical scanning and parsing are both tasks that compilers do to discover the higher-level constructs that are present in streams of lower-level elements. A lexical scanner discovers punctuation, literal values, variables, keywords, comments, and the like in a file of characters. A parser discovers expressions and statements in a sequence of lexical elements.

Lexical scanning and parsing algorithms *consolidate* a number of characters into tokens or a number of tokens into a statement. A characteristic of these algorithms is that some state change is required to consolidate the inputs prior to creating each output. A generator provides these characteristics by preserving the generator's state each time an output is yielded.

In both lexical scanning and parsing, the generator function will be looping through a sequence of input values, discovering a high-level element, and then yielding that element. The **yield** statement returns the sequence of results from a generator function, and also saves all the local variables, and even the location of the **yield** statement so that the generator's next request will resume processing right after the **yield** .

19.3 Defining a Generator Function

The presence of the **yield** statement in a function means that the function is actually a generator object, and will have the an iterator-like interface built automatically. In effect it becomes a stateful object with a `next()` method defined – so it will work with the `next()` function and **for** statement – and it will raise the `StopIteration` exception when it returns.

The syntax for a function definition is in *Function Definition: The def and return Statements* ; a generator is similar.

```
def name ( parameter ⟨, ... ⟩ ):
    suite
```

The suite of statements must include at least one **yield** statement.

The **yield** statement specifies the values emitted by the generator. Note that the expression is required.

```
yield expression
```

If a **return** statement is used in the function, it ends the generator by raising the `StopIteration` exception to alert the **for** statement. For obvious reasons, the **return** statement cannot return a value.

Here's a complete, but silly example of a generator.

```
def primes():
    yield 2
    yield 3
    yield 5
    yield 7
    yield 11
    return
```

In this case, we simply yield a fixed sequence of values. After yielding five values, it exits. Here's how this generator is used by a **for** statement.

```
>>> for p in primes():
...     print p
2
3
5
7
11
```

19.4 Generator Functions

The `iter()` function can be used to acquire an iterator object associated with a container like a sequence, `set`, file or `dict`. We can then manipulate this iterator explicitly to handle some common situations.

`iter`(*iterable*)
: Returns the iterator for an object. This iterator interacts with built-in types in obvious ways. For sequences, this will return each element in order. For `set`s, it will return each element in no particular order. For dictionaries, it will return the keys in no particular order. For files, it will return each line in order.

Gettimg an explicit iterator – outside a **for** statement – is handy for dealing with data structures (like files) which have a head-body structure. In this case, there are one or more elements (the head) which are processed one way and the remaining elements (the body) which are processed another way.

We'll return to this in detail in *Files*. For now, here's a small example.

```
>>> someSeq = range(2,20,2)
>>> seq_iter = iter(someSeq)
>>> next(seq_iter)
2
>>> for value in seq_iter:
...     print value,
...
4 6 8 10 12 14 16 18
```

1. We create a sequence, `someSeq`. Any iterable object would work here; any sequence, `set`, `dict` or file.
2. We create the iterator for this sequence, and assign it to `seq_iter`. This object has a `next()` method which is used by the `next()` function and the **for** statement.
3. We call '`next(seq_iter)`' explicitly to get past one heading item in the sequence.

4. We then provide the iterator to the **for** statement. The **for** statement repeatedly evaluates the `next()` function on the iterator object and executes its suite of statements.

19.5 Generator Statements

What the for statement really does

In *Iterative Processing: The for Statement*, we defined a for statement using the following summary:

```
for variable in iterable :
    suite
```

We glossed over the *iterable*, showing how to create simple sequence objects using the `range()` function or explicit list literals.

At this point, we can use a number of data structures that are "iterable": they respond the the `iter()` function by creating an iterator.

Also, we can define generator functions, which are also iterable.

The Secret World of for. Once we've looked at generator functions and iterators, we can see what the **for** statement really does. The purpose of the **for** statement is to visit each value yielded by an iterator, assigning each value to the *variable*.

Note that there are two parts to this.

First, the '`for variable in object`' evalates '`iter(object)`' to get an iterator. Objects will return an an iterator all primed and ready to yield. A generator function will – effectively – return itself, all primed and ready to yield.

Second, the iterator object (or generator function) must yield a sequence of values.

Looking forward, we'll see many additional applications of the way the **for** statement works. As we look at designing our own objects in *Data + Processing = Objects*, we'll want to assure that our objects work well with the **for** statement, also.

19.6 Iterators Everywhere

Iterators are ubiquitous. We have – up to this point – been breezy and casual about all the places iterators are used.

We've looked at many functions (`max()`, `min()`, `any()`, `all()`, `sum()`, `sorted()`, `reversed()`, and `enumerate()`) which apply to all the various container classes. Actually, these functions all apply to iterators and our containers return the iterators these functions expect.

As a simple example, we can define our own version of `enumerate()`.

```
def enumerate( iterable, start=0 ):
    for item in iterable:
        yield start, item
        start += 1
```

That's all that's required to write a function which works with an iterable, and is itself an iterator. This style of programming is called *functional*, and is beyond the scope of this book.

Additionally, we've looked at the `range()` function without looking too closely at it's sibling `xrange()`.

Important: Python 3 and Range

In Python 3, the `range()` function – which created a list object – will be replaced with an iterator.

To create a list object, you'll do this

```
someList = list( range( 6 ) )
```

In effect, the `xrange()` iterator will be renamed `range()`. The legacy `range()` function will go away.

It turns out that we've been making heavy use of iterators. Functions like `sorted()`, `reversed()`, `any()`, `all()`, and `sum()` all work with iterators not simply list objects.

We'll look at how to create our own iterator objects in *Collection Special Method Names for Iterators and Iterable*.

19.7 Generator Function Example

Let's look at an example which summarizes some details, yielding the summaries. Assume we have the `list` of `tuple`s named `spins`. We want to know how many red spins separate a pair of black spins, on average. We need a function which will yield the count of gaps as it examines the spins. We can then call this function repeatedly to get the gap information.

generator.py

```
spins = [('red', '18'), ('black', '13'), ('red', '7'),
    ('red', '5'), ('black', '13'), ('red', '25'),
    ('red', '9'), ('black', '26'), ('black', '15'),
    ('black', '20'), ('black', '31'), ('red', '3')]

def countReds( aList ):
    count= 0
    for color,number in aList:
        if color == 'black':
            yield count
            count= 0
        else:
            count += 1
    yield count

gaps= [ gap for gap in countReds(spins) ]
print gaps
```

1. The `spins` variable defines our sample data. This might be an actual record of spins.
2. We define our `gapCount()` function. This function initializes `count` to show the number of non-black's before a black. It then steps through the individual spins, in the order presented. For non-black's, the count is incremented.
3. For black spins, however, we yield the length of the gap between the last black. When we yield a result, the generator produces a result value, and also saves all the other processing information about this function so that it can be continued from this point.

   When the function is continued, it resumes right after the **yield** statement: the count will be reset, and the **for** loop will advance to examine the next number in the sequence.

4. When the sequence is exhausted, we also yield the final count. The first and last gap counts may have to be discarded for certain kinds of statistical analysis.

5. This `gaps` statement shows how we use the generator. In this case, we create a list comprehension from the results; the **for** clause will step through the values yielded by the generator until the it exits normally. This sequence of values is collected into a `list` that we can the use for statistical analysis.

19.8 Generator Exercises

1. **The Sieve of Eratosthones (Again)**. Look at *The Sieve of Eratosthones* and *The Sieve of Eratosthones*. We created a `list` or a `set` of candidate prime numbers.

   This exercise has three parts: initialization, generating the `list` (or `set`) or prime numbers, then reporting. In the `list` version, we had to filter the sequence of boolean values to determine the primes. In the `set` version, the `set` contained the primes.

   Within the *Generate* step, there is a point where we know that the value of `p` is prime. At this point, we can yield p. If we yield each value as we discover it, we eliminate the entire "report" step from the function.

2. **The Generator Version of `range()`**. The `range()` function creates a sequence. For very large sequences, this consumes a lot of memory. You can write a version of range which does not create the entire sequence, but instead yields the individual values. Using a generator will have the same effect as iterating through a sequence, but won't consume as much memory.

   Define a generator, `genrange()`, which generates the same sequence of values as `range()`, without creating a `list` object.

   Check the documentation for the built-in function `xrange()`.

3. **Prime Factors**. There are two kinds of positive numbers: prime numbers and composite numbers. A composite number is the product of a sequence of prime numbers. You can write a simple function to factor numbers and yield each prime factor of the number.

   Your `factor()` function can accept a number, `n`, for factoring. The function will test values, `f`, between 2 and the square root of `n` to see if the expression '`n % f == 0`' is true. If this is true. then the factor, `f`, divides `n` with no remainder; `f` is a factor.

   Don't use a simple-looking **for** -loop; the prime factor of 128 is 2, repeated 7 times. You'll need to use a **while** loop.

CHAPTER

TWENTY

FILES

The 'file' Class; The with Statement

Programs often deal with external data; data outside of volatile primary memory. This external data could be persistent data on a file system or transient data on an input-output device. Most operating systems provide a simple, uniform interface to external data via objects of the `file` class.

In *File Semantics*, we provide an overview of the semantics of files. We cover the most important of Python's built-in functions for working with files in *Built-in Functions*. We'll review statements for dealing with files in *File Statements*. In *File Methods*, we describe some method functions of file objects.

Files are a deep, deep subject. We'll touch on several modules that are related to managing files in *Components, Modules and Packages*. These include *File Handling Modules* and *File Formats: CSV, Tab, XML, Logs and Others*.

20.1 File Semantics

In one sense a file is a container for a sequence of bytes. A more useful view, however, is that a `file` is a container of data objects, encoded as a sequence of bytes. Files can be kept on persistent but slow devices like disks. Files can also be presented as a stream of bytes flowing through a network interface. Even the user's keyboard can be processed as if it was a file; in this case the file forces our software to wait until the person types something.

Our operating systems use the abstraction of *file* as a way to unify access to a large number of devices and operating system services. In the Linux world, all external devices, plus a large number of in-memory data structures are accessible through the file interface. The wide variety of things with file-like interfaces is a consequence of how Unix was originally designed. Since the number and types of devices that will be connected to a computer is essentially infinite, device drivers were designed as a simple, flexible plug-in to the operating system. For more information on the ubiquity of files, see *Additional Background*.

Files include more than disk drives and network interfaces. Kernel memory, random data generators, semaphores, shared memory blocks, and other things have file interfaces, even though they aren't – strictly speaking – devices. Our OS applies the file abstraction to many things. Python, similarly, extends the file interface to include certain kinds of in-memory buffers.

All GNU/Linux operating systems make all devices available through a standard file-oriented interface. Windows makes most devices available through a reasonably consistent file interface. Python's `file` class provides access to the OS file API's, giving our applications the same uniform access to a variety of devices.

Important: Terminology

The terminology is sometimes confusing. We have physical files on our disk, the file abstraction in our operating system, and `file` objects in our Python program. Our Python `file` object makes use of the operating system file API's which, in turn, manipulate the files on a disk.

We'll try to be clear, but with only one overloaded word for three different things, this chapter may sometimes be confusing.

We rarely have a reason to talk about a physical file on a disk. Generally we'll talk about the OS abstraction of file and the Python class of `file`.

Standard Files. Consistent with POSIX standards, all Python programs have three files available: `sys.stdin`, `sys.stdout`, `sys.stderr`. These files are used by certain built-in statements and functions. The **print** statement (and `print()` function), for example, writes to `sys.stdout` by default. The `raw_input()` function writes the prompt to `sys.stdout` and reads the input from `sys.stdin`.

These standard files are always available, and Python assures that they are handled consistently by all operating systems. The `sys` module makes these files available for explict use. Newbies may want to check *File Redirection for Newbies* for some additional notes on these standard files.

File Redirection for Newbies

The presence of a standard input file and two standard output files is a powerful tool for simplifying programs and making them more reusable. Programs which read from standard input and write to standard output can be combined into processing sequences, called pipelines. The POSIX-standard syntax for creating a pipeline is shown below.

```
$ ./step1.py <source.dat | ./step2.py >result.dat
```

This pipeline has two steps: `step1.py` reads input from stdin and writes to stdout. We've told the shell to redirect stdin so that it reads the file `source.dat`. We've also told the shell to connect `step1.py` standard output to `step2.py` standard input. We've also redirected `step2.py` standard output to a file, `result.dat`.
We can simplify our programs when we make the shell responsible for file name and pipeline connections.

20.2 File Organization and Structure

Some operating systems provide support for a large variety of file organizations. Different file organizations will include different record termination rules, possibly with record keys, and possibly fixed length records. The POSIX standard, however, considers a file to be nothing more than a sequence of bytes. It becomes entirely the job of the application program, or libraries outside the operating system to impose any organization on those bytes.

The basic `file` objects in Python consider a file to be a sequence of text characters (ASCII or Unicode) or bytes. The characters can be processed as a sequence of variable length lines; each line terminated with a newline character. Files moved from a Windows environment may contain lines which appear to have an extraneous ASCII carriage return character (`\r`), which is easily removed with the `string strip()` method.

Ordinary text files can be managed directly with the built-in `file` objects and their methods for reading and writing lines of data. We will cover this basic text file processing in the rest of this chapter.

Files which are a sequence of bytes don't – properly – have line boundaries. Byte-oriented files could include characters (in ASCII or a Unicode encoding) or other data objects encoded as bytes. We'll address some byte-oriented files with library modules like `pickle` and `csv`.

20.3 Additional Background

The GNU/Linux view of files can be surprising for programmers with a background that focuses on mainframe Z/OS or Windows. This is additional background information for programmers who are new to the POSIX use of the file abstraction. This POSIX view informs how Python works.

In the Z/OS world, files are called *data sets*, and can be managed by the OS catalog or left uncataloged. Uncataloged data sets are fairly common.

In the GNU/Linux world, the catalog (called a directory) is seamless, silent and automatic. Files are almost always cataloged In the GNU/Linux world, uncataloged, temporary files are atypical, rarely used, and require a special API call.

In the Z/OS world, files are generally limited to disk files and nothing else. This is different from the GNU/Linux use of file to mean almost any kind of external device or service.

Block Mode Files. File devices can be organized into two different kinds of structures: *block mode* and *character mode*. Block mode devices are exemplified by magnetic disks: the data is structured into blocks of bytes that can be accessed in any order. Both the media (disk) and read-write head can move; the device can be repositioned to any block as often as necessary. A disk provides direct (sometimes also called random) access to each block of data.

Character mode devices are exemplified by network connections: the bytes come pouring into the processor buffers. The stream cannot be repositioned. If the buffer fills up and bytes are missed, the lost data are gone forever.

Operating system support for block mode devices includes file directories and file management utilities for deleting, renaming and copying files. Modern operating systems include file navigators (Finders or Explorers), iconic representations of files, and standard GUI dialogs for opening files from within application programs. The operating system also handles moving data blocks from memory buffers to disk and from disk to memory buffers. All of the device-specific vagaries are handled by having a variety of *device drivers* so that a range of physical devices can be supported in a uniform manner by a single operating system software interface.

Files on block mode devices are sometimes called *seekable*. They support the operating system `seek()` function that can begin reading from any byte of the file. If the file is structured in fixed-size blocks or records, this seek function can be very simple and effective. Typically, database applications are designed to work with fixed-size blocks so that seeking is always done to a block, from which database rows are manipulated.

Character Mode Devices and Keyboards. Operating systems also provide rich support for character mode devices like networks and keyboards. Typically, a network connection requires a *protocol stack* that interprets the bytes into packets, and handles the error correction, sequencing and retransmission of the packets. One of the most famous protocol stacks is the TCP/IP stack. TCP/IP can make a streaming device appear like a sequential file of bytes. Most operating systems come with numerous client programs that make heavy use of the netrowk, examples include sendmail, ftp, and a web browser.

A special kind of character mode file is the *console*; it usually provides input from the keyboard. The POSIX standard allows a program to be run so that input comes from files, pipes or the actual user. If the input file is a *TTY* (teletype), this is the actual human user's keyboard. If the file is a pipe, this is a connection to another process running concurrently. The keyboard console or TTY is different from ordinary character mode devices, pipes or files for two reasons. First, the keyboard often needs to explicitly echo characters back so that a person can see what they are typing. Second, pre-processing must often be done to make backspaces work as expected by people.

The echo feature is enabled for entering ordinary data or disabled for entering passwords. The echo feature is accomplished by having keyboard events be queued up for the program to read as if from a file. These same keyboard events are automatically sent to update the GUI if echo is turned on.

The pre-processing feature is used to allow some standard edits of the input before the application program receives the buffer of input. A common example is handling the backspace character. Most experienced computer users expect that the backspace key will remove the last character typed. This is handled by the OS: it buffers ordinary characters, removes characters from the buffer when backspace is received, and provides the final buffer of characters to the application when the user hits the Return key. This handling of backspaces can also be disabled; the application would then see the keyboard events as *raw* characters. The usual mode is for the OS to provide *cooked* characters, with backspace characters handled before the application sees any data.

Typically, this is all handled in a GUI in modern applications. However, Python provides some functions to interact with Unix TTY console software to enable and disable echo and process raw keyboard input.

File Formats and Access Methods. In Z/OS (and Open VMS, and a few other operating systems) files have very specific formats, and data access is mediated by the operating system. In Z/OS, they call these *access methods*, and they have names like BDAM or VSAM. This view is handy in some respects, but it tends to limit you to the access methods supplied by the OS vendor.

The GNU/Linux view is that files should be managed minimally by the operating system. At the OS level, files are just bytes. If you would like to impose some organization on the bytes of the file, your application should provide the access method. You can, for example, use a database management system (DBMS) to structure your bytes into tables, rows and columns.

The C-language standard I/O library (stdio) can access files as a sequence of individual lines; each line is terminated by the newline character, '`n`' . Since Python is built in the C libraries, Python can also read files as a sequence of lines.

20.4 Built-in Functions

There are two built-in functions that create a new file or open an existing file.

`open`(*filename, [mode], [buffering]*)
: Create a Python file object associated with an operating system file. `filename` is the name of the file. `mode` can be 'r', 'w' or 'a' for reading (default), writing or appending. The file will be created if it doesn't exist when opened for writing or appending; it will be truncated when opened for writing. Add a 'b' to the mode for binary files. Add a '+' to the mode to allow simultaneous reading and writing. If the `buffering` argument is given, 0 means unbuffered, 1 means line buffered, and larger numbers specify the buffer size.

`file`(*filename, [mode], [buffering]*)
: Does the same thing as the `open()`. This is present so that the name of this factory function matches the class of the object being created.

  The `open()` function is more descriptive of what is really going on in the program.

  The `file()` function is used for type comparisons.

Creating File Name Strings. A filename string can be given as a standard name, or it can use OS-specific punctuation. The standard is to use '`/`' to separate elements of a file path; Python can do OS-specific translation.

Windows, however, uses '\' for most levels of the path, but has a leading device character separated by a '`:`' .

Rather than force your program to implement the various operating system punctuation rules, Python provides modules to help you construct and process file names. The `os.path` module should be used to construct file names. Best practice is to use the `os.path.join()` function to make file names from sequences of `strings`. We'll look at this in *File Handling Modules*.

The `filename` string can be a simple file name, also called a *relative path* `string`, where the OS rules of applying a current working directory are used to create a full, absolute path. Or the filename `string` can be a full *absolute path* to the file.

File Mode Strings. The `mode` string specifies how the file will be accessed by the program. There are three separate issues addressed by the mode `string`: opening, text handling and operations.

- **Opening**. For the opening part of the mode string, there are three alternatives:

  'r' Open for reading. Start at the beginning of the file. If the file does not exist, raise an `IOError` exception. This is implied if nothing else is specified.

  'w' Open for writing. Start at he beginning of the file, overwriting an existing file. If the file does not exist, create the file.

  'a' Open for appending. Start at the end of the file. If the file does not exist, create the file.

- **Text Handling**. For the text handling part of the mode string, there are two alternatives:

  'b' Interpret the file as bytes, not text.

  (nothing) The default, if nothing is specified is to interpret the content as text: a sequence of characters with newlines at the end of each line.

  'U' The capital 'U' mode (when used with 'r') enables "universal newline" reading. This allows your program to cope with the non-standard line-ending characters present in some Windows files. The standard end-of-line is a single newline character, `\n`. In Windows, an additional `\r` character may also be present.

- **Operations**. For the additional operations part of the mode `string`, there are two alternatives:

  '+' Allow both read and write operations.

  (nothing) If nothing is specified, allow only reads for files opened with "r"; allow only writes for files opened with "w" or "a".

Typical combinations include `"rb"` to read data as bytes and `"w+"` to create a text file for reading and writing.

Examples. The following examples create file objects for further processing:

```
myLogin = open( ".login", "r" )
newSource = open( "somefile.c", "w" )
theErrors = open( "error.log", "a" )
someData = open( 'source.dat', 'rb' )
```

myLogin A text file, opened for reading.

newSource A text file, opened for writing. If the file exists, it is overwritten.

theErrors A text file, opened for appending. If the file doesn't exist, it's created.

someData A binary file, opened for reading.

Buffering files is typically left as a default, specifying nothing. However, for some situations buffering can improve performance. Error logs, for instance, are often unbuffered, so the data is available immediately. Large input files may have large buffer numbers specified to encourage the operating system to optimize input operations by reading a few large chunks of data instead of a large number of smaller chunks.

20.5 File Statements

There are a number of statements that have specific features related to `tuple` objects.

The for Statement. Principally, we use the **for** statement to work with files. Text files are iterable, making them a natural fit with the **for** statement.

The most common pattern is the following:

```
source = open( "someFile.txt", "r" )
for line in source:
    # process line
source.close()
```

Additionally, we use the **with** statement with files. This assures that we have – without exception – closed the file when we're done using it.

The with Statement. The **with** statement is used to be absolutely sure that we have closed a file (or other resource) when we're done using it.

The **with** statement uses an object called a "context manager". This manager object can be assigned to a temporary variable and used in the **with** statement's suite. See *Managing Contexts: the with Statement* for more information on creating a context manager.

The two central features are

1. The context manager will be closed at the end of the **with** statement. This is guaranteed, irrespective of any exceptions that are raised.
2. A `file` is a context manager. It will be closed.

with Statement Syntax. The **with** statement has the following syntax.

```
with expression as variable :
    suite
```

A `file` object conforms to the context manager interface. It has an `__enter__()` and a `__exit__()` method. It will be closed at the end of the **with** statement.

Generally, we use this as follows.

```
with file("somefile","r") as source:
    for line in source:
        print line
```

At the end of the **with** statement, irrespective of any exceptions which are handled – or not handled – the file will be closed and the relevant resources released.

20.6 File Methods

The built-in `file()` function creates a `file` object. The resulting object has a number of operations that change the state of the file, read or write data, or return information about the file.

Read Methods. The following methods read from a file. As data is read, the file position is advanced from the beginning to the end of the file. The file must be opened with a mode that includes or implies `'r'` for these methods to work.

`read`(*[size]*)
: Read as many as `size` characters or bytes from the file. If `size` is negative or omitted, the rest of the file is read.

`readline`(*[size]*)
: Read the next line. If `size` is negative or omitted, the next complete line is read. If the `size` is given and positive, read as many as `size` characters from the file; an incomplete line can be read.

  If a complete line is read, it includes the trailing newline character, `\n`. If the file is at the end, this will return a zero length `string`.

  If the file has a blank line, the blank like will be a `string` of length 1 (the newline character at the end of the line.)

`readlines`(*[hint]*)
: Read the next lines or as many lines from the next `hint` characters from file. The value of `hint` may be rounded up to match an internal buffer size. If `hint` is negative or omitted, the rest of the file is read. All lines will include the trailing newline character, `\n`. If the file is at the end, this returns a zero length `list`.

Write Methods. The following methods write to a file. As data is written, the file position is advanced, possibly growing the file. If the file is opened for write, the position begins at the beginning of the file. If the file is opened for append, the position begins at the end of the file. If the file does not already exist, both writing and appending are equivalent. The file must be opened with a mode that includes `'a'` or `'w'` for these methods to work.

`flush`()
: Flush all accumulated data from the internal buffers to the OS file. Depending on your OS, this may also force all the data to be written to the device.

`write`(*string*)
: Write the given `string` to the file. Buffering may mean that the string does not appear on any console until a `close()` or `flush()` method is used.

`writelines`(*list*)
: Write the `list` of `string`s to the file. Buffering may mean that the `string`s do not appear on any console until a `close()` or `flush()` operation is used.

`truncate`(*[size]*)
: Truncate the file. If `size` is not given, the file is truncated at the current position. If `size` is given, the file will be truncated at `size`. If the file isn't as large as the given `size`, the results vary by operating system. This function is not available on all platforms.

Position Control Methods. The current position of a file can be examined and changed. Ordinary reads and writes will alter the position. These methods will report the position, and allow you to change the position that will be used for the next operation.

`seek`(*offset, [whence]*)
: Change the position from which the file will be processed. There are three values for `whence` which determine the direction of the move. If `whence` is zero (or omitted), move to the absolute position given by `offset`. '`f.seek(0)`' will rewind file `f`.

  If `whence` is `1`, move relative to the current position by `offset` bytes. If offset is negative, move backwards; otherwise move forward.

  If `whence` is `2`, move relative to the end of file. '`f.seek(0,2)`' will advance file *f* to the end, making it possible to append to the file.

`tell`()
: Return the position from which the file will be processed. This is a partner to the `seek()` method; any

position returned by the `tell()` method can be used as an argument to the `seek()` method to restore the file to that position.

Other Methods. These are additional useful methods of a file object.

`close()`
Close the file, flushing all data. The closed flag is set. Any further operations (except a redundant close) raise an `IOError` exception.

`fileno()`
Return the internal file descriptor (FD) used by the OS library when working with this file. A number of Python modules provide functions that use the OS libraries; the OS libraries need the FD.

`isatty()`
Return `True` if the file is connected to the console or keyboard.

Some handy attributes of a file.

`file.closed -> boolean`
This attribute is `True` if the file is closed.

`file.mode -> string`
This attribute is the mode argument to the `open()` function that was used to create the file object.

`file.name -> string`
This attribute of is the filename argument to the `open()` function that was used to create the file object.

`file.encoding -> string`
This is the encoding for the file. Many Unicode files will have a Byte Order Mark (BOM) that provides the encoding.

20.7 Several Examples

We'll look at four examples of file processing. In all cases, we'll read simple text files. We'll show some traditional kinds of file processing programs and how those can be implemented using Python.

20.7.1 Reading a Text File

The following program will examine a standard unix password file. We'll use the explicit `readline()` method to show the processing in detail. We'll use the `split()` method of the input `string` as an example of parsing a line of input.

readpswd.py

```
pswd = file( "/etc/passwd", "r" )
for aLine in pswd
    fields= aLine.split( ":" )
    print fields[0], fields[1]
pswd.close()
```

1. This program creates a `file` object, `pswd`, that represents the `/etc/passwd` file, opened for reading.
2. A `file` is an iterator over lines of text. We can use a `file` in the **for** statement; the `file` object will return each individual line in response to the `iterator.next()` method.

3. The input string is split into individual fields using :literal>:*":"* boundaries. Two particular fields are printed. Field 0 is the username and field 1 is the password.
4. Closing the file releases any resources used by the file processing.

For non-unix users, a password file looks like the following:

```
root:q.mJzTnu8icF.:0:10:Sysadmin:/:/bin/csh
fred:6k/7KCFRPNVXg:508:10:% Fredericks:/usr2/fred:/bin/csh
```

The ':' separated fields inlcude the user name, password, user id, group id, user name, home directory and shell to run upon login.

20.7.2 Reading a CSV File the Hard Way

This file will have a CSV (Comma-Separated Values) file format that we will parse. The `csv` module does a far better job than this little program. We'll look at that module in *Comma-Separated Values: The csv Module*.

A popular stock quoting service on the Internet will provide CSV files with current stock quotes. The files have comma-separated values in the following format:

```
stock, lastPrice, date, time, change, openPrice, daysHi, daysLo, volume
```

The stock, date and time are typically quoted strings. The other fields are numbers, typically in dollars or percents with two digits of precision. We can use the Python `eval()` function on each column to gracefully evaluate each value, which will eliminate the quotes, and transform a string of digits into a floating-point price value. We'll look at dates in *Dates and Times: the time and datetime Modules*.

This is an example of the file:

```
"^DJI",10623.64,"6/15/2001","4:09PM",-66.49,10680.81,10716.30,10566.55,N/A
"AAPL",20.44,"6/15/2001","4:01PM",+0.56,20.10,20.75,19.35,8122800
"CAPBX",10.81,"6/15/2001","5:57PM",+0.01,N/A,N/A,N/A,N/A
```

The first line shows a quote for an index: the Dow-Jones Industrial average. The trading volume doesn't apply to an index, so it is "N/A". The second line shows a regular stock (Apple Computer) that traded 8,122,800 shares on June 15, 2001. The third line shows a mutual fund. The detailed opening price, day's high, day's low and volume are not reported for mutual funds.

After looking at the results on line, we clicked on the link to save the results as a CSV file. We called it `quotes.csv`. The following program will open and read the `quotes.csv` file after we download it from this service.

readquotes.py

```
qFile= file( "quotes.csv", "r" )
for q in qFile:
    try:
        stock, price, date, time, change, opPrc, dHi, dLo, vol\
        = q.strip().split( "," )
        print eval(stock), float(price), date, time, change, vol
    except ValueError:
        pass
qFile.close()
```

1. We open our quotes file, `quotes.csv`, for reading, creating an object named `qFile`.
2. We use a **for** statement to iterate through the sequence of lines in the file.
3. The quotes file typically has an empty line at the end, which splits into zero fields, so we surround this with a **try** statement. The empty line will raise a `ValueError` exception, which is caught in the **except** clause and ignored.
4. Each stock quote, `q`, is a string. We use the `string.strip()` method to remove whitespace; on the resulting string we use the `string.split()` method to split the string on `","`. This transforms the input string into a list of individual fields.

   We use multiple assignment to assign each field to a relevant variable. Note that we strip this file into nine fields, leading to a long statement. We put a '\' to break the statement into two lines.
5. The name of the stock is a string which includes extra quotes. In order to gracefully remove the quotes, we use the `eval()` function.

   The price is a string. We could also use eval function to evaluate this string as a Python value. Instead, we use the `float()` function to convert the price string to a proper numeric value for further processing.

   As a practical matter, this is a currency value, and we need to use a Decimal value, not a float value. The `decimal` module handles currency very nicely.

20.7.3 Read, Sort and Write

For COBOL expatriates, here's an example that shows a short way to read a file into an in-memory sequence, sort that sequence and print the results. This is a very common COBOL design pattern, and it tends to be rather long and complex in COBOL.

This example looks forward to some slightly more advanced techniques like `list` sorting. We'll delve into sorting in *Functional Programming with Collections*.

sortquotes.py

```
data= []
with file( "quotes.csv", "r" ) as qFile:
    for q in qFile:
        fields= tuple( q.strip().split( "," ) )
        if len(fields) == 9: data.append( fields )
def priceVolume(a):
    return a[1], a[8]
data.sort( key=priceVolume )
for stock, price, date, time, change, opPrc, dHi,  dLo, vol in data:
    print stock, price, date, time, change, volume
```

1. We create an empty sequence, `data`, to which we will append `tuple`s created from splitting each line into fields.
2. We create file object, `qFile` that will read all the lines of our CSV-format file.
3. This **for** loop will set `q` to each line in the file.
4. The variable `fields` is created by stripping whitespace from the line, `q`, breaking it up on the `","` boundaries into separate fields, and making the resulting sequence of field values into a `tuple`.

If the line has the expected nine fields, the `tuple` is appended to the `data`, sequence. Lines with the wrong number of fields are typically the blank lines at the beginning or end of the file.

5. To prepare for the sort, we define a key function. This will extract fields 1 and 8, price and volume.

   If we don't use a key function, the tuple will be sorted by fields in order. The first field is stock name.

6. We can then sort the `data` sequence. Note that the `list.sort()` method does not return a value. It mutates the list.

   The sort method will use our `priceVolume()` function to extract keys for comparing records. This kind of sort is covered in depth in *Advanced List Sorting*.

7. Once the sequence of data elements is sorted, we can then print a report showing our stocks ranked by price, and for stocks of the same price, ranked by volume. We could expand on this by using the % operator to provide a nicer-looking report format.

Note that we aren't obligated to sort the sequence. We can use the `sorted()` function here, also.

```
for stock, price, date, time, change, opPrc, dHi,  dLo, vol \
in sorted( data, key=priceVolume ):
    print stock, price, date, time, change, volume
```

This does not update the `data` list, but is otherwise identical.

20.7.4 Reading "Records"

In languages like C or COBOL a "record" or "struct" will describe the contents of a file. The advantage of a record is that the fields have names instead of numeric positions. In Python, we can acheive the same level of clarity using a `dict` for each line in the file.

For this, we'll download files from a web-based portfolio manager. This portfolio manager gives us stock information in a file called `display.csv`. Here is an example.

```
+/-,Ticker,Price,Price Change,Current Value,Links,# Shares,P/E,Purchase Price,
-0.0400,CAT,54.15,-0.04,2707.50,CAT,50,19,43.50,
-0.4700,DD,45.76,-0.47,2288.00,DD,50,23,42.80,
0.3000,EK,46.74,0.30,2337.00,EK,50,11,42.10,
-0.8600,GM,59.35,-0.86,2967.50,GM,50,16,53.90,
```

This file contains a header line that names the data columns, making processing considerably more reliable. We can use the column titles to create a `dict` for each line of data. By using each data line along with the column titles, we can make our program quite a bit more flexible. This shows a way of handling this kind of well-structured information.

readportfolio.py

```
invest= 0
current= 0
with open( "display.csv", "rU" ) as quotes:
    titles= quotes.next().strip().split( ',' )
    for q in quotes:
        values= q.strip().split( ',' )
        data= dict( zip(titles,values) )
        print data
        invest += float(data["Purchase Price"])*float(data["# Shares"])
```

```
        current += float(data["Price"])*float(data["# Shares"])
print invest, current, (current-invest)/invest
```

1. We open our portfolio file, `display.csv`, for reading, creating a file object named `quotes`.
2. The first line of input, '`varname.next()`', is the set of column titles. We strip any extraneous whitespace characters from this line, and then perform a split to create a `list` of individual column title `str`s. This `list` is tagged with the variable `titles`.
3. We also initialize two counters, `invest` and `current` to zero. These will accumulate our initial investment and the current value of this portfolio.
4. We use a **for** statement to iterate through the remaining lines in `quotes` file. Each line is assigned to `q`.
5. Each stock quote, `q`, is stripped and split to separate the fields into a `list`. We assign this `list` to the variable `values`.
6. We create a `dict`, `data`; the column titles in the `titles` `list` are the keys. The data fields from the current record, in `values` are used to fill this `dict`. The built-in `zip()` function is designed for precisely this situation: it interleaves values from each `list` to create a new `list` of `tuple`s.

   Now, we have access to each piece of data using it's proper column tile. The number of shares is in the column titled `"# Shares"`. We can find this information in '`data["# Shares"]`'.
7. We perform some simple calculations on each `dict`. In this case, we convert the purchase price to a number, convert the number of shares to a number and multiply to determine how much we spent on this stock. We accumulate the sum of these products into `invest`.

   We also convert the current price to a number and multiply this by the number of shares to get the current value of this stock. We accumulate the sum of these products into `current`.
8. When the loop has terminated, we can write out the two numbers, and compute the percent change.

20.8 File Exercises

1. **File Structures**. What is required to process variable length lines of data in an arbitrary (random) order? How is the application program to know where each line begins?
2. **Device Structures**. Some disk devices are organized into cylinders and tracks instead of blocks. A disk may have a number of parallel platters; a cylinder is the stack of tracks across the platters available without moving the read-write head. A track is the data on one circular section of a single disk platter. What advantages does this have? What (if any) complexity could this lead to? How does an application program specify the tracks and sectors to be used?

   Some disk devices are described as a simple sequence of blocks, in no particular order. Each block has a unique numeric identifier. What advantages could this have?

   Some disk devices can be partitioned into a number of "logical" devices. Each partition appears to be a separate device. What (if any) relevance does this have to file processing?
3. **Portfolio Position**. We can create a simple CSV file that contains a description of a block of stock. We'll call this the portfolio file. If we have access to a spreadsheet, we can create a simple file with four columns: stock, shares, purchase date and purchase price. We can save this as a CSV file. If we don't have access to a spreadsheet, we can create this file in IDLE. Here's an example line.

```
stock,shares,"Purchase Date","Purchase Price"
"AAPL", 100, "10/1/95", 14.50
"GE", 100, "3/5/02", 38.56
```

We can read this file, multiply shares by purchase price, and write a simple report showing our initial position in each stock.

Note that each line will be a simple string. When we split this string on the ,'s (using the string `split()` method) we get a list of strings. We'll still need to convert the number of shares and the purchase price from strings to numbers in order to do the multiplication.

4. **Aggregated Portfolio Position**. In *Porfolio Position* we read a file and did a simple computation on each row to get the purchase price. If we have multiple blocks of a given stock, these will be reported as separate lines of detail. We'd like to combine (or aggregate) any blocks of stock into an overall position. Programmers familiar with COBOL (or RPG) or similar languages often use a *Control-Break* reporting design which sorts the data into order by the keys, then reads the lines of data looking for break in the keys. This design uses very little memory, but is rather slow and complex.

   It's far simpler to use a Python dictionary than it is to use the Control-Break algorithm. Unless the number of distinct key values is vast (on the order of hundreds of thousands of values) most small computers will fit the entire summary in a simple dictionary.

   A program which produces summaries, then, would have the following design pattern.

   (a) Create an empty dictionary for retaining aggregates.

   (b) Open and read the header line from the file. This has the field names.

   (c) Read the portfolio file. For each line in the file, do the following.

      i. Create a tuple from the data fields. You can create a row dictionary from a `zip()` of the header fields zipped with a row.

      ii. If the stock name key does not exist in the aggregate dictionary, insert the necessary element, and provide a suitable initial value.

      iii. Locate the stock name in the dictionary, accumulate a new aggregate value.

   (d) Write the aggregate dictionary keys and values as the final report.

   Some people like to see the aggregates sorted into order. This is a matter of using `sorted()` to iterate through the dictionary keys in the desired order to write the final report.

5. **Portfolio Value**. In *Reading a CSV File the Hard Way*, we looked at a simple CSV-format file with stock symbols and prices. This file has the stock symbol and last price, which serves as a daily quote for this stock's price. We'll call this the stock-price file.

   We can now compute the aggregate value for our portfolio by extracting prices from the stock price file and number of shares from the portfolio file.

   If you're familiar with SQL, this is called a *join operation* ; and most databases provide a number of algorithms to match rows between two tables. If you're familiar with COBOL, this is often done by creating a *lookup table*, which is an in-memory array of values.

   We'll create a dictionary from the stock-price file. We can then read our portfolio, locate the price in our dictionary, and write our final report of current value of the portfolio. This leads to a program with the following design pattern.

   (a) Load the price mapping from the stock-price file.

      i. Create an empty stock price dictionary.

ii. Read the stock price file. For each line in the file, populate the dictionary, using the stock name as the key, and the most recent sale price is the value.

(b) Process the position information from the portfolio file. See *Aggregated Portfolio Position* and *Porfolio Position* for the skeleton of this process.

In the case of a stock with no price, the program should produce a "no price quote" line in the output report. It should not produce a `KeyError` exception.

CHAPTER

TWENTYONE

FUNCTIONAL PROGRAMMING WITH COLLECTIONS

This chapter presents some advanced collection concepts. In *Lists of Tuples* we describe the relatively common Python data structure built from a `list` of `tuple`s. We'll cover a powerful `list` construction method called a *list comprehension* in *List Comprehensions*. We can use this to simplify some common list-processing patterns.

In *Sequence Processing Functions: map(), filter() and reduce()* we'll cover three functions that can simplify some list processing. `map()`, `filter()` and `reduce()` provide features that overlap with list comprehensions.

In *Advanced List Sorting* we cover some advanced sequence sorting techniques. In particular, we'll look closely at how to provide a suitable key function to control sorting.

We'll look at *lambda forms* in *The Lambda*. These aren't essential for Python programming, but they're handy for clarifying a piece of code in some rare cases.

In *Multi-Dimensional Arrays or Matrices* we cover simple multidimensional sequences. These are sometimes called matrices or arrays.

Even more complex data structures are available, of course. Numerous modules handle the sophisticated representation schemes described in the Internet standards (called Requests for Comments, RFC's). We'll touch on these in *The Python Library*.

21.1 Lists of Tuples

The `list` of `tuple` structure is remarkably useful. In other languages, like Java or C++, we are forced to either use built-in arrays or create an entire class definition to simply keep a few values togther.

One common situation is processing list of simple coordinate pairs for 2-dimensional or 3-dimensional geometries. Additional examples might include examining a list of tuples that contain the three levels for red, green and blue that define a color. Or – for printing – the values for cyan, magenta, yellow and black that define a color.

As an example of using a red, green, blue `tuple`, we may have a list of individual colors that looks like the following.

```
colorScheme = [ (0,0,0), (0x20,0x30,0x20), (0x10,0xff,0xff) ]
```

We've already seen how dictionaries (*Mappings and Dictionaries*) have an `dict.items()` method that provides the dictionary keys and values as a `list` of 2-tuples. Additionally, the `zip()` built-in function interleaves two or more sequences to create a `list` of `tuple`s.

The for Statement. A interesting form of the **for** statement is one that exploits multiple assignment to work with a `list` of `tuple`s. Consider the following examples:

```
for c,f in [ ("red",18), ("black",18), ("green",2) ]:
    print "%s occurs %f" % (c, f/38.0)

for r, g, b in [ (0,0,0), (0x20,0x30,0x20), (0x10,0xff,0xff) ]:
    print "red: %x, green: %x, blue: %x" % ( 255-r, 255-g, 255-b )
```

In these examples, we have created a `list` of `tuple`s. The **for** statement uses a form of multiple assignment to split up each `tuple` into a fixed number of variables.

The first example is equivalent to the following.

```
for p in [ ("red",18), ("black",18), ("green",2) ]:
    c,f = p
    print "%s occurs %f" % (c, f/38.0)
```

This technique works because tuples are expected to have a fixed, known number of elements.

Here's an example using `dict.items()`. We looked at dictionaries in *Mappings and Dictionaries*.

```
d = { 'red':18, 'black':18, 'green':2 }
for c,f in d.items():
    print "%s occurs %f" % (c, f/38.0)
```

21.2 List Comprehensions

Python provides several `list` literals or "displays". The most common list display is the simple literal value shown in *List Literal Values*: values are written as follows:

```
[ expression ⟨ , ... ⟩ ]
```

Python has a second kind of list display, based on a *list comphrehension*. A list comprehension is an expression that combines a function, a **for** statement and an optional **if** statement into one tidy package. This allows a simple, clear expression of the processing that will build up an iterable sequence.

List Comprehension Semantics. The most important thing about a list comprehension is that it is an iterable that applies a calculation to another iterable. A list display can use a list comprehension iterable to create a new list.

When we write a list comprehension, we will provide an iterable, a variable and an expression. Python will process the iterator as if it was a for-loop, iterating through a sequence of values. It evaluates the expression, once for each iteration of the for-loop. The resulting values can be collected into a fresh, new list, or used anywhere an iterator is used.

List Comprehension Syntax. A list comprehension is – technically – a complex expression. It's often used in list displays, but can be used in a variety of places where an iterator is expected.

```
expr for-clause
```

The *expr* is any expression. It can be a simple constant, or any other expression (including a nested list comprehension).

The *for-clause* mirrors the **for** statement:

```
for variable in sequence
```

A common use for this is in a list display. We'll show some list comprehension examples used to create new lists.

```
even = [ 2*x for x in range(18) ]
hardways = [ (x,x) for x in (2,3,4,5) ]
samples = [ random.random() for x in range(10) ]
```

even This is a list of values $[0, 2, 4, ..., 14]$.

hardways This is a list of 2-tuples. Each 2-tuple is built from the values in the given sequence. The result is `[(2,2), (3,3), (4,4), (5,5)]`.

samples This is a list of 10 random numbers.

A list display that uses a list comprehension behaves like the following loop:

```
r= []
for  variable in sequence :
    r.append( expr )
```

The basic process, then, is to iterate through the sequence in the *for-clause*, evaluating the expression, *expr*. The values that result are assembled into the `list`. If the expression depends on the *for-clause*, each value in the `list` can be different. If the expression doesn't depend on the *for-clause*, each value will be the same.

Here's an example where the expression depends on the for-clause.

```
>>> [ v*2+1 for v in range(10) ]
[1, 3, 5, 7, 9, 11, 13, 15, 17, 19]
>>> sum(_)
100
```

This creates the first 10 odd numbers. It starts with the sequence created by '`range(10)`'. The *for-clause* assigns each value in this sequence to the local variable `v`. The expression, '`v*2+1`', is evaluated for each distinct value of `v`. The expression values are assembled into the resulting `list`.

Here's an example where the expression doesn't depend on the *for-clause*.

```
b= [ 0 for i in range(10) ]
```

`b` will be a `list` of 10 zeroes.

Comprehensions Outside List Displays. A list comprehension can be used outside of a list display. When we write a list display (using '`[`' and '`]`') were using an iterable (the list comprehension) to create a new list.

We can use the iterable list comprehension in other contexts that expect an iterator.

```
square = sum( (2*a+1) for a in range(10) )
column_1 = tuple( 3*b+1 for b in range(12) )
rolls = ( (random.randint(1,6),random.randint(1,6)) for u in range(100) )
hardways = any( d1==d2 for d1,d2 in rolls )
```

square This is the sum of odd numbers. The list comprehension ('`(2*a+1) for a in range(10)`') is an iterable which the `sum()` function can use.

column_1 This creates a tuple of 12 values using a a list comprehension.

rolls This creates a generator object that will iterate over 100 values using a list comprehension. This does not actually create 100 values – it defines an iterator that will produce 100 values.

Note that this generator has an internal state: it can only be used once. Once it has generated all it's values, it will not generate any other values.

A statement like '`r1 = list(rolls)`' will use the iterator object, `rolls` with the `list()` function to actually create an object that has 100 random values.

hardways This iterates through the iterator named `rolls` to see if any of the pairs had the number rolled "the hard way" with both values equal.

The if Clause. A list comprehension can also have an *if-clause*.

The basic syntax is as follows:

```
expr for-clause if-clause
```

The *for-clause* mirrors the **for** statement:

```
for variable in sequence
```

The *if-clause* mirrors the **if** statement:

```
if filter
```

Here is an example of a complex list comprehension in a list display.

```
hardways = [ (x,x) for x in range(1,7) if x+x not in (2, 12) ]
```

This more complex list comprehension behaves like the following loop:

```
r= []
for  variable in sequence :
    if filter:
        r.append( expr )
```

The basic process, then, is to iterate through the sequence in the *for-clause*, evaluating the *if-clause*. When the *if-clause* is `True`, evaluate the expression, *expr*. The values that result are assembled into the `list`.

Here's another example.

```
>>> [ (x,2*x+1) for x in range(10) if x%3 == 0 ]
[(0, 1), (3, 7), (6, 13), (9, 19)]
```

This works as follows:

1. The *for-clause* iterates through the 10 values given by '`range(10)`', assigning each value to the local variable *x*.
2. The *if-clause* evaluates the filter function, '`x%3==0`'. If it is `False`, the value is skipped. If it is `True`, the expression, at '`(x,2*x+1)`', is evaluated and retained.
3. The sequence of 2-tuples are assembled into a `list`.

A list comprehension can have any number of *for-clauses* and *if-clauses*, freely-intermixed. A *for-clause* must be first. The clauses are evaluated from left to right.

21.3 Sequence Processing Functions: `map()`, `filter()` and `reduce()`

The `map()`, `filter()`, and `reduce()` built-in functions are handy functions for processing sequences without writing lengthy for-loops. These owe much to the world of functional programming languages. The idea of each is to take a small function you write and apply it to all the elements of a sequence, saving you from writing an explicit loop. The implicit loop within each of these functions may be faster than an explicit **for** loop.

Additionally, each of these is a pure function, returning a result value. This allows the results of the functions to be combined into complex expressions relatively easily.

Processing Pipeline. It is very, very common to apply a single function to every value of a list. In some cases, we may apply multiple simple functions in a kind of "processing pipeline".

Here's an example.

```
>>> def ftin_2_in( ftin ):
...     feet, inches = ftin
...     return 12.0*feet + inches
...
>>> heights = [ (5,8), (5,9), (6,2), (6,1), (6,7) ]
>>> map( ftin_2_in, heights )
[68.0, 69.0, 74.0, 73.0, 79.0]
>>>
>>> def in_2_m( inches ):
...     return inches * 0.0254
...
>>> map( in_2_m, map( ftin_2_in, heights ) )
[1.7271999999999998, 1.7525999999999999, 1.8795999999999999, 1.8541999999999998, 2.0065999999999997]
```

1. We defined a simple function, `ftin_2_in()` that converts a distance in the form '`(ft,in)`' into a distance measured in inches.
2. We defined a set of people's heights in `heights`.
3. We used the `map()` function to apply our `ftin_2_in()` function to each value in `heights`, creating a new list of values.
4. We defined a simple function, `in_2_m()` that converts a distance in inches into a distance in meters.
5. We did a fairly complex calculation where we applied `ftin_2_in()` to each value in `heights`. We then applied `in_2_m()` to each of those values. We've converted a list of values from English '`(ft,in)`' to proper metric units by applying two simple functions to each value.

This concept can be used extensively using these functions and list comprehensions to create complex and sophisticated software from a series of simple transformations.

Definitions. Each of the `map()`, `filter()` and `reduce()` functions transform an iterable (a sequence or generator function).

The `map()` and `filter()` each apply some function to a sequence to create a new sequence.

The `reduce()` function applies a function which will reduce the sequence to a single value. There are a number of special-purpose reduce functions that we've already seen. These reductions include `sum()`, `any()`, `all()`.

The `map()` and `filter()` functions have no internal state, they simply apply the function to each individual value of the sequence. The `reduce()` function, in contrast, maintains an internal state which is seeded from an initial value, passed to the function along with each value of the sequence and returned as the final result.

Here are the formal definitions.

`map`(*function, sequence, [...]*)

Create a new `list` from the results of applying the given `function` to the items of the the given `sequence`.

```
>>> map( int, [ "10", "12", "14", 3.1415926, 5L ] )
[10, 12, 14, 3, 5]
```

This function behaves as if it had the following definition.

```
def map( aFunction, aSequence ):
    return [ aFunction(v) for v in aSequence ]
```

It turns out that more than one sequence can be given. In this case, the function must accept multiple arguments, and there must be as many sequences as arguments to the function. The corresponding items from each sequence are provided as arguments to the function.

If any sequence is too short, `None` is used for missing the values. If the `function` is `None`, `map()` will create tuples from corresponding items in each list, much like the `zip()` function.

`filter`(*function, sequence*)

Return a `list` containing those items of `sequence` for which the given function is `True`. If the function is `None`, return a `list` of items that are equivalent to `True`.

This function behaves as if it had the following definition.

```
def filter( aFunction, aSequence ):
    return [ v for v in aSequence if aFunction(v) ]
```

Here's an example

```
>>> import random
>>> rolls = list( (random.randint(1,6),random.randint(1,6)) for u in range(100) )
>>> def hardways( pair ):
...     d1, d2 = pair
...     return d1 == d2 and d1+d2 in ( 4, 6, 8, 10 )
>>> filter( hardways, rolls )
[(4, 4), (5, 5), (2, 2), (5, 5), (4, 4), (5, 5), (5, 5), (3, 3), (2, 2), (2, 2), (5, 5), (4, 4)]
>>> len(_)
12
```

1. We created 100 random rolls.
2. We defined a function that evaluates a roll to see if the point was made the "hard way".
3. We applied our filter to our rolls to see that 12/100 rolls are hardway rolls.

Here's anther example

```
>>> def over_2( m ):
...     return m > 2.0
>>> filter( over_2, map( in_2_m, map( ftin_2_in, heights ) ) )
[2.0065999999999997]
```

1. We defined a filter function which returns `True` if the argument value is greater than 2.0.
2. We filtered our list of heights to locate any heights over 2.0 meters.

`reduce`(*function, sequence, [initial=0]*)

The given function must accept two argument values. This function will apply that function to an internal accumulator and each item of a sequence, from left to right, so as to reduce the sequence to a single value.

The internal accumulator is initialized with the given initial value (or `0` if no value is provided.)

This behaves as if it had the following definition.

```
def reduce( aFunction, aSequence, init= 0 ):
    r= init
    for s in aSequence:
        r= aFunction( r, s )
    return r
```

Here's an example.

```
>>> def plus( a, b ):
...     return a+b
>>> reduce( plus, [1, 3, 5, 7, 9] )
25
```

Note that Python has a number of built-in reductions: `sum()`, `any()` and `all()` are kinds of reduce functions.

Costs and Benefits. What are the advantages? First, the functional version can be clearer. It's a single line of code that summarizes the processing. Second, and more important, Python can execute the sequence processing functions far faster than the equivalent explicit loop.

You can see that `map()` and `filter()` are equivalent to simple list comprehensions. This gives you two ways to specify these operations, both of which have approximately equivalent performance. This also means that `map()` and `filter()` aren't *essential* to Python, but they are widely used.

The `reduce()` function is a bit of a problem. It can have remarkably bad performance if it is misused. Consequently, there is some debate about the value of having this function.

Another Example. Here's an interesting example that combines `reduce()` and `map()`. This uses two functions defined in earlier examples, `add()` and `oddn()`.

```
def plus( a, b ):
    return a+b
def oddn( n ):
    return 2*n+1
for i in range(10):
    sq=reduce( plus, map(oddn, range(i)), 0 )
    print i, sq
```

Let's look at the evaluation of `sq` from innermost to outermost.

1. The '`range(i)`' generates a sequence of numbers from 0 to `i` -1.
2. A `map()` function applies `oddn()` to the sequence created by '`range(i)`', creating i odd values. The `oddn()` function returns the n^{th} odd value.
3. A `reduce()` function applies `plus()` to the sequence of odd values, creating a sum.

The `zip()` Function. The `zip()` function interleaves values from two or more sequences to create a new sequence. The new sequence is a sequence of `tuple`s. Each item of a `tuple` is the corresponding values from from each sequence.

`zip`(*sequence, [sequence...]*)
Interleave values from the various sequences to create tuples. If any sequence is too long, truncate it.

Here's an example.

```
>>> zip( range(5), range(1,12,2) )
[(0, 1), (1, 3), (2, 5), (3, 7), (4, 9)]
```

In this example, we zipped two sequences together. The first sequence was '`range(5)`', which has five values. The second sequence was '`range(1,12,2)`' which has 6 odd numbers from 1 to 11. Since `zip()` truncates to the shorter list, we get five tuples, each of which has the matching values from both lists.

The `map()` function behaves a little like `zip()` when there is no function provided, just sequences. However, `map()` does not truncate, it fills the shorter list with `None` values.

```
>>> map( None, range(5), range(1,12,2) )
[(0, 1), (1, 3), (2, 5), (3, 7), (4, 9), (None, 11)]
```

21.4 Advanced List Sorting

Consider a `list` of `tuple`s. We could get such a `list` when processing information that was extracted from a spreadsheet program.

For example, if we had a spreadsheet with raw census data, we can easily transform it into a sequence of `tuple` s that look like the following.

```
jobData= [
(001,'Albany','NY',162692),
(003,'Allegany','NY',11986),
...
(121,'Wyoming','NY',8722),
(123,'Yates','NY',5094)
]
```

We can also save the spreadsheet data in `csv` format and use the `csv` module to read it. We'll return to the `csv` module in *Components, Modules and Packages*.

List of Tuples from Spreadsheet Rows

To create a list of tuples from a spreadsheet, you can do the following.
In each row of the spreadsheet, put in a formula that creates a tuple from the various cells. This formula will have to include the necessary additional quotes.
If you're using an Open Office .ORG spreadsheet, it might look something like this

```
="(" & CONCATENATE( """ & A1 & """,";  """ & B1 & """,";  """ & C1 & """," ) & ")"
```

Once we have each row as a `tuple`, we can put some '`[]`' in front of the first tuple and after the last tuple to make a proper list display.
We can also slap an Python assignment statement onto this `list` of rows and turn our spreadsheet into a Python statement. We can copy and paste this data into our Python script.

Sorting this `list` can be done trivially with the `list.sort()` method.

```
jobData.sort()
```

Recall that this updates the list in place. The sort() method specifically does not return a result. A common mistake is to say something like: 'a= b.sort()'. The sort method always returns None.

This kind of sort will simply compare the tuple items in the order presented in the tuple. In this case, the county number is first. What if we want to sort by some other column, like state name or jobs?

Let's say we wanted to sort by state name, the third element in the tuple. We have two strategies for sorting when we don't want the simplistic comparison of elements in order.

1. We can provide a "key extraction" function to the sort() method. This will locate the key value (or a tuple of key values) within the given objects.
2. We can use the "decorate - sort - undecorate" pattern. What we do is decorate each element in the list, making it into a new kind of 2-tuple with the fields on which we want to sort as the first element of this tuple and the original data as the second element of the tuple.

   This has the side effect of creating a second copy of the original list.

Sorting With Key Extraction. The sort() method of a list can accept a keyword parameter, key, that provides a key extraction function. This function returns a value which can be used for comparison purposes. To sort our jobData by the third field, we can use a function like the following.

```
def byState( a ):
    return a[2]
jobData.sort( key=byState )
```

This byState() function returns the selected key value, which is then used by sort to order the tuples in the original list. If we want to sort by a multi-part key, we cna do something like the following.

```
def byStateJobs( a ):
    return ( a[2], a[3] )
```

This function will create a two-value tuple and use these two values for ordering the items in the list.

Sorting With List Decoration. Superficially, this method appears more complex. However it is remarkably flexible. This is a slightly more general solution than using a key extractor function.

The idea is to transform the initial list of values into a new list of 2-tuples, with the first item being the key and the second item being the original tuple. The first item, only used for sorting, is a decoration placed in front of the original value.

In this example, we decorate our values with a 2-tuple of state names and number of jobs. We can sort this temporary list of 2-tuples. Then we can strip off the decoration and recover the original values.

Here's the example shown as three distinct steps.

```
deco= [ ((a[2],a[3]),a) for a in jobData ]
deco.sort()
state_jobs= [ v for k,v in deco ]
```

Here's an example shown with a single operation.

```
state_jobs = [ v for k,v in sorted( ((a[2],a[3]),a) for a in jobData ) ]
```

This works by evaluating the "undecorate" list comprehension, 'v for k,v in sorted()'. That list comprehension depends on the output from the sorted() function. The sorted() function depends on the "decorate" list comprehension, '(...,a) for a in jobData'.

21.5 The Lambda

The functions `map()`, `filter()`, `reduce()`, and the `list.sort()` method all use small functions to control their operations.

For example, we would write something like:

```
def byState( x ):
    return x[2]
data.sort( key=byState )
```

In this case, we provided the `byState()` function to the `list.sort()` method.

In many cases, this function is used only once, and it hardly seems necessary to define a function object for a single use like this.

Instead of defining a function, Python allows us to provide a *lambda form*. This is a kind of anonymous, one-use-only function body in places where we only need a very, very simple function.

A lambda form is like a defined function: it has parameters and computes a value. The body of a lambda, however, can only be a single expression, limiting it to relatively simple operations. If it gets complex, you'll have to define a real function.

Syntax. The syntax is relatively simple.

```
lambda :replaceable: parameter ⟨ , ... ⟩ : expression
```

There can be any number of parameters. The result of the expression is the value when the lambda is applied to arguments. No actual **return** statement is required. No statements can be used, just an expression.

Note that a lambda form is not a statement; it's an expression that's used within other expressions. The lambda form does not define an object with a long life-time. The lambda form object – generally – exists just in the scope of a single statement's execution.

Generally, a lambda will look like this.

```
lambda a: a[0]*2+a[1]
```

This is a lambda which takes a tuple argument value and returns a value based on the first two elements of the tuple.

Examples. Here's an example of using a lambda form and applying it directly to it's arguments.

```
>>> from math import pi
>>> (lambda x: pi*x*x)(5)
78.539816339744831
```

1. The '`(lambda x: pi*x*x)`' is a function with no name; it accepts a single argument, `x`, and computes '`pi*x*x`'.
2. We apply the lambda to an argument value of 5. The value of applying the lambda to 5 is the value $5^2\pi = 25\pi$.

Here's a lambda form used in the map function.

```
>>> map( lambda x: pi*x*x, range(8) )
[0.0, 3.1415926535897931, 12.566370614359172, 28.274333882308138,
50.26548245743669, 78.539816339744831, 113.09733552923255,
153.93804002589985]
```

This map() function applies a lambda form to the values from 0 to 7 as created by the range(). The input sequence is mapped to the output sequence by having the lambda object applied to each value.

Parameterizing a Lambda. Sometimes we want to have a lambda with an argument defined by the "context" or "scope" in which the lambda is being used.

This is very similar to a *closure*, in which a free variable is bound into the lambda expression.

Here's the basic form that's commonly used to create a closure in Python. This is a function that returns a lambda for later use.

```
>>> def timesX( x ):
...     return lambda a: x*a
...
>>> t2= timesX(2)
>>> t2(5)
10
>>> t3= timesX(3)
>>> t3(5)
15
```

We can use this kind of thing as follows. We call our "closure" function to create a lambda that's got a constant bound into it. We can then use the resulting lambda. In this case, we're using it in a map() function evaluation.

```
>>> map( timesX(3), range(5) )
[0, 3, 6, 9, 12]
```

Consider this more complex example.

```
>>> spins = [ (23,"red"), (21,"red"), (0,"green"), (24,"black") ]
>>> def byColor( color ):
...     return lambda t: color == t[1]
...
>>> filter( byColor("red"), spins )
[(23, 'red'), (21, 'red')]
>>> filter( byColor("green"), spins )
[(0, 'green')]
```

1. We have four sample spins of a roulette wheel, `spins`.
2. We have a function, `byColor()`, that creates a closure. This function binds the name of a color into a simple lambda, '`lambda t: color == t[1]`'.

   The resulting lambda can be used anywhere a function is required.
3. We use the `byColor()` function to create a lambda what we use for filtering our collection of spins. We create a lambda with '`byColor("red")`' that will return `True` for spins that have the color of `"red"`.
4. We use the `byColor()` function to create another lambda what we use for filtering our collection of spins. We create a lambda with '`byColor("green")`' that will return `True` for spins that have the color of `"green"`.

As an alternative to creating lists with the filter() function, similar results can be created with a list comprehension.

```
>>> byRed= byColor("red")
>>> [ s for s in spins if byRed(s) ]
[(23, 'red'), (21, 'red')]
```

21.6 Multi-Dimensional Arrays or Matrices

There are situations that demand multi-dimensional arrays or matrices. In many languages (Java, COBOL, BASIC) this notion of multi-dimensionality is handled by pre-declaring the dimensions (and limiting the sizes of each dimension). In Python, these are handled somewhat more simply.

If you have a need for more sophisticated processing than we show in this section, you'll need to get the Python `Numeric` module, also known as `NumPy`. This is a Source Forge project, and can be found at http://numpy.sourceforge.net/.

Let's look at a simple two-dimensional tabular summary. When rolling two dice, there are 36 possible outcomes. We can tabulate these in a two-dimensional table with one die in the rows and one die in the columns:

	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

In Python, a multi-dimensional table like this can be implemented as a sequence of sequences. A table is a sequence of rows. Each row is a sequence of individual cells. This allows us to use mathematical-like notation. Where the mathematician might say $A_{i,j}$, in Python we can say '`A[i][j]`'. In Python, we want the row `i` from table A, and column `j` from that row.

This is essentiall the like the `list` of `tuple`s, yet again. See *Lists of Tuples*.

List of Lists Example. We can build a table using a nested list comprehension. The following example creates a table as a sequence of sequences and then fills in each cell of the table.

```
table= [ [ 0 for i in range(6) ] for j in range(6) ]
print table
for d1 in range(6):
    for d2 in range(6):
        table[d1][d2]= d1+d2+2
print table
```

This program produced the following output.

```
[[0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0],
[0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0], [0, 0, 0, 0, 0, 0]]
[[2, 3, 4, 5, 6, 7], [3, 4, 5, 6, 7, 8], [4, 5, 6, 7, 8, 9],
[5, 6, 7, 8, 9, 10], [6, 7, 8, 9, 10, 11], [7, 8, 9, 10, 11, 12]]
```

1. First, we created a six by six table of zeroes, named `table`.

   Each item in the table is a 6-item `list` of zeroes. We used a list comprehension to create an object for each value of `j` in the range of 0 to 6. Each of the objects is a `list` of zeroes, one for each value of `i` in the range of 0 to 6.

2. We printed that list of lists.

3. We then filled this with each possible combination of two dice. We iterate over all combinations of two dice, filling in each cell of the table. This is done as two nested loops, one loop for each of the two dice. The outer enumerates all values of one die, `d1`. The loop enumerates all values of a second die, `d2`.

Updating each cell involves selecting the row with '`table[d1]`'; this is a `list` of 6 values. The specific cell in this `list` is selected by '`[d2]`'. We set this cell to the number rolled on the dice, '`d1+d2+2`'.

Additional Examples. The printed `list` of `list` structure is a little hard to read. The following loop would display the table in a more readable form.

```
>>> for row in table:
...     print row
...
[2, 3, 4, 5, 6, 7]
[3, 4, 5, 6, 7, 8]
[4, 5, 6, 7, 8, 9]
[5, 6, 7, 8, 9, 10]
[6, 7, 8, 9, 10, 11]
[7, 8, 9, 10, 11, 12]
```

As an exercise, we'll leave it to the reader to add some features to this to print column and row headings along with the contents. As a hint, the '`"%2d" % value`' `string` operation might be useful to get fixed-size numeric conversions.

Explicit Index Values. Let's summarize our matrix of die rolls, and accumulate a frequency table. We'll use a simple list with 13 buckets (numbered from 0 to 12) to accumulate the frequency of each die roll.

```
fq= 13*[0]
for i in range(6):
    for j in range(6):
        c= table[i][j]
        fq[ c ] += 1
```

1. We initialize the frequency table, `fq`, to be a `list` of 13 zeroes.
2. The outer loop sets the variable `i` to the values from 0 to 5.
3. The inner loop sets the variable `j` to the values from 0 to 5.
4. We use the index value of `i` to select a row from the table, and the index value of `j` to select a column from that row. This is the value, `c` . We then accumulate the frequency occurances in the frequency table, `fq` .

This looks very mathematical and formal. However, Python gives us an alternative, which can be somewhat simpler.

Using List Iterators Instead of Index Values. Since our table is a list of lists, we can make use of the power of the **for** statement to step through the elements without using an index.

```
fq= 13*[0]
print fq
for row in table:
    for c in row:
        fq[c] += 1
```

1. We initialize the frequency table, `fq`, to be a `list` of 13 zeroes.
2. The outer loop sets the variable `row` to each element of the original `table` variable. This decomposes the table into individual rows, each of which is a 6-element `list`.
3. The inner loop sets the variable `c` to each column's value within the row. This decomposes the row into the individual values.

4. We count the actual occurances of each value, `c` by using the value as an index into the frequency table, `fq` . The increment the frequency value by 1.

Mathematical Matrices. We use the explicit index technique for managing the mathematically-defined matrix operations. Matrix operations are done more clearly with this style of explicit index operations.

We'll show matrix addition as an example, here, and leave matrix multiplication as an exercise in a later section.

```
m1 = [ [1, 2, 3, 0], [4, 5, 6, 0], [7, 8, 9, 0] ]
m2 = [ [2, 4, 6, 0], [1, 3, 5, 0], [0, -1, -2, 0] ]
m3= [ 4*[0] for i in range(3) ]
for i in range(3):
    for j in range(4):
        m3[i][j]= m1[i][j]+m2[i][j]
```

1. In this example we created two input matrices, `m1` and `m2`, each three by four.
2. We initialized a third matrix, `m3`, to three rows of four zeroes, using a comprehension.
3. We iterated through all rows (using the `i` variable), and all columns (using the `j` variable) and computed the sum of `m1` and `m2`.

Python provides a number of modules for handling this kind of processing. In *Components, Modules and Packages* we'll look at modules for more sophisticated matrix handling.

21.7 Exercises

1. **All Dice Combinations**. Write a list comprehension that uses nested for-clauses to create a single `list` with all 36 different dice combinations from (1,1) to (6,6).
2. **Temperature Table**. Write a list comprehension that creates a `list` of `tuple` s. Each `tuple` has two values, a temperature in Farenheit and a temperature in Celsius.

   Create one `list` for Farenheit values from 0 to 100 in steps of 5 and the matching Celsius values.

   Create another `list` for Celsius values from -10 to 50 in steps of 2 and the matching Farenheit values.
3. **Define max() and min()**. Use `reduce()` to create versions of the built-ins `max()` and `min()`.

   You may find this difficult to do this with a simple lambda form. However, consider the following. We can pick a value from a `tuple` like this: '`(a,b)[0] == a`', and '`(a,b)[1] == b`'. What are the values of '`(a,b)[a<b]`' and '`(a,b)[a>b]`'?
4. **Compute the Average or Mean**. A number of standard descriptive statistics can be built with `reduce()`. The basic formulae are given in *Tuples*.

   Write a function based on `reduce()` which computes the mean. Mean is a simple "add-reduction" of the values in a sequence divided by the length.

   In essence, you're inventing a version of `sum()` based on `reduce()`.
5. **Compute the Variance and Standard Deviation**. A number of standard descriptive statistics can be built with `reduce()`. The basic formulae are given in *Tuples*.

   Given a sequence of values $A = \{a_0, a_1, ..., a_n\}$, the standard deviation has a number of alternative definitions. One approach is to sum the values and square this number, as well as sum the squares of

each number. Summing squares can be done as a `map()` to compute squares and then use the `sum()` function.

$$
\begin{aligned}
s_1 &\leftarrow \sum_{0 \le i < n} (A_i^2) \\
s_2 &\leftarrow (\sum_{0 \le i < n} A_i)^2 \\
v &\leftarrow \frac{s_1 - s_2}{n} \\
\sigma_A &\leftarrow \sqrt{v}
\end{aligned}
$$

Also the standard deviation can be defined as the square root of the average variance.

$$
\begin{aligned}
m &\leftarrow \frac{\sum_{0 \le i < n} A_i}{n} \\
v &\leftarrow \frac{\sum_{0 \le i < n} (A_i - m)^2}{n - 1} \\
\sigma_A &\leftarrow \sqrt{v}
\end{aligned}
$$

6. **Distinct Values In A Sequence**. In *List Exercises*, one of the exercises looked at accumulating the distinct values in a sequence.

   Given an input sequence, `seq`, we can easily sort this sequence. This will put all equal-valued elements together. The comparison for unique values is now done between adjacent values, instead of a lookup in the resulting sequence.

Unique Values of a Sequence, *seq* , using `sort()`

Initalize

Set *result* ← [ ] an empty sequence.

Sort the input sequence, *seq*.

Loop. For each value, *v*, in the sorted *seq*.

Already in `result`? Is *v* the last element in `result`? If so, ignore it. If not, append *v* to the sequence `result`.

Result. Return array `result`, which has distinct values from *seq*.

While this is appealing in it's simplicity, the sort operation makes it relatively inefficient.

7. **Compute the Median**. The median function arranges the values in sorted order. It locates either the mid-most value (if there are an odd number) or it averages two adjacent values (if there are an even number).

   If '`len(data) % 2 == 1`', there is an odd number of values, and '`(len(data)+1)/2`' is the midmost value. Otherwise there is an even number of values, and the '`len(data)/2`' and '`len(data)/2-1`' are the two mid-most values which must be averaged.

8. **Portfolio Reporting**. In *Tuple Exercises*, one of the exercises presented a stock portfolio as a sequence of `tuple`s. Plus, we wrote two simple functions to evaluate purchase price and total gain or loss for this portfolio.

   Develop a function (or a lambda form) to sort this porfolio into ascending order by current value (current price ×number of shares). This function (or lambda) will require comparing the products of two fields instead of simply comparing two fields.

9. **Matrix Formatting**. Given a 6 ×6 matrix of dice rolls, produce a nicely formatted result. Each cell should be printed with a format like '`"| %2s"`' so that vertical lines separate the columns. Each row should end with an '|'. The top and bottom should have rows of '`"----"`' printed to make a complete table.

10. **Three Dimensions**. If the rolls of two dice can be expressed in a two-dimensional table, then the rolls of three dice can be expressed in a three-dimensional table. Develop a three dimensional table, 6 x 6 x 6, that has all 216 different rolls of three dice.

    Write a loop that extracts the different values and summarizes them in a frequency table. The range of values will be from 3 to 18.

CHAPTER

TWENTYTWO

ADVANCED MAPPING TECHNIQUES

This chapter presents two advanced map concepts. In *Default Dictionaries* we show how to use the `collections.defaultdict` class. In *Inverting a Dictionary* we discuss "inverting" a dictionary to process it by value instead of by key.

22.1 Default Dictionaries

Python has a module, called `collections`, that includes a number of more advanced collection classes. We'll look at one particularly useful one, `defaultdict`.

The point of a `defaultdict` is to handle the `dict.get()` method in a different way.

- When the builtin `dict` class is confronted with a missing key, it raises a `KeyError` exception.
- When the `collections.defaultdict` class is confronted with a missing key, it will use a supplied function to create a default entry in the dictionary.

Consider this snippet.

```
frequency = {}
for i in range(100):
    d1, d2 = random.randint(1,6), random.randint(1,6)
    frequency[d1+d2] += 1
```

This is elegantly simply, but all it does is crash in a `KeyError` exception. We can add code, using `dict.setdefault()` to handle missing keys. However, `defaultdict` allows us to write this simple thing and have it work as expected.

Importing `defaultdict`. We can make the `defaultdict` container available via the following:

```
from collections import defaultdict
```

We'll look at the **import** statement in detail in *Components, Modules and Packages*.

Creating a `defaultdict`. We create a new `defaultdict` by providing a function which will create a default value for us. Most applications of `defaultdict` will be used for counting or accumulating lists, so the most common initializations are the following two.

```
from collections import defaultdict
frequency_table = defaultdict( int )
search_index = defaultdict( list )
```

frequency_table We create a default dict using the built-in `int()` function to create default values. Calling '`int()`' returns a zero, which is a useful default for frequency tables.

This dict allows you to say '`frequency_table[someKey] += 1`' without worrying about `KeyError` exceptions. If the key value is in the dictionary, then that value is incremented. If the key value is not in the dictionary, the initialization function ('`int`') will evaluated to create the default value.

search_index We create a default dict using the built-in `list()` function to create default values. Calling '`list()`' returns a an empty list, which is a useful default for a non-unique search index.

This dict allows you to say '`search_index[someKey].append( someValue )`' without worrying about `KeyError` exceptions. If the key value is in the dictionary, then list value is append to. If the key value is not in the dictionary, the initialization function ('`list`') will evaluated to create the default value, an empty list. This can then be appended to.

Example. The following example accumulates a frequency table of 1000 dice rolls.

```
from collections import defaultdict
from random import randint
frequency = defaultdict( int )
for i in range(100):
    d1, d2 = randint(1,6), randint(1,6)
    frequency[d1+d2] += 1
```

22.2 Inverting a Dictionary

An "inverted database" has one copy of each distinct value. This single copy is then associated the list of record identifiers that share this value.

Rather than this:

key	name	year
1	KaDiMa	1972
2	Dekkan	2000
3	Swell	1972

We would have something like this.

name	record list
KaDiMa	[1]
Dekkan	[2]
Swell	[3]

And this

year	record list
1972	[1, 3]
2000	[2]

This "inversion" technique often to mappings. We may want to search a dictionary for a particular value instead of a particular key. In some cases, we may have multiple searches over the same base collection of information.

Let's look at the simplest case first.

We have a frequency table like the following:

```
frequency= {2: 2, 3: 1, 4: 4, 5: 10, 6: 12, 7: 22,
    8: 19, 9: 11, 10: 12, 11: 4, 12: 3}
```

We'd like to "invert" this dictionary, and display the dictionary in ascending order by value. Ths issue is that the values may not be unique.

```
>>> byFreq = defaultdict(list)
>>> for k in frequency:
...     byFreq[frequency[k]].append( k )
...
>>> byFreq
defaultdict(<type 'list'>, {1: [3], 2: [2], 3: [12], 4: [4, 11],
    10: [5], 11: [9], 12: [6, 10], 19: [8], 22: [7]})
```

This technique creats a new dictionary with the original values as keys and a list of the original keys as values.

22.3 Exercises

1. **Compute the Mode**. The mode function finds the most common value in a data set. This can be done by computing the frequency with which each unique value occurs.

   You'll need to "invert" the dictionary so that you work with the values (the frequencies) instead of the keys.

   The simplest solution is to find the maximum frequency, the associated key is the mode.

   However, there may be ties for first. This may mean thay you have a *bimodal* or even *multi-modal* distribution. Because of this it's best to sort and check the top two frequencies to be sure there isn't a tie.

   If there is a tie, there are several possible response. One is to define the mode function to return a tuple with all the values tied for most frequency. Generally, there will only be a single frequent value, but in the event of ties, all top values will be in the tuple. Another choice is to raise an exception.

2. **Stock Purchases by Year**. In *Dictionary Exercises*, we looked at blocks of stock where each block was represented as a simple tuple.

   ```
   purchases = [ ( 'GE', 100, '10-sep-2001', 48 ),
    ( 'CAT', 100, '1-apr-1999', 24 ),
    ( 'GE', 200, '1-jul-1999', 56 ) ]
   ```

   Create a dictionary where the index is the year of purchase, and the value is a list of purchases.

   Parsing the date can be simplified to '`date[-4:]`' for now. Later in *Components, Modules and Packages*, we'll address date-time parsing.

3. **Efficiency**. What is the typical complexity of a sort algorithm? What is the complexity of a hash table?

   Compare and contrast sorting and using a dictionary to summarize data according to distinct values.

   In SQL, we specify a dictionary-like summary of data using a '`GROUP BY`' clause. Why does a database use a sort?

Part IV

Data + Processing = Objects

Encapsulating Data and Processing into Class Definitions

In *Language Basics*, we examined the core statements in the Python language. In *Data Structures*, we examined the built-in data structures available to us as programmers. Using these data structures gave us some hands-on experience with a number of classes. After using this variety of built-in objects, we are better prepared to design our own objects.

Classes introduces basics of class definitions and *Advanced Class Definition* introduces simple inheritance. We extend this discussion further to include several common design patterns that use polymorphism. In *Some Design Patterns* we cover a few common design patterns. *Creating or Extending Data Types* describes the mechanism for adding types to Python that behave like the built-in types.

We will spend some time on Python's flexible notion of "attribute" in *Attributes, Properties and Descriptors*. It turns out that an attribute can be a simple instance variable or it can be a method function that manages an instance variable.

We'll look at Python's decorators in *Decorators*; this is handy syntax for assuring that specific aspects of a family of classes are implemented consistently. We'll look at the various ways to define properties in objects.properties. Additionally, we'll look how we can manage more sophisticated object protocols in *Managing Contexts: the with Statement*.

Data Types. We've looked at most of these data types in *Data Structures*. This is a kind of road-map of some of the most important built-in features.

- **None**. A unique constant, handy as a placeholder when no other value is appropriate. A number of built-in functions return values of `None` to indicate that no useful work can be done.
- **NotImplemented**. A unique constant, returned by special methods to indicate that the method is not implemented. See *Numeric Type Special Methods* for more information.
- Numeric types have relatively simple values. These are immutable objects: they cannot have their values changed, but they can participate in numerous arithmetic and comparison operations like '`+`', '`-`', '`*`', '`/`', '`//`', '`**`'.
  - **Boolean**. (`bool`) A variety of values are treated as logically false: `False`, 0, `None`, `""`, `()`, `[]`, `{}`, '`set()`'. All other values are logically `True`.
  - **Integer**. (`int`) Typically 32-bit numbers with a range of -2,147,483,648 through 2,147,483,647.
  - **Long**. (`long`) These are specially coded integers of arbitrary length. They grow as needed to accurately represent numeric results. Literals end with '`L`'.

    In Python 3, the integer and long types will be unified and the remaining distinctions removed.
  - **Float**. (`float`) These are floating point, scientific notation numbers. They are represented using the platform's floating point notation, so ranges and precisions vary. Typically these are called "double precision" in other languages, and are often 64-bits long.
  - **Complex**. (`complex`) These are a pair of floating point numbers of the form $a + bj$, where a is the real part and b is the "imaginary" part. $j = \sqrt{-1}$.
- **Sequence**. Collections of objects identified by their order or position.
  - Immutable sequences are created as needed and can be used but never changed.
    * **String**. (`str`) A sequence of individual ASCII characters.
    * **Unicode**. (`unicode`) A sequence of individual Unicode characters.

      In Python 3, String and Unicode will be unified into a single class named `str` that includes features of `unicode`.

        * **Tuple**. (`tuple`) A sequence of a fixed number of Python items. Literals look like **(** *expression* ⟨ **,** ... ⟩ **)**

    - Mutable sequences can be created, appended-to, changed, and have elements deleted.

        * **List**. (`list`) A sequence Python items. Literals look like [*expression* ⟨ **,** ... ⟩] Operations like `append()`, `pop()` and `sort()` can be used to change lists.

- **Set and Frozenset**. (`set`, `frozenset`) Collections of objects. The collection is neither ordered nor keyed. Each item stands for itself. A `set` is mutable; we can append, change and delete elements from a set. A `frozenset` is immutable.
- **Mapping**. Collections of objects identified by keys instead of order.
    - *Dictionary.* (`dict`) A collection of objects which are indexed by other objects. It is like a sequence of '`key:value`' pairs, where keys can be found efficiently. Any Python object can be used as the value. Keys have a small restriction: mutable lists and other mappings cannot be used as keys. Literals look like **{** *key* **:** *value* ⟨ **,** ... ⟩ **}**
- **File**. (classname:*file*) Python supports several operations on files, most notably reading, writing and closing. Python also provides numerous modules for interacting with the operating system's management of files.
- **Callable**. When we create a function with the **def** statement, we create a `callable` object. We can also define our own classes with a special method of `__call__()` to make a callable object that behaves like a function.
- **Class**. What we'll cover in this part.

There are numerous additional data structures that are part of Python's implementation internals; they are beyond the scope of this book.

One of the most powerful and useful features of Python, is its ability to define new *classes*. The next chapters will introduce the class and the basics of object-oriented programming.

CHAPTER

TWENTYTHREE

CLASSES

Object-oriented programming permits us to organize our programs around the interactions of *objects*. A *class* provides the definition of the structure and behavior of the objects; each object is an instance of a class. Consequently, a typical program is a number of class definitions and a final main function. The main function creates the objects that will perform the job of the program.

This chapter presents the basic techniques of defining classes. In *Semantics* we define the semantics of objects and the classes which define their attributes (instance variables) and behaviors. In *Class Definition: the class Statement* we show the syntax for creating class definitions; we cover the use of objects in *Creating and Using Objects*.

Python has some system-defined names that classes can exploit to make them behave like built-in Python classes, a few of these are introduced in *Special Method Names*. We provide some examples in *Some Examples*. Perhaps the most important part of working with objects is how they collaborate to do useful work; we introduce this in *Object Collaboration*

23.1 Semantics

Object-oriented programming focuses software design and implementation around the definitions of and interactions between individual objects. An object is said to *encapsulate* a state of being and a set of behaviors; it is both data and processing. Each instance of a class has individual copies of attributes which are tightly coupled with the class-wide operations. We can understand objects by looking at four features, adapted from [Rumbaugh91].

- **Identity**. Each object is unique and is distinguishable from all other objects. In the real world, two otherwise identical coffee cups can be distiguished as distinct objects. For example, they occupy different locations on our desk. In the world of a computer's memory, objects could be identified by their address, which would make them unique.
- **Classification**. This is sometimes called *Encapsulation*. Objects with the same attributes and behavior belong to a common *class*. Each individual object has unique attribute values. We saw this when we looked at the various collection classes. Two different `list` objects have the same general structure, and the same behavior. Both lists respond to `append()`, `pop()`, and all of the other methods of a `list`. However, each `list` object has a unique sequence of values.
- **Inheritance**. A class can inherit methods from a parent class, reusing common features. A superclass is more general, a subclass overrides superclass features, and is more specific. With the built-in Python classes, we've looked at the ways in which all immutable sequences are alike.
- **Polymorphism**. A general operation can have variant implementation methods, depending on the class of the object. We saw this when we noted that almost every class on Python has a + operation.

Between two floating-point numbers the + operation adds the numbers, between two lists, however, the + operation concatenates the lists.

Python's Implementation. A *class* is the Python-language definition of the features of individual *objects*: the names of the *attributes* and definitions of the *operations*.

Python implements the general notion of attribute as a dictionary of *instance variables* for an object. Python implements the general idea of an operation through a collection of methods or *method functions* of an object's class.

Note that all Python objects are instances of some class. This includes something as simple as `None` or `True`.

```
>>> type(None)
<type 'NoneType'>
>>> type(True)
<type 'bool'>
```

Additionally, a class also constructs new object instances for us. Once we've defined the class, we can then use it as a kind of factory to create new objects.

Class Definition. Python class definitions require us to provide a number of things.

- We must provide a distinct name to the class.
- We list the superclasses from which a subclass inherits features.

  In Python 2, classes should explicitly be defined as subclasses of `object`. In Python 3, this will be the default.

  We have *multiple inheritance* available in Python. This differs from the single-inheritance approach used by languages like Java.
- We provide method functions which define the operations for the class. We define the behavior of each object through its method functions.

  Note that the attributes of each object are created by an initialization method function (named `__init__()`) when the object is created.
- We can define attributes as part of the class definition. If we do, these will be class-level attributes, shared by all instances of the class.
- Python provides the required mechanism for unique identity. You can use the `id()` function to interrogate the unique identifier for each object.

Technically, a class definition creates a new `class` object. This Python object contains the definitions of the method functions. Additionally, a class object can also own class-level variables; these are, in effect, attributes which are shared by each individual object of that class.

We can use this class object to create class instance objects. It's the instances that do the real work of our programs. The class is simply a template or factory for creating the instance objects.

Duck Typing. Note that our instance variables are not a formal part of the class definition. This differs from Java or C++ where the instance variables must be statically declared.

Another consequence of Python's dynamic nature is that polymorphism is based on simple matching of method names. This is distinct from languages like Java or C++ where polymorphism depends on inheritance and precise class (or interface) relationships.

Python's approach to polymorphism is sometimes called *duck typing*: "if it quacks like a duck and walks like a duck it is a duck." If several objects have the common method names, they are effectively polymorphic with respect to those methods.

We're All Adults. The best programming practice is to treat each object as if the internal implementation details where completely opaque. Often, a class will have "public" methods that are a well-defined and supported interface, plus it will have "private" methods that are implementation details which can be changed without notice.

All other objects within an application should use only the methods and attributes that comprise the class interface. Some languages (like C++ or Java) have a formal distinction between interface and implementation. Python has a limited mechanism for making a distinction between the defined interface and the private implementation of a class.

The Python philosophy is sometimes called *We're All Adults*: there's little need for the (childish) formality between interface and implementation. Programmers can (and should) be trusted to read the documentation for a class and use the methods appropriately.

Python offers two simple technique sfor separating interface from implementation.

- We can use a leading '_' on an instance variable or method function name to make it more-or-less private to the class.
- We can use properties or descriptors to create more sophisticated protocols for accessing instance variables. We'll wait until *Attributes, Properties and Descriptors* to cover these more advanced techniques.

An Object's Lifecycle. Each instance of every class has a lifecycle. The following is typical of most objects.

1. **Definition**. The class definition is read by the Python interpreter (or it is a builtin class). Class definitions are created by the **class** statement. Examples of built-in classes include `file`, `str`, `int`, etc.
2. **Construction**. An instance of the class is constructed: Python allocates the namespace for the object's instance variables and associating the object with the class definition. The `__init__()` method is executed to initialize any attributes of the newly created instance.
3. **Access and Manipulation**. The instance's methods are called (similar to function calls we covered in *Functions*), by client objects or the main script. There is a considerable amount of collaboration among objects in most programs. Methods that report on the state of the object are sometimes called *accessors*; methods that change the state of the object are sometimes called *mutators* or *manipulators*.
4. **Garbage Collection**. Eventually, there are no more references to this instance. Typically, the variable with an object reference was part of the body of a function that finished, the namespace is dropped, and the variables no longer exist. Python detects this, and removes the referenced object from memory, freeing up the storage for subsequent reuse. This freeing of memory is termed *garbage collection*, and happens automatically. See *Garbage Collection* for more information.

Garbage Collection

It is important to note that Python counts references to objects. When object is no longer in use, the reference count is zero, the object can be removed from memory. This is true for all objects, especially objects of built-in classes like `str`. This frees us from the details of memory management as practiced by C++ programmers. When we do something like the following:

```
s= "123"
s= s+"456"
```

The following happens.

1. Python creates the string `"123"` and puts a reference to this string into the variable `s`.
2. Python creates the string `"456"`.
3. Python performs the string concatenation method between the string referenced by `s` and the string `"456"`, creating a new string `"123456"`.
4. Python assigns the reference to this new `"123456"` string into the variable `s`.
5. At this point, strings `"123"` and `"456"` are no longer referenced by any variables. These objects will be destroyed as part of garbage collection.

23.2 Class Definition: the class Statement

We create a class definition with a **class** statement. We provide the class name, the parent classes, and the method function definitions.

```
class name ( parent ) :
    suite
```

The *name* is the name of the class, and this name is used to create new objects that are instances of the class. Traditionally, class names are capitalized and class elements (variables and methods) are not capitalized.

The *parent* is the name of the parent class, from which this class can inherit attributes and operations. For simple classes, we define the parent as `object`. Failing to list `object` as a parent class is not – strictly speaking – a problem; using `object` as the superclass does make a few of the built-in functions a little easier to use.

Important: Python 3.0

In Python 3.0, using `object` as a parent class will no longer be necessary.

In Python 2.6, however, it is highly recommended.

The *suite* is a series of function definitions, which define the class. All of these function definitions must have a first positional argument, `self`, which Python uses to identify each object's unique attribute values.

The *suite* can also contain assignment statements which create instance variables and provide default values.

The suite typically begins with a comment string (often a triple-quoted string) that provides basic documentation on the class. This string becomes a special attribute, called `__doc__`. It is available via the `help()` function.

For example:

```
import random
class Die(object):
    """Simulate a 6-sided die."""
    def roll( self ):
        self.value= random.randint(1,6)
```

```
        return self.value
    def getValue( self ):
        return self.value
```

1. We imported the `random` module to provide the random number generator.
2. We defined the simple class named `Die`, and claimed it as a subclass of `object`. The indented suite contains three elements.
   - The docstring, which provides a simple definition of the real-world thing that this class represents. As with functions, the docstring is retrieved with the `help()` function.
   - We defined a method function named `roll()`. This method function has the mandatory positional parameter, `self`, which is used to qualifty the instance variables. The `self` variable is a namespace for all of the attributes and methods of this object.
   - We defined a method function named `getValue()`. This function will return the last value rolled.

When the `roll()` method of a `Die` object is executed, it sets that object's instance variable, `self.value`, to a random value. Since the variable name, `value`, is qualified by the instance variable, `self`, the variable is local to the specific instance of the object.

If we omitted the `self` qualifier, Python would create a variable in the local namespace. The local namespace ceases to exist at the end of the method function execution, removing the local variables.

23.3 Creating and Using Objects

Once we have a class definition, we can make objects which are instances of that class. We do this by evaluating the class as if it were a function: for example, '`Die()`'. When we make one of these class calls, two things will happpen.

- A new object is created. This object has a reference to its class definition.
- The object's initializer method, `__init__()`, is called. We'll look at how you define this method function in th next section.

Let's create two instances of our `Die` class.

```
>>> d1= Die()
>>> d2= Die()
>>> d1.roll(), d2.roll()
(6, 5)
>>> d1.getValue(), d2.getValue()
(6, 5)
>>> d1, d2
(<__main__.Die object at 0x607bb0>, <__main__.Die object at 0x607b10>)
>>> d1.roll(), d2.roll()
(1, 3)
>>> d1.value, d2.value
(1, 3)
```

1. We use the `Die` class object to create two variables, `d1`, and `d2`; both are new objects, instances of `Die`.
2. We evaluate the `roll()` method of `d1`; we also evaluate the `roll()` method of `d2`. Each of these calls sets the object's `value` variable to a unique, random number. There's a pretty good chance (1 in 6) that both values might happen to be the same. If they are, simply call '`d1.roll()`' and '`d2.roll()`' again to get new values.

3. We evaluate the `getValue()` method of each object. The results aren't too surprising, since the `value` attribute was set by the `roll()` method. This attribute will be changed the next time we call the `roll()` method.

4. We also ask for a representation of each object. If we provide a method named `__str__()` in our class, that method is used; otherwise Python shows the memory address associated with the object. All we can see is that the numbers are different, indicating that these instances are distinct objects.

23.4 Special Method Names

There are several special methods that are essential to the implementation of a class. Each of them has a name that begins and ends with double underscores. These method names are used implicitly by Python. Section 3.3 of the *Python Language Reference* provides the complete list of these special method names.

We'll look at the special method names in depth in *Creating or Extending Data Types*. Until then, we'll look at a few special method names that are used heavily.

`__init__`(*self, ...*)
: The `__init__()` method of a class is called by Python to initialize a newly-created object.

  Note that The `__init__()` method can accept parameters, but does not return anything. It sets the internal state of the object.

`__str__`(*self*)
: The `__str__()` method of a class is called whenever Python needs a string representation of an object. This is the method used by the `str()` built-in function. When printing an object, the `str()` is called implicitly to get the value that is printed.

`__repr__`(*self*)
: The `__repr__()` method of a class is used when we want to see the details of an object's values. This method is used by the `repr()` function.

Initializing an Object with `__init__()`. When you create an object, Python will both create the object and also call the object's `__init__()` method. This method function can create the object's instance variables and perform any other one-time initialization. There are, typically, two kinds of instance variables that are created by the `__init__()` method: variables based on parameters and variables that are independent of any parameters.

Here's an example of a company description that might be suitable for evaluating stock performance. In this example, all of the instance variables (`self.name`, `self.symbol`, `self.price`) are based on parameters to the `__init__()` method.

```
class Company( object ):
    def __init__( self, name, symbol, stockPrice ):
        self.name= name
        self.symbol= symbol
        self.price= stockPrice
    def valueOf( self, shares ):
        return shares * self.price
```

When we create an instance of Company, we use code like this.

```
c1= Company( "General Electric", "GE", 30.125 )
```

This will provide three values to the parameters of `__init__()`.

String value of an object with `__str__()`. The `__str__()` method function is called whenever an instance of a class needs to be converted to a string. Typically, this occus when we use the `str()` function on an object. Also, when we reference object in a **print** statement, the `str()` function is evaluated. Consider this definition of the class `Card`.

```
class Card( object ):
    def __init__( self, rank, suit ):
        self.rank= rank
        self.suit= suit
        self.points= rank
    def hard( self ):
        return self.points
    def soft( self ):
        return self.points
```

When we try to print an instance of the class, we get something like the following.

```
>>> c = Card( 3, "D" )
>>> c
<__main__.Card object at 0x607fb0>
>>> str(c)
'<__main__.Card object at 0x607fb0>'
```

This is the default behavior for the `__str__()` method. We can, however, override this with a function that produces a more useful-looking result.

```
def __str__( self ):
    return "%2d%s" % (self.rank, self.suit)
```

Adding this method function converts the current value of the die to a string and returns this. Now we get something much more useful.

```
>>> d = Card( 4, "D" )
>>> d
<__main__.Card object at 0x607ed0>
>>> str(d)
' 4D'
>>> print d
 4D
```

Representation details with `__repr__()`. While the `__str__()` method produces a human-readable string, we sometimes want the nitty-gritty details. The `__repr__()` method function is evaluated whenever an instance of a class must have its detailed representation shown. This is usually done in response to evaluating the `repr()` function. Examples include the following:

```
>>> repr(c)
'<__main__.Card object at 0x607fb0>'
```

If we would like to produce a more useful result, we can override the `__repr__()` function. The objective is to produce a piece of Python programming that would reconstruct the original object.

```
def __repr__( self ):
    return "Card(%d,%r)" % (self.rank,self.suit)
```

We use `__repr__()` to produce a clear definition of how to recreate the given object.

```
>>> c = Card( 5, "D" )
>>> repr(c)
"Card(5,'D')"
```

Special Attribute Names. In addition to the special method names, each object has a number of special attributes. These are documented in section 2.3.10 of the *Python Library Reference*.

We'll look at just a few, including `__dict__`, `__class__` and `__doc__`.

`__dict__` The attribute variables of a class instance are kept in a special dictionary object named `__dict__`. As a consequence, when you say `self.attribute= value`, this has almost identical meaning to `self.__dict__['attribute']= value`.

Combined with the % string formatting operation, this feature is handy for writing `__str__()` and `__repr__()` functions.

```
def __str__( self  ):
    return "%(rank)2s%(suit)s" % self.__dict__
def __repr__( self ):
    return "Card(%(rank)r,%(suit)r)" % self.__dict__
```

`__class__` This is the class to which the object belongs.

`__doc__` The docstring from the class definition.

23.5 Some Examples

We'll look at two examples of class definitions. In the both examples, we'll write a script which defines a class and then uses the class.

die.py

```
#!/usr/bin/env python
"""Define a Die and simulate rolling it a dozen times."""
import random
class Die(object):
    """Simulate a generic die."""
    def __init__( self ):
        self.sides= 6
        self.roll()
    def roll( self ):
        """roll() -&gt; number
        Updates the die with a random roll."""
        self.value= 1+random.randrange(self.sides)
        return self.value
    def getValue( self ):
        """getValue() -&gt; number
        Return the last value set by roll()."""
        retur self.value

def main():
    d1, d2 = Die(), Die()
    for n in range(12):
```

```
        print d1.roll(), d2.roll()

main()
```

1. This version of the `Die` class contains a doc string and three methods: `__init__()`, `roll()` and `getValue()`.
2. The `__init__()` method, called a *constructor*, is called automatically when the object is created. We provide a body that sets two instance variables of a `Die` object. It sets the number of sides, `sides` to 6 and it then rolls the die a first time to set a value.
3. The `roll()` method, called a *manipulator*, generates a random number, updating the `value` instance variable.
4. The `getValue()` method, called a *getter* or an *accessor*, returns the value of the value instance variable, `value`. Why write this kind of function? Why not simply use the instance variable? We'll address this in the FAQ's at the end of this chapter.<
5. The `main()` function is outside the `Die` class, and makes use of the class definition. This function creates two `Die`, `d1` and `d2`, and then rolls those two `Die` a dozen times.
6. This is the top-level script in this file. It executes the `main()` function, which – in turn – then creates `Die` objects.

The `__init__()` method can accept arguments. This allows us to correctly initialize an object while creating it. For example:

point.py

```
#!/usr/bin/env python
"""Define a geometric point and a few common manipulations."""
class Point( object ):
    """A 2-D geometric point."""
    def __init__( self, x, y ):
        """Create a point at (x,y)."""
        self.x, self.y = x, y
    def offset( self, xo, yo ):
        """Offset the point by xo parallel to the x-axis
        and yo parallel to the y-axis."""
        self.x += xo
        self.y += yo
    def offset2( self, val ):
        """Offset the point by val parallel to both axes."""
        self.offset( val, val )
    def __str__( self ):
        """Return a pleasant representation."""
        return "(%g,%g)" % ( self.x, self.y )
```

1. This class, `Point`, initializes each point object with the x and y coordinate values of the point. It also provides a few member functions to manipulate the point.
2. The `__init__()` method requires two argument values. A client program would use '`Point( 640, 480 )`' to create a `Point` object and provide arguments to the `__init__()` method function.
3. The `offset()` method requires two argument values. This is a manipulator which changes the state of the point. It moves the point to a new location based on the offset values.

4. The `offset2()` method requires one argument value. This method makes use of the `offset()` method. This kind of reuse assures that both methods are perfectly consistent.
5. We've added a `__str__()` method, which returns the string representation of the object. When we print any object, the **print** statement (or `print()` function) automatically calls the `str()` built-in function. The `str()` function uses the `__str__()` method of an object to get a string representation of the object.

```
def main():
    obj1_corner = Point( 12, 24 )
    obj2_corner = Point( 8, 16 )
    obj1_corner.offset( -4, -8 )
    print obj1_corner
    print obj2_corner

main()
```

1. We construct a `Point`, named `obj1_corner`.
2. We manipulate the `obj1_corner Point` to move it a few pixels left and up.
3. We access the `obj1_corner` object by printing it. This will call the `str()` function, which will use the `__str__()` method to get a string representation of the `Point`.

The `self` Variable. These examples should drive home the ubiquirty of the `self` variable. Within a class, we must be sure to use `self.` in front of the method function names as well as attribute names. For example, our `offset2()` function accepts a single value and calls the object's `offset()` function using '`self.offset( val, val )`'.

The `self` variable is so important, we'll highlight it.

Important: The `self` variable

In Python, the `self` qualifier is simply required all the time.

Programmers experienced in Java or C++ may object to seeing the explicit `self.` in front of all variable names and method function names. In Java and C++, there is a `this.` qualifier which is assumed by the compiler. Sometimes this qualifier is required to disambiguate names, other times the compiler can work out what you meant.

Some programmers complain that `self` is too much typing, and use another variable name like `my` . This is unusual, generally described as a bad policy, but it is not unheard of.

An object is a namespace; it contains the attributes. We can call the attributes *instance variables* to distinguish them from global variables and free variables.

Instance Variables These are part of an object's namespace. Within the method functions of a class, these variables are qualified by `self`.

Outside the method functions of the class, these variables are qualified by the object's name. In *die.py*, the `main()` function would refer to '`d1.value`' to get the value attribute of object `d1`.

Global Variables Global variables are pare of a special global namespace. The **global** statement creates the variable name in the global namespace instead of the local namespace. See *The global Statement* for more information.

While it's easy to refer to global variables, it's not as easy to create them.

Free Variables Within a method function, a variable that is not qualified by `self.`, nor marked by **global** is a free variable. Python checks the local namespace, then the global namespace for this variable. This ambiguity is, generally, not a good idea.

23.6 Object Collaboration

Object-oriented programming helps us by encapsulating data and processing into a tidy class definition. This encapsulation assures us that our data is processed correctly. It also helps us understand what a program does by allowing us to ignore the details of an object's implementation.

When we combine multiple objects into a collaboration, we exploit the power of ecapsulation. We'll look at a simple example of creating a composite object, which has a number of detailed objects inside it.

Defining Collaboration. Defining a collaboration means that we are creating a class which depends on one or more other classes. Here's a new class, `Dice`, which uses instances of our `Die` class. We can now work with a `Dice` collection, and not worry about the details of the individual `Die` objects.

dice.py - part 1

```
class Dice( object ):
    """Simulate a pair of dice."""
    def __init__( self ):
        "Create the two Die objects."
        self.myDice = ( Die(), Die() )
    def roll( self ):
        "Return a random roll of the dice."
        for d in self.myDice:
            d.roll()
    def getTotal( self ):
        "Return the total of two dice."
        t= 0
        for d in self.myDice:
            t += d.getValue()
        return t
    def getTuple( self ):
        "Return a tuple of the dice values."
        return tuple( [d.getValue() for d in self.myDice] )
    def hardways( self ):
        "Return True if this is a hardways roll."
        return self.myDice[0].getValue() == self.myDice[1].getValue()
```

1. We're building on the definition of a single `Die`, from the `die.py` example. We didn't repeat it here to save some space in the example.
2. This class, `Dice`, defines a pair of `Die` instances.
3. The `__init__()` method creates an instance variable, `myDice`, which has a tuple of two instances of the `Die` class.
4. The `roll()` method changes the overall state of a given `Dice` object by changing the two individual `Die` objects it contains. This manipulator uses a **for** loop to assign each of the internal `Die` objects to `d`. In the loop it calls the `roll()` method of the `Die` object, `d`. This technique is called *delegation*: a `Dice` object delegates the work to two individual `Die` objects. We don't know, or care, how each `Die` computes it's next value.
5. The `getTotal()` method computes a sum of all of the `Die` objects. It uses a **for** loop to assign each of the internal `Die` objects to `d`. It then uses the `getValue()` method of `d`. This is the official interface method; by using it, we can remain blissfully unaware of how `Die` saves it's state.
6. The `getTuple()` method returns the values of each `Die` object. It uses a list comprehension to create a `list` of the `value` instance variables of each `Die` object. The built-in function `tuple()` converts the

list into an immutable tuple.

7. The `hardways()` method examines the value of each `Die` objec to see if they are the same. If they are, the total was made "the hard way."

The `getTotal()` and `getTuple()` methods return basic attribute information about the state of the object. These kinds of methods are often called *getters* because their names start with "get".

Collaborating Objects. The following function exercises an instance this class to roll a `Dice` object a dozen times and print the results.

```
def test2():
    x= Dice()
    for i in range(12):
        x.roll()
        print x.getTotal(), x.getTuple()
```

This function creates an instance of `Dice`, called `x`. It then enters a loop to perform a suite of statements 12 times. The suite of statements first manipulates the `Dice` object using its `roll()` method. Then it accesses the `Dice` object using `getTotal()` and `getTuple()` method.

Here's another function which uses a `Dice` object. This function rolls the dice 1000 times, and counts the number of hardways rolls as compared with the number of other rolls. The fraction of rolls which are hardways is ideally 1/6, 16.6%.

```
def test3():
    x= Dice()
    hard= 0
    soft= 0
    for i in range(1000):
        x.roll()
        if x.hardways(): hard += 1
        else: soft += 1
    print hard/1000., soft/1000.
```

Independence. One point of object collaboration is to allow us to modify one class definition without breaking the entire program. As long as we make changes to Die that don't change the interface that Die uses, we can alter the implementation of Die all we want. Similarly, we can change the implementation of Dice, as long as the basic set of methods are still present, we are free to provide any alternative implementation we choose.

We can, for example, rework the definition of `Die` confident that we won't disturb `Dice` or the functions that use `Dice` (`test2()` and `test3()`). Let's change the way it represents the value rolled on the die.

Here's an alternate implemetation of Die. In this case, the private instance variable, `value`, will have a value in the range $0 \leq value < 5$. When `getValue()` adds 1, the value is in the usual range for a single die, $1 \leq value < 6$.

```
class Die(object):
    """Simulate a 6-sided die."""
    def __init__( self ):
        self.roll()
    def roll( self ):
        self.value= random.randint(0,5)
        retuen self.value
    def getValue( self ):
        return 1+self.value
```

Since this version of `Die` has the same interface as other versions of `Die` in this chapter, it is polymorphic with them. There could be performance differences, depending on the performance of `random.randint()` and `random.randrange()` functions. Since `random.randint()` has a slightly simpler definition, it may process more quickly.

Similarly, we can replace `Die` with the following alternative. Depending on the performance of `choice()`, this may be faster or slower than other versions of `Die`.

```
class Die(object):
    """Simulate a 6-sided die."""
    def __init__( self ):
        self.domain= range(1,7)
    def roll( self ):
        self.value= random.choice(self.domain)
        return self.value
    def getValue( self ):
        return self.value
```

23.7 Class Definition Exercises

These exercises are considerably more sophisticated then the exercises in previous parts. Each of these sections describes a small project that requires you to create a number of distinct classes which must collaborate to produce a useful result.

When we document a method function, we don't mention the `self` variable. This is required when you actually write the class definition. However, we don't show it in the documentation.

23.7.1 Stock Valuation

A `Block` of stock has a number of attributes, including a purchase price, purchase date, and number of shares. Commonly, methods are needed to compute the total spent to buy the stock, and the current value of the stock. A `Position` is the current ownership of a company reflected by all of the blocks of stock. A `Portfolio` is a collection of `Positions` ; it has methods to compute the total value of all `Blocks` of stock.

When we purchase stocks a little at a time, each `Block` has a different price. We want to compute the total value of the entire set of `Block` s, plus an average purchase price for the set of `Block` s.

The StockBlock class. First, define a `StockBlock` class which has the purchase date, price per share and number of shares. Here are the method functions this class should have.

`__init__`(*self, date, price, number_of_shares*)
: Populate the individual fields of date, price and number of shares. This is information which is part of the `Position`, made up of individual blocks.

  Don't include the company name or ticker symbol.

`__str__`(*self*)
: Return a nicely formatted string that shows the date, price and shares.

`getPurchValue`(*self*)
: Compute the value as purchase price per share ×shares.

`getSaleValue`(*self, salePrice*)
: Use `salePrice` to compute the value as sale price per share ×shares.

`getROI`(*self, salePrice*)
Use `salePrice` to compute the return on investment as (sale value - purchase value) ÷purchase value.

Note that this is not the annualized ROI. We'll address this issue below.

We can load a simple database with a piece of code the looks like the following. The first statement will create a sequence with four blocks of stock. We chose variable name that would remind us that the ticker symbols for all four is 'GM'. The second statement will create another sequence with four blocks.

```
blocksGM = [
    StockBlock( purchDate='25-Jan-2001', purchPrice=44.89, shares=17 ),
    StockBlock( purchDate='25-Apr-2001', purchPrice=46.12, shares=17 ),
    StockBlock( purchDate='25-Jul-2001', purchPrice=52.79, shares=15 ),
    StockBlock( purchDate='25-Oct-2001', purchPrice=37.73, shares=21 ),
]
blocksEK = [
    StockBlock( purchDate='25-Jan-2001', purchPrice=35.86, shares=22 ),
    StockBlock( purchDate='25-Apr-2001', purchPrice=37.66, shares=21 ),
    StockBlock( purchDate='25-Jul-2001', purchPrice=38.57, shares=20 ),
    StockBlock( purchDate='25-Oct-2001', purchPrice=27.61, shares=28 ),
]
```

The Position class. A separate class, `Position`, will have an the name, symbol and a sequence of `StockBlocks` for a given company. Here are some of the method functions this class should have.

`Position.()`

`__init__`(*self, name, symbol, * blocks*)
Accept the company name, ticker symbol and a collection of `StockBlock` instances.

`__str__`(*self*)
Return a string that contains the symbol, the total number of shares in all blocks and the total purchse price for all blocks.

`getPurchValue`(*self*)
Sum the purchase values for all of the `StockBlocks` in this `Position`. It delegates the hard part of the work to each `StockBlock`'s `getPurchValue()` method.

`getSaleValue`(*self, salePrice*)
The `getSaleValue()` method requires a `salePrice`; it sums the sale values for all of the `StockBlocks` in this `Position`. It delegates the hard part of the work to each `StockBlock`'s `getSaleValue()` method.

`getROI`(*self, salePrice*)
The `getROI()` method requires a `salePrice`; it computes the return on investment as (sale value - purchase value) ÷purchase value. This is an ROI based on an overall yield.

Note that this is not the annualized ROI. We'll address this issue below.

We can create our `Position` objects with the following kind of initializer. This creates a sequence of three individual `Position` objects; one has a sequence of GM blocks, one has a sequence of EK blocks and the third has a single CAT block.

```
portfolio= [
    Position( "General Motors", "GM", blocksGM ),
    Position( "Eastman Kodak", "EK", blocksEK )
    Position( "Caterpillar", "CAT",
        [ StockBlock( purchDate='25-Oct-2001',
            purchPrice=42.84, shares=18 ) ] )
]
```

An Analysis Program. You can now write a main program that writes some simple reports on each `Position` object in the `portfolio`. One report should display the individual blocks purchased, and the purchase value of the block. This requires iterating through the `Positions` in the `portfolio`, and then delegating the detailed reporting to the individual `StockBlocks` within each `Position`.

Another report should summarize each position with the symbol, the total number of shares and the total value of the stock purchased. The overall average price paid is the total value divided by the total number of shares.

In addition to the collection of `StockBlock` objects that make up a `Position`, one additional piece of information that is useful is the current trading price for the `Position`. First, add a `currentPrice` attribute, and a method to set that attribute. Then, add a `getCurrentValue()` method which computes a sum of the `getSaleValue()` method of each `StockBlock`, using the trading price of the `Position`.

Annualized Return on Investment. In order to compare portfolios, we might want to compute an annualized ROI. This is ROI as if the stock were held for eactly one year. In this case, since each block has different ownership period, the annualized ROI of each block has to be computed. Then we return an average of each annual ROI weighted by the sale value.

The annualization requires computing the duration of stock ownership. This requires use of the `time` module. We'll cover that in depth in *Dates and Times: the time and datetime Modules*. The essential feature, however, is to parse the date string to create a time object and then get the number of days between two time objects. Here's a code snippet that does most of what we want.

```
>>> import datetime
>>> dt1="25-JAN-2001"
>>> tm1= datetime.datetime.strptime( dt1, "%d-%b-%Y" ).date()
>>> tm1
datetime.date(2001, 1, 25)
>>> dt2= "25-JUN-2001"
>>> tm2= datetime.datetime.strptime( dt2, "%d-%b-%Y" ).date()
>>> tm2
datetime.date(2001, 6, 25)
>>> tm2-tm1
datetime.timedelta(151)
>>> (tm2-tm1).days/365.25
0.4134154688569473
```

In this example, `tm1` and `tm2` are `datetime.date` objects with details parsed from the date string by `datetime.datetime.strptime()`.

We can subtract two `datetime.date` objects and get a `datetime.timedelta` that has the number of days between the two dates. A timedelta can be used on `datetime.datetime` objects to get days and seconds between two date-time stamps.

In this case, there are 151 days between the two dates. When we divide by the number of days in a year (including leap days) we get the fraction of a year between the two dates.

`ownedFor`(*self, saleDate*)
: This method computes the number of years the stock was owned.

`annualROI`(*self, salePrice, saleDate*)
: This methods divides the gross ROI by the duration in years to return the annualized ROI.

Once we've added the necessary support to `StockBlock`, we can then add to `Position`.

`annualROI`(*self, salePrice, saleDate*)
: Given the `StockBlock.annualROI()` method, we can then compute a weighted average of each block's ROI. This is the annualized ROI for the entire position.

23.7.2 Dive Logging and Surface Air Consumption Rate

The Surface Air Consumption Rate is used by SCUBA divers to predict air used at a particular depth. If we have a sequence of `Dive` objects with the details of each dive, we can do some simple calculations to get averages and ranges for our air consumption rate.

For each dive, we convert our air consumption at that dive's depth to a normalized air consumption at the surface. Given depth (in feet), d, tarting tank pressure (psi), s, final tank pressure (psi), f, and time (in minutes) of t, the SACR, c, is given by the following formula.

$$c = \frac{33(s-f)}{t(d+33)}$$

Typically, you will average the SACR over a number of similar dives.

The `Dive` Class. You will want to create a `Dive` class that contains attributes which include start pressure, finish pressure, time and depth. Typical values are a starting pressure of 3000, ending pressure of 700, depth of 30 to 80 feet and times of 30 minutes (at 80 feet) to 60 minutes (at 30 feet). SACR's are typically between 10 and 20. Your `Dive` class should have a method named `Dive.getSACR()` which returns the SACR for that dive.

To make life a little simpler putting the data in, we'll treat time as string of '`HH:MM`', and use string functions to pick this apart into hours and minutes. We can save this as tuple of two intgers: hours and minutes. To compute the duration of a dive, we need to normalize our times to minutes past midnight, by doing '`hh*60+mm`'. Once we have our times in minutes past midnight, we can easily subtract to get the number of minutes of duration for the dive. You'll want to create a method function `Dive.getDuration()` to do just this computation for each dive.

`__init__`(*self, pressure_start, pressure_finish, time_start, time_finish, depth*)
: The `__init__()` method will initialize a `Dive` with the start and finish pressure in PSI, the in and out time as a string, and the depth as an integer. This method should parse both the `time_start` string and `time_finish` string and normalize each to be minutes after midnight so that it can compute the duration of the dive. Note that a practical dive log would have additional information like the date, the location, the air and water temperature, sea state, equipment used and other comments on the dive.

`__str__`(*self*)
: The `__str__()` method should return a nice string representation of the dive information.

`getSACR`(*self*)
: The `getSACR()` method can compute the SACR value from the starting pressure, final pressure, time and depth information.

The `DiveLog` Class. We'll want to initialize our dive log as follows:

```
log = [
    Dive( start=3100, finish=1300, in="11:52", out="12:45", depth=35 ),
    Dive( start=2700, finish=1000, in="11:16", out="12:06", depth=40 ),
    Dive( start=2800, finish=1200, in="11:26", out="12:06", depth=60 ),
    Dive( start=2800, finish=1150, in="11:54", out="12:16", depth=95 ),
]
```

Rather than use a simple sequence of `Dive` objects, you can create a `DiveLog` class which has a sequence of `Dive` objects plus a `DiveLog.getAvgSACR()` method. Your `DiveLog` method can be initiatlized with a sequence of dives, and can have an append method to put another dive into the sequence.

Exercising the Dive and DiveLog Classes. Here's how the final application could look. Note that we're using an arbitrary number of argument values to the `Dive.__init__()` function, therefore, it has to be declared as '`def __init__( self, *listOfDives )`'

```
log= DiveLog(
    Dive( start=3100, finish=1300, in="11:52", out="12:45", depth=35 ),
    Dive( start=2700, finish=1000, in="11:16", out="12:06", depth=40 ),
    Dive( start=2800, finish=1200, in="11:26", out="12:06", depth=60 ),
    Dive( start=2800, finish=1150, in="11:54", out="12:16", depth=95 ),
)
print log.getAvgSACR()
for d in log.dives:
    print d
```

23.7.3 Multi-Dice

If we want to simulate multi-dice games like Yacht, Kismet, Yatzee, Zilch, Zork, Greed or Ten Thousand, we'll need a collection that holds more than two dice. The most common configuration is a five-dice collection. In order to be flexible, we'll need to define a `Dice` object which will use a `tuple`, `list` or `Set` of individual `Die` instances. Since the number of dice in a game rarely varies, we can also use a `FrozenSet`.

Once you have a `Dice` class which can hold a collection of dice, you can gather some statistics on various multi-dice games. These games fall into two types. In both cases, the player's turn starts with rolling all the dice, the player can then elect to re-roll or preserve selected dice.

- **Scorecard Games**. In Yacht, Kismet and Yatzee, five dice are used.

  The first step in a player's turn is a roll of all five dice. This can be followed by up to two additional steps in which the player decides which dice to preserve and which dice to roll.

  The player is trying to make a scoring hand. A typical scorecard for these games lists a dozen or more "hands" with associated point values. Each turn must fill in one line of the scorecard; if the dice match a hand which has not been scored, the player enters a score. If a turn does not result in a hand that matches an unscored hand, then a score of zero is entered.

  The game ends when the scorecard is filled.

  A typical score card has spaces for 3-of-a-kinds (1 through 6) worth the sum of the scoring dice; a four-of-a-kind and full house (3 of a kind and a pair) worth the sum of the dice; a small straight (4 in a row) worth 25 points; a long straight (all 5 in a row) worth 30 points; a "chance" (sum of the dice), plus 5-of-a-kind worth 50 points.

  Some games award a 35 point bonus for getting all six 3-of-a-kind scores.

- **Point Games**. In Zilch, Zork, Green or Ten Thousand, five dice are typical, but there are some variations.

  The player in this game has no limit on the number of steps in their turn. The first step is to roll all the dice and determine a score. Their turn ends when they perceive the risk of another step to be too high, or they've made a roll which gives them a score of zero (or zilch) for the turn.

  Typically, if the newly rolled dice are non-scoring, their turn is over with a score of zero. At each step, the player is looking at newly rolled dice which improve their score.

  The game ends when someone has a score of 10,000.

  A tyipcal set of rules awards a straight 1000. Three-of-a-kind scores 100 ×the die's value (except three ones is 1000 points). After removing any three-of-a-kinds, each die showing 1 scores 100, each die showing 5 scores 50. Additionally, some folks will score 1000 ×the die's value for five-of-a-kind.

Our `MultiDice` class will be based on the example of `Dice` in this chapter. In addition to a collection of `Die` instances (a sequence, `Set` or `FrozenSet`), the class will have the following methods.

`__init__`(*self, dice*)
When initializing an instance of `MultiDice`, you'll create a collection of individual `Die` instances. You can use a sequence of some kind, a `Set` or a `FrozenSet`.

`roll`(*self*)
Roll all dice in the sequence or Set. Note that your choice of collection doesn't materially alter this method. That's a cool feature of Python.

`getDice`(*self*)
This method returns the collection of dice as a tuple so that a client class can examine them and potentialy re-roll some or all of the dice.

`reroll`(*self, * dice*)
Roll just the given dice. Remember that the `MultiDice.getDice()` returned the actual dice objects from our set. When the client program gives these objects back to us, we don't need to search through our sequence or set to locate the underlying objects. We've been given the objects.

`score`(*self*)
This method will score the hand, returning a `list` of two-tuples. Each two-tuple will have the name of the hand and the point value for the particular game. In some cases, there will be multiple ways to score a hand, and the `list` will reflect all possible scorings of the hand, in order from most valuable to least valuable. In other cases, the `list` will only have a single element.

It isn't practical to attempt to write a universal `MultiDice` class that covers all variations of dice games. Rather than write a gigantic does-everything class, the better policy is to create a family of classes that build on each other using inheritance. We'll look at this in *Inheritance*.

For this exercise, you'll have to pick one game and compute the score for that particular game. Later, we'll see how to create an inheritance hierarchy that can cover all of these multi-dice games.

For the scorecard games (Yacht, Kismet, Yatzee), we want to know if this set of dice matches any of the scorecard hands. In many cases, a set of dice can match a number of potential hands. A hand of all five dice showing the same value (e.g, a 6) is matches the sixes, three of a kind, four of a kind, five of a kind and wild-card rows on most game score-sheets. A sequence of five dice will match both a long straight and a short straight.

Common Scoring Methods. No matter which family of games you elect to pursue, you'll need some common method functions to help score a hand. The following methods will help to evaluate a set of dice to see which hand it might be.

`matchDie`(*self, die*)
Give a `Die`, use `matchValue()` to partition the dice based on the value of the given `Die`'s value.

`matchValue`(*self, number*)
Given a numeric value, partition the dice into two sets: the dice which have a value that matches the given `Die`, and the remaining `Die` which do not match the value.

Return both sets.

`NOfAKind`(*self, n*)
This functions will evaluate `MultiDice.matchDie()` for each `Die` in the collection. If any given `Die` has a `matchDie()` with a match set that contains `n` matching dice, the hand as a whole matches the template.

This method can be used for 3 of a kind, 4 of a kind and 5 of a kind.

This method returns the matching dice or None if the hand did not have N-of-a-kind. The matching dice set can then be summed (for the hands that count only scoring dice) or the entire set of dice can be summed (for the hands that count all dice.)

`largeStraight`(*self*)
: This function must establish that all five dice form a sequence of values from 1 to 5 or 2 to 6. There must be no gaps and no duplicated values.

`smallStraight`(*self*)
: This function must establish that four of the five dice form a sequence of values. There are a variety of ways of approaching this; it is actually a challenging algorithm.

  Here's one approach: create a sequence of dice, and sort them into order. Look for an ascending sequence with one "irrelevant" die in it. This irrelevant die must be either (a) a gap at the start of the sequence (1, 3, 4, 5, 6) or (b) a gap at the end of the sequence (1, 2, 3, 4, 6) or (c) a single duplicated value (1, 2, 2, 3, 4, 5) within the sequence.

`chance`(*self*)
: The sum of the dice values. It is a number between 5 and 30.

Design Notes

This isn't the best way to handle scoring. A better way is to use the **Strategy** design pattern and define a separate class for scoring a game. The overall game can then use a simple, generic `MultiDice` instance.
Each game's scoring class, in turn, would use **Strategy** to delegate the rules for matching and scoring a hand to separate objects.
We would define a class for each kind of hand. Each various kinds of hand objects can interrogate the dice to determine if the dice matched its distinct pattern. Each hand object, besides checking for a match, can also encapsulate the score for the hand.
This is something we'll look at in *Strategy*.

Scoring Yacht, Kismet and Yatzee. For scoring these hands, your overall `score()` method function will step through the candidate hands in a specific order. Generally, you'll want to check for `fiveOfAKind()` first, since `fourOfAKind()` and `threeOfAKind()` will also be true for this hand. Similarly, you'll have to check for `largeStraight()` before `smallStraight()`.

Your `score()` method will evaluate each of the scoring methods. If the method matches, your method will append a two-tuple with the name and points to the list of scores.

Scoring Zilch, Zork and 10,000. A scoring hand's description can be relatively complex in these games. For example, you may have a hand with three 2's, a 1 and a 5. This is worth 350. The description has two parts: the three-of-a-kind and the extra 1's and 5's. Here are the steps for scoring this game.

1. Evaluate the `largeStraight()` method. If the hand matches, then return a `list` with an appropriate 2-tuple.
2. If you're building a game variation where five of a kind is a scoring hand, then evaluate `fiveOfAKind()`. If the hand matches, then return a list with an appropriate 2-tuple.
3. Three of a kind. Evaluate the `threeOfAKind()` method. This will create the first part of the hand's description.
   - If the matching set has exactly three dice, then the set of unmatched dice must be examined for additional 1's and 5's. The first part of the hand's description string is three-of-a-kind.
   - If the matching has four or five dice, then one or two dice must be popped from the matching set and added to the non-matching set. The set of unmatched dice must be examined for addtional 1's and 5's. The first part of the hand's description string is three-of-a-kind.
   - If there was no set of three matching dice, then all the dice are in the non-matching set, which is checked for 1's and 5's. The string which describes the hand has no first part, since there was no three-of-a-kind.

4. 1-5's. Any non-matching dice from the `threeOfAKind()` test are then checked using `matchValue()` to see if there are 1's or 5's. If there are any, this is the second part of the hand's description. If there are none, then there's no second part of the description.

5. The final step is to assemble the description. There are four cases: nothing, three-of-a-kind with no 1-5's, 1-5's with no three-of-a-kind, and three-of-a-kind plus 1-5's.

   In the nothing case, this is a non-scoring hand. In the other three cases, it is a scoring hand, and you can assign point values to each part of the description.

Exercising The Dice. Your main script should create a `MultiDice` object, execute an initial roll and score the result. It should then pick three dice to re-roll and score the result. Finally, it should pick one die, re-roll this die and score the result. This doesn't make sophisticated strategic decisions, but it does exercise your `MultiDice` object thoroughly.

When playing a scorecard game, the list of potential hands is examined to fill in another line on the scorecard. When playing a points game, each throw must result in a higher score than the previous throw or the turn is over.

The Player's Decision

When playing these games, a human player will generally glance at the dice, form a pattern, and decide if the dice are "close" to one of the given hands. This is a challenging deision process to model.
To create a proper odds-based judgement of possible outcomes, one would have to enumerate all possible games trees.
Consider that there are 7,776 possible ways to roll the initial five dice. From here one can reroll from 0 to all five (7,776 outcomes) dice.
For scorecard games, it's possible to enumerate all possible game trees because there are only three total rolls. While there are a lot of different ways for the game to evolve, there are only a few scoring hands as the final result. Each scoring hand has a value and a count of alternative trees that lead to that hand.

23.7.4 Rational Numbers

A Rational number is a ratio of two integers. Examples include $1/2, 2/3, 22/7, 355/113$. We can do arithmetic operations on rational numbers. We can display them as proper fractions (`3 1/7`), improper fractions (`22/7`) or decimal expansions (`3.1428571428571428`).

The essence of this class is to save a rational number and perform arithmetic operations on this number or between two rational numbers.

It's also important to note that all arithmetic operations will create a new `Rational` number computed from the inputs. This makes our object mostly immutable, which is the expected behavior for numbers.

We'll start by defining methods to add and multiply two rational values. Later, we'll delve into the additional methods you'd need to write to create a robust, complete implementation.

You'll write `__add__()` and `__mul__()` methods that will perform their processing with two `Rational` values: `self` and `other`. In both cases, the variable `other` has to be another `Rational` number instance.

You can check this with a simple **assert** statement. '`assert type(self) == type(other)`'. Generally, however, this extra checking isn't essential. If you try to use a non-Rational number, you'll get an `AttributeError` exception when you try to access the various parts of the Rational number.

Design. A Rational class has two attributes: the numerator and the denominator of the value. These are both integers. Here are the various methods you should create.

`__init__`(*self, numerator, denominator=1*)
Accept the numerator and denominator values. It can have a default value for the denominator of 1. This gives us two constructors: '`Rational(2,3)`' and '`Rational(4)`'. The first creates the fraction 2/3. The second creates the fraction 4/1.

This method should call the `Rational._reduce()` method to assure that the fraction is properly reduced. For example, '`Rational(8,4)`' should automatically reduce to a numerator of 2 and a denominator of 1.

`__str__`(*self*)
Return a nice string representation for the rational number, typically as an improper fraction. This gives you the most direct view of your `Rational` number.

You should provide a separate method to provide a proper fraction string with a whole number and a fraction. This other method would do additional processing to extract a whole name and remainder.

`__float__`(*self*)
Return the floating-point value for the fraction. This method is called when a program does '`float( rational )`'.

`__add__`(*self, other*)
Create and return a new `Rational` number that is the sum of `self` and `other`.

Sum of $S + O$ where S and O are `Rational` numbers, $\frac{S_n}{S_d}$ and $\frac{O_n}{O_d}$.

$$\frac{S_n}{S_d} + \frac{O_n}{O_d} = \frac{S_n \times O_d + O_n \times S_d}{S_d \times O_d}$$

Example: 3/5 + 7/11 = (33 + 35)/55 = 71/55.

`__mul__`(*self, other*)
Create and returns a new `Rational` number that is the product of `self` and `other`.

This new fraction that has a numerator of (self.numerator ×other.numerator), and a denominator of (self.denominator ×other.denominator).

Product of $S + O$ where S and O are `Rational` numbers, $\frac{S_n}{S_d}$ and $\frac{O_n}{O_d}$.

$$\frac{S_n}{S_d} \times \frac{O_n}{O_d} = \frac{S_n \times O_n}{S_d \times O_d}$$

Example: 3/5 ×7/11 = 21/55.

`_reduce`(*self*)
Reduce this Rational number by removing the greatest common divisor from the numerator and the denominator. This is called by `Rational.__init__()`, `Rational.__add__()`, `Rational.__mul__()`, assure that all fractions are reduced.

Reduce is a two-step operation. First, find the greatest common divisor between the numerator and denominator. Second, divide both by this divisor. For example 8/4 has a GCD of 4, and reduces to 2/1.

The Greatest Common Divisor (GCD) algorithm is given in *Greatest Common Divisor* and *Greatest Common Divisor*.

Note that we've given this method a name that begins with '`_`' to make it private. It's a "mutator" and updates the object, something that may violate the expectation of immutability.

23.7.5 Playing Cards and Decks

Standard playing cards have a rank (ace, two through ten, jack, queen and king) and suit (clubs, diamonds, hearts, spades). These form a nifty `Card` object with two simple attributes. We can add a few generally useful functions.

Here are the methods for your `Card` class.

`__init__`(*self, rank, suit*)
: Set the rank and suit of the card. The suits can be coded with a single character ("C", "D", "H", "S"), and the ranks can be coded with a number from 1 to 13. The number 1 is an ace. The numbers 11, 12, 13 are Jack, Queen and King, respectively.

`__str__`(*self*)
: Return the rank and suit in the form "2C" or "AS" or "JD". A rank of 1 would become "A", a rank of 11, 12 or 13 would become "J", "Q" or "K", respectively.

`__eq__`(*self, other*)
: Compare this card with other card considering both rank and suit.

`__ne__`(*self, other*)
: This can be implemented as '`not self == other`'.

`__lt__`(*self, other*)
: Compare this card with other, return True if this card's rank is less than the other. If the ranks are equal compare the suits.

`__le__`(*self, other*)
: This can be implemented as '`self < other or self == other`'.

`__gt__`(*self, other*)
: This can be implemented as '`not self <= other`'.

`__ge__`(*self, other*)
: This can be implemented as '`not self < other`'.

Dealing and Decks. `Card` s are dealt from a `Deck`; a collection of `Card` s that includes some methods for shuffling and dealing. Here are the methods that comprise a `Deck`.

`__init__`(*self*)
: Create all 52 cards. It can use two loops to iterate through the sequence of suits `("C", "D", "H", "S")` and iterate through the ranks '`range(1,14)`' . After creating each `Card`, it can append each `Card` to a sequence like a `list`.

`deal`(*self*)
: This method needs to do two things. First it must shuffle the cards. The `random` module has a `shuffle()` function which does precisely this.

  Second, it should deal the shuffled cards. Dealing is best done with a generator method function. The `deal()` method function should have a simple for-loop that yields each individual `Card`; this can be used by a client application to generate hands. The presence of the **yield** statement will make this method function usable by a **for** statement in a client application script.

Basic Testing. You should do some basic tests of your Card objects to be sure that they respond appropriately to comparison operations. For example,

```
>>> x1= Card(11,"C")
>>> x1
JC
>>> x2= Card(12,"D")
```

```
>>> x1 < x2
True
```

You can write a simple test script which can the do the following to deal `Cards` from a `Deck`. In this example, the variable `dealer` will be the iterator object that the **for** statement uses internally.

```
d= Deck()
dealer= d.deal()
c1= dealer.next()
c2= dealer.next()
```

Hands. Many card games involve collecting a hand of cards. A Hand is a collection of `Card` s plus some addition methods to score the hand in way that's appropriate to the given game. We have a number of collection classes that we can use: `list`, `tuple`, `dictionary` and `set`.

In Blackjack, the `Hand` will have two `Card`s assigned initially; it will then be scored. After this, the player must choose among accepting another card (a hit), using this hand against the dealer (standing), doubling the bet and taking one more card, or splitting the hand into two hands. Ignoring the split option for now, it's clear that the collection of `Card`s has to grow and then get scored again. What are the pros and cons of `list`, `tuple`, `set` and `dictionary` for a hand which grows?

When considering Poker, we have to contend with the innumerable variations on poker; we'll look at simple five-card draw poker. Games like seven-card stud require you to score potential hands given only two cards, and as many as 21 alternative five-card hands made from seven cards. Texas Hold-Em has from three to five common cards plus two private cards, making the scoring rather complex. For five-card draw, the `Hand` will have five cards assigned initially, and it will be scored. Then some cards can be removed and replaced, and the hand scored again. Since a valid poker hand is an ascending sequence of cards, called a straight, it is handy to sort the collection of cards. What are the pros and cons of `list`, `tuple`, `set` and `dictionary`?

23.7.6 Blackjack Hands

For Blackjack, we'll extend our `Card` class to score hands. When used in Blackjack, a `Card` has a point value in addition to a rank and suit. Aces are either 1 or 11; two through ten are worth 2-10; the face cards are all worth 10 points. When an ace is counted as 1 point, the total is called the hard total. When an ace is counted as 11 points, the total is called a soft total.

You can add a point attribute to your card class. This can be set as part of `__init__()` processing. In that case, the following methods simple return the point value.

As an alternative, you can compute the point value each time it is requested. This has the obvious disadvantage of being slower. However, it is considerably simpler to add methods to a class without revising the existing `__init__()` method.

Here are the methods you'll need to add to your `Card` class in order to handle Blackjack hands.

`getHardValue`(*self*)
: Returns the points. For most ranks, the points are the rank. For ranks of 11, 12 and 13 return a point value of 10.

`getSoftValue`(*self*)
: Returns the points. For most ranks, the points are the rank. For ranks of 11, 12 and 13 return a point value of 10. A rank of 1 returns a point value of 11.

As a teaser for the next chapter, we'll note that these methods should be part of a Blackjack-specific subclass of the generic `Card` class. For now, however, we'll just update the `Card` class definition.When we look at inheritance in *Inheritance*, we'll see that a class hierarchy can be simpler than the if-statements in the `getHardValue()` and `getSoftValue()` methods.

Scoring Blackjack Hands. The objective of Blackjack is to accumulate a Hand with a total point value that is less than or equal to 21. Since an ace can count as 1 or 11, it's clear that only one of the aces in a hand can have a value of 11, and any other aces must have a value of 1.

Each `Card` produces a hard and soft point total. The Hand as a whole also has hard and soft point totals. Often, both hard and soft total are equal. When there is an ace, however, the hard and soft totals for the hand will be different.

We have to look at two cases.

- No Aces. The hard and soft total of the hand will be the same; it's the total of the hard value of each card. If the hard total is less than 21 the hand is in play. If it is equal to 21, it is a potential winner. If it is over 21, the hand has gone bust. Both totals will be computed as the hard value of all cards.
- One or more Aces. The hard and soft total of the hand are different. The hard total for the hand is the sum of the hard point values of all cards. The soft total for the hand is the soft value of one ace plus the hard total of the rest of the cards. If the hard or soft total is 21, the hand is a potential winner. If the hard total is less than 21 the hand is in play. If the hard total is over 21, the hand has gone bust.

The Hand class has a collection of `Cards`, usually a sequence, but a Set will also work. Here are the methods of the Hand class.

`__init__`(*self, * cards*)
: This method should be given two instances of `Card` to represent the initial deal. It should create a sequence or Set with these two initial cards.

`__str__`(*self*)
: Return a string with all of the individual cards. A construct like the following works out well: '`","".join( map(str, self.cards ) )`'. This gets the string representation of each card in the `self.cards` collection, and then uses the `string`s' `join()` method to assemble the final display of cards.

`hardTotal`(*self*)
: Sums the hard value of each `Card`.

`softTotal`(*self*)
: Check for any `Card` with a different hard and soft point value (this will be an ace). The first such card, if found, is the `softSet`. The remaining cards form the `hardSet`.

  It's entirely possible that the `softSet` will be empty. It's also entirely possible that there are multiple cards which could be part of the `softSet`.

  The value of this function is the total of the hard values for all of the cards in the `hardSet` plus the soft value of the card in the `softSet`.

`add`(*self, card*)
: This method will add another `Card()` to the Hand().

Exercising Card, Deck and Hand. Once you have the `Card`, `Deck` and Hand classes, you can exercise these with a simple function to play one hand of blackjack. This program will create a `Deck` and a Hand; it will deal two `Card` s into the Hand. While the Hand 's total is soft 16 or less, it will add `Card`s. Finally, it will print the resulting Hand.

There are two sets of rules for how to fill a Hand. The dealer is tightly constrained, but players are more free to make their own decisions. Note that the player's hands which go bust are settled immediately, irrespective of what happens to the dealer. On the other hand, the player's hands which total 21 aren't resolved until the dealer finishes taking cards.

The dealer must add cards to a hand with a soft 16 or less. If the dealer has a soft total between 17 and 21, they stop. If the dealer has a soft total which is over 21, but a hard total of 16 or less, they will take cards. If the dealer has a hard total of 17 or more, they will stop.

A player may add cards freely until their hard total is 21 or more. Typically, a player will stop at a soft 21; other than that, almost anything is possible.

Additional Plays. We've avoided discussing the options to split a hand or double the bet. These are more advanced topics that don't have much bearing on the basics of defining `Card`, `Deck` and `Hand`. Splitting simply creates additional `Hand`s. Doubling down changes the bet and gets just one additional card.

23.7.7 Poker Hands

We'll extend the `Card` class we created in *Playing Cards and Decks* to score hands in Poker, where both the rank and suit are used to determine the hand that is held.

Poker hands are ranked in the following order, from most desirable (and least likely) down to least desirable (and all too common).

1. **Straight Flush**. Five cards of adjacent ranks, all of the same suit.
2. **Four of a Kind**. Four cards of the same rank, plus another card.
3. **Full House**. Three cards of the same rank, plus two cards of the same rank.
4. **Flush**. Five cards of the same suit.
5. **Straight**. Five cards of adjacent ranks. In this case, Ace can be above King or below 2.
6. **Three of a Kind**. Three cards of the same rank, plus two cards of other ranks.
7. **Two Pair**. Two cards of one rank, plus two cards of another rank, plus one card of a third rank.
8. **Pair**. Two cards of one rank, plus three cards of other ranks.
9. **High Card**. The highest ranking card in the hand.

Note that a straight flush is both a straight and a flush; four of a kind is also two pair as well as one pair; a full house is also two pair, as well as a one pair. It is important, then, to evaluate poker hands in decreasing order of importance in order to find the best hand possible.

In order to distinguish between two straights or two full-houses, it is important to also record the highest scoring card. A straight with a high card of a Queen, beats a straight with a high card of a 10. Similarly, a full house or two pair is described as "queens over threes", meaning there are three queens and two threes comprising the hand. We'll need a numeric ranking that includes the hand's rank from 9 down to 1, plus the cards in order of "importance" to the scoring of the hand.

The importance of a card depends on the hand. For a straight or straight flush, the most important card is the highest-ranking card. For a full house, the most important cards are the three-of-a kind cards, followed by the pair of cards. For two pair, however, the most important cards are the high-ranking pair, followed by the low-ranking pair. This allows us to compare "two pair 10's and 4's" against "two pair 10's and 9's". Both hands have a pair of 10's, meaning we need to look at the third card in order of importance to determine the winner.

Scoring Poker Hands. The `Hand` class should look like the following. This definition provides a number of methods to check for straight, flush and the patterns of matching cards. These functions are used by the `score()` method, shown below.

```
class PokerHand:
    def __init__( self, cards ):
        self.cards= cards
        self.rankCount= {}
    def straight( self ): all in sequence

    def straight( self ): all of one suit
```

```
    def matches( self ): tuple with counts of each rank in the hand

    def sortByRank( self ): sort into rank order

    def sortByMatch( self ): sort into order by count of each rank, then rank
```

This function to score a hand checks each of the poker hand rules in descending order.

```
def score( self ):
    if self.straight() and self.flush():
        self.sortByRank()
        return 9
    elif self.matches() == ( 4, 1 ):
        self.sortByMatch()
        return 8
    elif self.matches() == ( 3, 2 ):
        self.sortByMatch()
        return 7
    elif self.flush():
        self.sortByRank()
        return 6
    elif self.straight():
        self.sortByRank()
        return 5
    elif self.matches() == ( 3, 1, 1 ):
        self.sortByMatch()
        return 4
    elif self.matches() == ( 2, 2, 1 ):
        self.sortByMatchAndRank()
        return 3
    elif self.matches() == ( 2, 1, 1, 1 ):
        self.sortByMatch()
        return 2
    else:
        self.sortByRank()
        return 1
```

You'll need to add the following methods to the PokerHand class.

straight(*self*)
: True if the cards form a straight. This can be tackled easily by sorting the cards into descending order by rank and then checking to see if the ranks all differ by exactly one.

flush(*self*)
: True if all cards have the same suit.

matches(*self*)
: Returns a tuple of the counts of cards grouped by rank. This can be done iterating through each card, using the card's rank as a key to the `self.rankCount` dictionary; the value for that dictionary entry is the count of the number of times that rank has been seen. The values of the dictionary can be sorted, and form six distinct patterns, five of which are shown above. The sixth is simply `(1, 1, 1, 1, 1)` , which means no two cards had the same rank.

sortByRank(*self*)
: Sorts the cards by rank.

sortByMatch(*self*)
: Uses the counts in the `self.rankCount` dictionary to update each card with its match count, and then

sorts the cards by match count.

`sortByMatchAndRank`(*self*)
Uses the counts in the `self.rankCount` dictionary to update each card with its match count, and then sorts the cards by match count and rank as two separate keys.

Exercising Card, Deck and Hand. Once you have the `Card`, `Deck` and `Hand` classes, you can exercise these with a simple function to play one hand of poker. This program will create a `Deck` and a `Hand`; it will deal five `Card`s into the `Hand`. It can score the hand. It can replace from zero to three cards and score the resulting hand.

CHAPTER

TWENTYFOUR

ADVANCED CLASS DEFINITION

This section builds up some additional class definition techniques. We describe the basics of inheritance in *Inheritance*. We turn to a specific inheritance technique, polymorphism in *Polymorphism*. There are some class-related functions, which we describe in *Built-in Functions*. We'll look at some specific class initializer technique in *Initializer Techniques*. We include a digression on design approaches in *Design Approaches*. In *Class Variables* we provide information on class-level variables, different from instance variables. We conclude this chapter with some style notes in *Style Notes*.

24.1 Inheritance

In *Semantics* we identified four important features of objects.

- Identity.
- Classification.
- Inheritance.
- Polymorphism.

The point of inheritance is to allow us to create a subclass which inherits all of the features of a superclass. The subclass can add or replace method functions of the superclass. This is typically used by defining a general-purpose superclass and creating specialized subclasses that all inherit the general-purpose features but add special-purposes features of their own.

We do this by specifying the parent class when we create a subclass.

```
class subclass ( superclass ) :
    suite
```

All of the methods of the superclass are, by definition, also part of the subclass. Often the suite of method functions will add to or override the definition of a parent method.

If we omit providing a superclass, we create a *classical* class definition, where the Python type is `instance`; we have to do additional processing to determine the actual type. Generally, we should avoid this kind of class definition. It works, but isn't ideal.

When we use `object` as the superclass, the Python type is reported more simply as the appropriate `class` object. As a general principle, every class definition should be a subclass of `object`, either directly or indirectly.

Important: Python 3

In Python 3, this distinction will be removed. A class with no explicit superclass will still be a subclass of `object`.

Extending a Class. There are two trivial subclassing techniques. One defines a subclass which adds new methods to the superclass. The other overrides a superclass method. The overriding technique leads to two classes which are polymorphic because they have the same interface. We'll return to polymorphism in *Polymorphism*.

Here's a revised version of our basic `Dice` class and a subclass to create `CrapsDice`.

crapsdice.py

```
#!/usr/bin/env python
"""Define a Die, Dice and CrapsDice."""

class Die(object):
    """Simulate a 6-sided die."""
    def __init__( self ):
        self.domain= range(1,7)
    def roll( self ):
        self.value= random.choice(self.domain)
        return self.value
    def getValue( self ):
        return self.value

class Dice( object ):
    """Simulate a pair of dice."""
    def __init__( self ):
        "Create the two Die objects."
        self.myDice = ( Die(), Die() )
    def roll( self ):
        "Return a random roll of the dice."
        for d in self.myDice:
            d.roll()
    def getTotal( self ):
        "Return the total of two dice."
        return self.myDice[0].value + self.myDice[1].value
    def getTuple( self ):
        "Return a tuple of the dice."
        return self.myDice

class CrapsDice( Dice ):
    """Extends Dice to add features specific to Craps."""
    def hardways( self ):
        """Returns True if this was a hardways roll?"""
        return self.myDice[0].value == self.myDice[1].value
    def isPoint( self, value ):
        """Returns True if this roll has the given total"""
        return self.getTotal() == value
```

The `CrapsDice` class contains all the features of `Dice` as well as the additional features we added in the class declaration.

We can, for example, evaluate the `roll()` and `hardways()` methods of `CrapsDice`. The `roll()` method is inherited from `Dice`, but the `hardways()` method is a direct part of `CrapsDice`.

Adding Instance Variables. Adding new instance variables requires that we extend the `__init__()` method.

In this case our subclass `__init__()` function must start out doing everything the superclass `__init__()` function does, and then creates a few more attributes.

Python provides us the `super()` function to help us do this. We can use `super()` to distinguish between method functions with the same name defined in the superclass and extended in a subclass.

super(*type, variable*)
: This will do two things: locate the superclass of the given type, and it then bind the given variable to create an object of the superclass. This is often used to call a superclass method from within a subclass: '`super( classname ,self).method()`'

Here's a template that shows how a subclass `__init__()` method uses `super()` to evaluate the superclass `__init__()` method.

```
class Subclass( Superclass ):
    def __init__( self ):
        super(Subclass,self)__init__()
        # Subclass-specific stuff follows
```

This will bind our `self` variable to the parent class so that we can evaluate the parent class `__init__()` method. After that, we can add our subclass initialization.

We'll look at additional techniques for creating very flexible `__init__()` methods in *Initializer Techniques*.

Various Kinds of Cards. Let's look closely at the problem of cards in Blackjack. All cards have several general features: they have a rank and a suit. All cards have a point value. However, some cards use their rank for point value, other cards use 10 for their point value and the aces can be either 1 or 11, depending on the the rest of the cards in the hand. We looked at this in the *Playing Cards and Decks* exercise in *Classes*.

We can model this very accurately by creating a `Card` class that encapsulates the generic features of rank, suit and point value. Our class will have instance variables for these attribites. The class will also have two functions to return the hard value and soft value of this card. In the case of ordinary non-face, non-ace cards, the point value is always the rank. We can use this `Card` class for the number cards, which are most common.

```
class Card( object ):
    """A standard playing card for Blackjack."""
    def __init__( self, r, s ):
        self.rank, self.suit = r, s
        self.pval= r
    def __str__( self ):
        return "%2d%s" % ( self.rank, self.suit )
    def getHardValue( self ):
        return self.pval
    def getSoftValue( self ):
        return self.pval
```

We can create a subclass of `Card` which is specialized to handle the face cards. This subclass simply overrides the value of `self.pval`, using 10 instead of the rank value. In this case we want a `FaceCard.__init__()` method that uses the parent's `Card.__init__()` method, and then does additional processing. The existing definitions of `getHardValue()` and `getSoftValue()` method functions, however, work fine for this subclass. Since `Card` is a subclass of `object`, so is `FaceCard`.

Additionally, we'd like to report the card ranks using letters (J, Q, K) instead of numbers. We can override the `__str__()` method function to do this translation from rank to label.

```
class FaceCard( Card ):
    """A 10-point face card: J, Q, K."""
```

```
    def __init__( self, r, s ):
        super(FaceCard,self).__init__( r, s )
        self.pval= 10
    def __str__( self ):
        label= ("J","Q","K")[self.rank-11]
        return "%2s%s" % ( label, self.suit )
```

We can also create a subclass of `Card` for Aces. This subclass inherits the parent class `__init__()` function, since the work done there is suitable for aces. The `Ace` class, however, provides a more complex algorithms for the `getHardValue()` and `getSoftValue()` method functions. The hard value is 1, the soft value is 11.

```
class Ace( Card ):
    """An Ace: either 1 or 11 points."""
    def __str__( self ):
        return "%2s%s" % ( "A", self.suit )
    def getHardValue( self ):
        return 1
    def getSoftValue( self ):
        return 11
```

Deck and Shoe as Collections of Cards. In a casino, we can see cards handled in a number of different kinds of collections. Dealers will work with a single deck of 52 cards or a multi-deck container called a shoe. We can also see the dealer putting cards on the table for the various player's hands, as well as a dealer's hand.

Each of these collections has some common features, but each also has unique features. Sometimes it's difficult to reason about the various classes and discern the common features. In these cases, it's easier to define a few classes and then refactor the common features to create a superclass with elements that have been removed from the subclasses. We'll do that with Decks and Shoes.

We can define a `Deck` as a sequence of `Card`s. The `deck.__init__()` method function of `Deck` creates appropriate `Card`s of each subclass. These are `Card` objects in the range 2 to 10, `FaceCard` obejcts with ranks of 11 to 13, and `Ace` objects with a rank of 1.

```
class Deck( object ):
    """A deck of cards."""
    def __init__( self ):
        self.cards= []
        for suit in ( "C", "D", "H", "S" ):
            self.cards+= [Card(r,suit) for r in range(2,11)]
            self.cards+= [TenCard(r,suit) for r in range(11,14)]
            self.cards+= [Ace(1,suit)]
    def deal( self ):
        for c in self.cards:
            yield c
```

In this example, we created a single instance variable `self.cards` within each `Deck` instance. For dealing cards, we've provided a generator function which yields the `Card` objects in a random order. We've omitted the randomization from the `deal()` function; we'll return to it in the exercises.

For each suit, we created the `Card`s of that suit in three steps.

1. We created the number cards with a list comprehension to generate all ranks in the range 2 through 10.
2. We created the face cards with a similar process, except we use the `TenCard` class constructor, since blackjack face cards all count as having ten points.

3. Finally, we created a one-item list of an `Ace` instance for the given suit.

We can use `Deck` objects to create an multi-deck *shoe*. (A shoe is what dealers use in casinos to handle several decks of slippery playing cards.) The `Shoe` class will create six separate decks, and then merge all 312 cards into a single sequence.

```
class Shoe( object ):
    """Model a multi-deck shoe of cards."""
    def __init__( self, decks=6 ):
        self.cards= []
        for i in range(decks):
            d= Deck()
            self.cards += d.cards
    def deal( self ):
        for c in self.cards:
            yield c
```

For dealing cards, we've provided a generator function which yields the `Card`s in a random order. We've omitted the randomization from the `deal()` function; we'll return to it in the exercises.

Factoring Out Common Features. When we compare Deck and Shoe, we see two obviously common features: they both have a collection of `Card`s, called `self.cards`. Also, they both have a `deal()` method which yields a sequence of cards.

We also see things which are different. The most obvious differences are details of initializing `self.cards`. It turns out that the usual procedure for dealing from a shoe involves shuffling all of the cards, but dealing from only four or five of the six available decks. This is done by inserting a marker one or two decks in from the end of the shoe.

In factoring out the common features, we have a number of strategies.

- One of our existing classes is already generic-enough to be the superclass. In the `Card` example, we used the generic `Card` class as superclass for other cards as well as the class used to implement the number cards. In this case we will make concrete object instances from the superclass.
- We may need to create a superclass out of our subclasses. Often, the superclass isn't useful by itself; only the subclasses are really suitable for making concrete object instances. In this case, the superclass is really just an abstraction, it isn't meant to be used by itself.

Here's an abstract `CardDealer` from which we can subclass `Deck` and `Shoe`. Note that it does not create any cards. Each subclass must do that. Similarly, it can't deal properly because it doesn't have a proper `shuffle()` method defined.

```
class CardDealer( object ):
    def __init__( self ):
        self.cards= []
    def deal( self ):
        for c in self.shuffle():
            yield c
    def shuffle( self ):
        ...to be done in the exercises...
```

Python does not have a formal notation for abstract or concrete superclasses. When creating an abstract superclass it is common to return `NotImplemented` or raise `NotImplementedError` to indicate that a method must be overridden by a subclass.

We can now rewrite `Deck` as subclasses of `CardDealer`.

```
class Deck( CardDealer ):
    def __init__( self ):
        super(Deck,self).__init__()
        for s in ("C","D","H","S"):
        for suit in ( "C", "D", "H", "S" ):
            self.cards+= [Card(r,suit) for r in range(2,11)]
            self.cards+= [TenCard(r,suit) for r in range(11,14)]
            self.cards+= [Ace(1,suit)]
```

We can also rewrite `Shoe` as subclasses of `CardDealer`.

```
class Shoe( CardDealer ):
    def __init__( self, decks=6 ):
        CardDealer.__init__( self )
        for i in range(decks):
            d= Deck()
            self.cards += d.cards
```

The benefit of this is to assure that `Deck` and `Shoe` actually share common features. This is not "cut and paste" sharing. This is "by definition" sharing. A change to `CardDealer` will change both Deck and Shoe, assuring complete consistency.

24.2 Polymorphism

In *Semantics* we identified four important features of objects.

- Identity.
- Classification.
- Inheritance.
- Polymorphism.

Polymorphism exists when we define a number of subclasses which have commonly named methods. A function can use objects of any of the polymorphic classes without being aware that the classes are distinct.

In some languages, it is essential that the polymorphic classes have the same interface (or be subinterfaces of a common parent interface), or be subclasses of a common superclass. This is sometimes called "strong, hierarchical typing", since the type rules are very rigid and follow the subclass/subinterface hierarchy.

Python implements something that is less rigid, often called "duck typing". The phrase follows from a quote attributed to James Whitcomb Riley: "When I see a bird that walks like a duck and swims like a duck and quacks like a duck, I call that bird a duck." In short, two objects are effectively of the class `Duck` if they have a common collection of methods (walk, swim and quack, for example.)

When we look at the examples for `Card`, `FaceCard`, `Ace` in *Inheritance*, we see that all three classes have the same method names, but have different implementations for some of these methods. These three classes are polymorphic.

A client class like `Hand` can contain individual objects of any of the subclasses of `Card`. A function can evaluate these polymorphic methods without knowing which specific subclass is being invoked.

In our example, both `FaceCard` and `Ace` were subclasses of `Card`. This subclass relationship isn't necesary for polymorphism to work correctly in Python. However, the subclass relationship is often an essential ingredient in an overall design that relies on polymorphic classes.

What's the Benefit? If we treat all of the various subclasses of `Card` in a uniform way, we effectively delegate any special-case processing into the relevant subclass. We concentrate the implementation of a special case in exactly one place.

The alternative is to include **if** statements all over our program to enforce special-case processing rules. This diffusing of special-case processing means that many components wind up with an implicit relationship. For example, all portions of a program that deal with `Card`s would need multiple **if** statements to separate the number card points, face card points and ace points.

By making our design polymorphic, all of our subclasses of `Card` have ranks and suits, as well as hard and soft point values. We we can design the `Deck` and `Shoe` classes to deal cards in a uniform way. We can also design a `Hand` class to total points without knowing which specific class to which a `Card` object belongs.

Similarly, we made our design for `Deck` and `Shoe` classes polymorphic. This allows us to model one-deck blackjack or multi-deck blackjack with no other changes to our application.

The Hand of Cards. In order to completely model Blackjack, we'll need a class for keeping the player and dealer's hands. There are some differences between the two hands: the dealer, for example, only reveals their first card, and the dealer can't split. There are, however, some important similarities. Every kind of `Hand` must determine the hard and soft point totals of the cards.

The hard point total for a hand is simply the hard total of all the cards. The soft total, on the other hand, is not simply the soft total of all cards. Only the `Ace` cards have different soft totals, and only one Ace can meaningfully contribute it's soft total of 11. Generally, all cards provide the same hard and soft point contributions. Of the cards where the hard and soft values differ, only one such card needs to be considered.

Note that we are using the values of the `getHardValue()` and `getSoftValue()` methods. Since this test applies to all classes of cards, we preserve polymorphism by checking this property of every card. We'll preserving just one of the cards with a soft value that is different from the hard value. At no time do use investigate the class of a `Card` to determine if the card is of the class `Ace`. Examining the class of each object needlessly constrains our algorithm. Using the polymorphic methods means that we can make changes to the class structure without breaking the processing of the `Hand` class.

Important: Pretty Poor Polymorphism

The most common indicator of poor use polymorphism is using the `type()`, `isinstance()` and `issubclass()` functions to determine the class of an object. These should used rarely, if at all. All processing should be focused on what is different about the objects, not the class to which an object belongs.

We have a number of ways to represent the presence of a `Card` with a distinct hard and soft value.

- An attribute with the point difference (usually 10).
- A collection of all `Card`s except for one `Card` with a point difference, and a single attribute for the extra card.

We'll choose the first implementation. We can use use a sequence to hold the cards. When cards are added to the hand, the first card that returns distinct values for the hard value and soft value will be used to set a variable has keeps the hard vs. soft point difference.

hand.py

```
class Hand( object ):
    """Model a player's hand."""
    def __init__( self ):
        self.cards = [ ]
        self.softDiff= 0
    def addCard( self, aCard ):
```

```
        self.cards.append( aCard )
        if aCard.getHardValue() != aCard.getSoftValue():
            if self.softDiff == 0:
                self.softDiff= aCard.getSoftValue()-aCard.getHardValue()
    def points( self ):
        """Compute the total points of cards held."""
        p= 0
        for c in self.cards:
            p += c.getHardValue()
        if p + self.softDiff &lt;= 21:
            return p + self.softDiff
        else:
            return p
```

1. The `__init__()` special function creates the instance variable, `self.cards`, which we will use to accumulate the `Card` objects that comprise the hand. This also sets `self.softDiff` which is the difference in points between hard and soft hands. Until we have an Ace, the difference is zero. When we get an Ace, the difference will be 10.
2. We provide an `addCard()` method that places an additional card into the hand. At this time, we examine the `Card` to see if the soft value is different from the hard value. If so, and we have not set the `self.softDiff` yet, we save this difference.
3. The `points()` method evaluates the hand. It initializes the point count, `p`, to zero. We start a **for**-loop to assign each card object to `c`. We could, as an alternative, use a `sum()` function to do this.

   If the total with the `self.softDiff` is 21 or under, we have a soft hand, and these are the total points. If the total with the `self.softDiff` is over 21, we have a hard hand. The hard hand may total more than 21, in which case, the hand is bust.

24.3 Built-in Functions

There are two built in functions of some importance to object oriented programming. These are used to determine the class of an object, as well as the inheritance hierarchy among classes.

`isinstance`(*object, type*)
: True if *object* is an instance of the given `type` or any of the subclasses of `type`.

`issubclass`(*parameter, base*)
: True if class `class` is a subclass of class `base`.

  This question is usually moot, because most programs are designed to provide the expected classes of objects. There are some occasions for deep paranoia; when working with untrusted software, your classes may need to be sure that other programmers are following the rules. In Java and C++, the compiler can check these situations. In Python, the compiler doesn't check this, so we may want to include run-time checks.

`super`(*type*)
: This will return the superclass of the given type.

All of the basic factory functions (`str`, `int`, `float`, `long`, `complex`, `unicode`, `tuple`, `list`, `dict`, `set`) are effectively class names. You can, therefore, use a test like '`isinstance( myParam ,int)`' to confirm that the argument value provided to this parameter is an integer.

An additional class, `basestring` is the parent class of both `str` and `unicode`.

The following example uses the `isinstance()` function to validate the type of argument values. First, we'll define a Roulette wheel class, `Wheel`, and two subclasses, `Wheel1` with a single zero and `Wheel2` with zero and double zero.

wheel.py

```
import random
class Wheel( object ):
    def value( self ):
        return NotImplemented

class Wheel1( Wheel ):
    def value( self ):
        spin= random.randrange(37)
        return str(spin)

class Wheel2( Wheel ):
    def __init__( self ):
        self.values= ['00'] + map( str, range(37) )
    def value( self ):
        return random.randchoice( self.values )
```

1. The `Wheel` class defines the interface for Roulette wheels. The actual class definition does nothing except show what the expected method functions should be. We could call this an abstract definition of a `Wheel`.
2. The `Wheel1` subclass uses a simple algorithm for creating the spin of a wheel. The `value()` method chooses a number between 0 and 36. It returns a string representation of the number. This has only a single zero.
3. The `Wheel2` subclass creates an instance variable, `values`, to contain all possible results. This includes the 37 values from 0 to 36, plus an additional '00' value. The `value()` method chooses one of these possible results.

The following function expects that its parameter, `w`, is one of the subclasses of `Wheel`.

```
def simulate( w ):
    if not isinstance( w, Wheel ):
        raise TypeError( "Must be a subclass of Wheel" )
    for i in range(10):
        print w.value()
```

In this case, the simulate function checks its argument, `w` to be sure that it is a subclass of `Wheel`. If not, the function raises the built in `TypeError`.

An alternative is to use an assertion for this.

```
def simulate( w ):
    assert isinstance( w, Wheel )
    for i in range(10):
        print w.value()
```

24.4 Collaborating with max(), min() and sort()

The min() and max() functions can interact with our classes in relatively simple ways. Similarly, the sort() method of a list can also interact with our new class definitions.

In all three cases, a keyword parameter of key can be used to control which attributes are used for determining minimum, maximum or sort order.

The key parameter must be given a function, and that function is evaluated on each item that is being compared. Here's a quick example.

```
class Boat( object ):
    def __init__( self, name, loa ):
        self.name= name
        self.loa= loa
def byName( aBoat ):
    return aBoat.name
def byLOA( aBoat ):
    return aBoat.loa
fleet = [ Boat("KaDiMa", 18 ), Boat( "Emomo", 21 ), Boat("Leprechaun", 30 ) ]
first= min( fleet, key=byName )
print "Alphabetically First:", first
longest= max( fleet, key=byLOA )
print "Longest:", longest
```

As min(), max() or sort traverse the sequence doing comparisons among the objects, they evaluate the key() function we provided. In this example, the provided function simply selects an attribute. Clearly the functions could do calculations or other operations on the objects.

24.5 Initializer Techniques

When we define a subclass, we are often extending some superclass to add features. One common design pattern is to do this by defining a subclass to use parameters in addition to those expected by the superclass. We must reuse the superclass constructor properly in our subclass.

Referring back to our Card and FaceCard example in *Inheritance*, we wrote an initializer in FaceCard that referred to Card.

The FaceCard.__init__() method evaluates 'super(FaceCard,self).__init__(rank, suit)'. It passed the same arguments to the Card.__init__() method.

Note: Older Programs

In older programs, you'll see an alternative to the super() function. Some classes will have an explicit call to 'Card.__init__(self, r, s)'.

We're naming the class (not an object of the class) and explicitly providing the self variable.

We can make use of the techniques covered in *Advanced Parameter Handling For Functions* to simplify our subclass initializer.

```
class FaceCard( Card ):
    """Model a 10-point face card: J, Q, K."""
    def __init__( self, * args ):
        super(FaceCard,self).__init__( * args )
        self.label= ("J","Q","K")[self.rank-11]
        self.pval= 10
```

```
    def __str__( self ):
        return "%2s%s" % ( self.label, self.suit )
```

In this case we use the '`def __init__( self, *args )`' to capture all of the positional parameters in a single sequence, named `args`. We then give that entire sequence of positional parameters to `Card.__init__()`. By using the * operator, we tell Python to explode the list into individual positional parameters.

Let's look at a slightly more sophisticated example.

boat.py

```
class Boat( object ):
    def __init__( self, name, loa ):
        """Create a new Boat( name, loa )"""
        self.name= name
        self.loa= loa

class Catboat( Boat )
    def __init__( self, sailarea, * args ):
        """Create a new Catboat( sail_area, name, loa )"""
        super(Catboat,self).__init__( * args )
        self.main_area= sail_area

class Sloop( CatBoat ):
    def __init__( self, jib_area, * args );
        """Create a new Sloop( jib_area, main_area, name, loa )"""
        super(Sloop,self).__init__( * args )
        self.jib_area= jib_area
```

1. The Boat class defines essential attributes for all kinds of boats: the name and the length overall (LOA).
2. In the case of a `Catboat`, we add a single sail area to be base definition of `Boat`. We use the superclass initialization to prepare the basic name and length overall attributes. Then our subclass adds the sailarea for the single sail on a catboat.
3. In the case of a `Sloop`, we add another sail to the definition of a `Catboat`. We add the new parameter first in the list, and the remaining parameters are simply given to the superclass for its initialization.

24.6 Class Variables

The notion of object depends on having instance variables (or "attributes") which have unique values for each object. We can extend this concept to include variables that are not unique to each instance, but shared by every instance of the class. Class level variables are created in the class definition itself; instance variables are created in the individual class method functions (usually `__init__()`).

Class level variables are usually "variables" with values that don't change; these are sometimes called manifest constants or named constants. In Python, there's no formal declaration for a named constant.

A class level variable that changes will be altered for all instances of the class. This use of class-level variables is often confusing to readers of your program. Class-level variables with state changes need a complete explanation.

This is an example of the more usual approach with class-level constants. These are variables whose values don't vary; instead, they exist to clarify and name certain values or codes.

wheel.py

```
import random
class Wheel( object ):
    """Simulate a roulette wheel."""
    green, red, black= 0, 1, 2
    redSet= [1,3,5,7,9,12,14,16,18,19,21,23,25,27,30,32, 34,36]
    def __init__( self ):
        self.lastSpin= ( None, None )
    def spin( self ):
        """spin() -&gt; ( number, color )

        Spin a roulette wheel, return the number and color."""
        n= random.randrange(38)
        if n in [ 0, 37 ]: n, color= 0, Wheel.green
        elif n in Wheel.redSet: color= Wheel.red
        else: color= Wheel.black
        self.lastSpin= ( n, color )
        return self.lastSpin
```

1. Part of definition of the class `Wheel` includes some class variables. These variables are used by all instances of the class. By defining three variables, `green`, `red` and `black`, we can make our programs somewhat more clear. Other parts of our program that use the `Wheel` class can then reference the colors by name, instead of by an obscure numeric code. A program would use `Wheel.green` to refer to the code for green within the `Wheel` class.

2. The `Wheel` class also creates a class-level variable called `redSet`. This is the set of red positions on the Roulette wheel. This is defined at the class level because it does not change, and there is no benefit to having a unique copy within each instance of `Wheel`.

3. The `__init__()` method creates an instance variable called `lastSpin`. If we had multiple wheel objects, each would have a unique value for `lastSpin`. They all would all, however, share a common definition of `green`, `red`, `black` and `redSet`.

4. The `spin()` method updates the state of the wheel. Notice that the class level variables are referenced with the class name: `Wheel.green`. The instance level variables are referenced with the instance parameter: `self.lastSpin`. The class level variables are also available using the instance parameter, `Wheel.green` is the same object as `self.green`.

   The `spin()` method determines a random number between 0 and 37. The numbers 0 and 37 are treated as 0 and 00, with a color of green; a number in the `Wheel.redSet` is red, and any other number is black. We also update the state of the `Wheel` by setting `self.lastSpin`.

   Finally, the `spin()` method returns a `tuple` with the number and the code for the color. Note that we can't easily tell 0 from 00 with this particular class definition.

The following program uses this `Wheel` class definition. It uses the class-level variables `red` and `black` to clarify the color code that is returned by `spin()`.

```
w= Wheel()
n,c= w.spin()
if c == Wheel.red: print n, "red"
elif c == Wheel.black: print n, "black"
else: print n
```

Our sample program creates an instance of `Wheel`, called `w`. The program calls the `spin()` method of `Wheel`, which updates `w.lastSpin` and returns the tuple that contains the number and color. We use multiple

assignment to separate the two parts of the tuple. We can then use the class-level variables to decode the color. If the color is `Wheel.red`, we can print `"red"`.

24.7 Static Methods and Class Method

In a few cases, our class may have methods which depend on only the argument values, or only on class variables. In this case, the `self` variable isn't terribly useful, since the method doesn't depend on any attributes of the instance. Objects which depend on argument values instead of internal status are called *Lightweight* or *Flyweight* objects.

A method which doesn't use the `self` variable is called a static method. These are defined using a built-in function named `staticmethod()`. Python has a handy syntax, called a decorator, to make it easier to apply the `staticmethod()` function to our method function definition. We'll return to decorators in *Decorators* .

Here's the syntax for using the `staticmethod()` decorator.

```
@staticmethod
def name ( param ⟨ , ... ⟩ ) :
    suite
```

To evaluate a static method function, we simply reference the method of the class: '`Class.method()`' instead of using a specific instance of the class.

Example of Static Method. Here's an example of a class which has a static method. We've defined a deck shuffler. It doesn't have any attributes of its own. Instead, it applies it's `shuffle()` algorithm to a `Deck` object.

```
class Shuffler( object ):
    @staticmethod
    def shuffle( aDeck ):
        for i in range(len(aDeck)):
            card= aDeck.get( random.randrange(len(aDeck)) )
            aDeck.put( i, card )
d1= Deck()
Shuffler.shuffle( d1 )
```

Class Method. The notion of a class method is relatively specialized. A class method applies to the class itself, not an instance of the class. A class method is generally used for "introspection" on the structure or definition of the class. It is commonly defined by a superclass so that all subclasses inherit the necessary introspection capability.

Generally, class methods are defined as part of sophisticated, dynamic frameworks. For our gambling examples, however, we do have some potential use for class methods. We might want to provide a base `Player` class who interacts with a particular `Game` to make betting decisions. Our superclass for all players can define methods that would be used in a subclass.

24.8 Design Approaches

When we consider class design, we have often have a built-in or library class which does some of the job we want. For example, we want to be able to accumulate a list of values and then determine the average: this is a very list-like behavior, extended with a new feature.

There are two overall approaches for extending a class: *wrapping* and *inheritance*.

- Wrap an existing class (for example, a tuple, list, set or map) in a new class which adds features. This allows you to redefine the interface to the existing class, which often involves removing features.
- Inherit from an existing class, adding features as part of the more specialized subclass. This may require you to read more of the original class documentation to see a little of how it works internally.

Both techniques work extremely well; there isn't a profound reason for making a particular choice. When wrapping a collection, you can provide a new, focused interface on the original collection; this allows you to narrow the choices for the user of the class. When subclassing, however, you often have a lot of capabilities in the original class you are extending.

"Duck" Typing. In *Polymorphism*, we mentioned "Duck" Typing. In Python, two classes are practically polymorphic if they have the same inteface methods. They do not have to be subclasses of the same class or interface (which is the rule in Java.)

This principle means that the distinction between wrapping and inheritance is more subtle in Python than in other languages. If you provide all of the appropriate interface methods to a class, it behaves as if it was a proper subclass. It may be a class that is wrapped by another class that provides the same interface.

For example, say we have a class `Dice`, which models a set of individual `Die` objects.

```
class Dice( object ):
    def __init__( self ):
        self.theDice= [ Die(), Die() ]
    def roll( self ):
        for d in self.theDice:
            d.roll()
        return self.theDice
```

In essence, our class is a wrapper around a list of dice, named `theDice`. However, we don't provide any of the interface methods that are parts of the built-in `list` class.

Even though this class is a wrapper around a `list` object, we can add method names based on the built-in `list` class: `append()`, `extend()`, `count()`, `insert()`, etc.

```
class Dice( object ):
    def __init__( self ):
        self.theDice= [ Die(), Die() ]
    def roll( self ):
        for d in self.theDice:
            d.roll()
        return self.theDice
    def append( self, aDie ):
        self.theDice.append( aDie )
    def __len__( self ):
        return len( self.theDice )
```

Once we've defined these list-like functions we have an ambiguous situation.

- We could have a subclass of `list`, which initializes itself to two `Die` objects and has a `roll()` method.
- We could have a distinct `Dice` class, which provides a `roll()` method and a number of other methods that make it look like a `list`.

For people who will read your Python, clarity is the most important feature of the program. In making design decisions, one of your first questions has to be "what is the real thing that I'm modeling?" Since many alternatives will work, your design should reflect something that clarifies the problem you're solving.

24.9 Advanced Class Definition Exercises

24.9.1 `Sample` Class with Statistical Methods

We can create a `Samples` class which holds a collection of sample values. This class can have functions for common statistics on the object's samples. For additional details on these algorithms, see the exercises in *Tuples* and *Sequence Processing Functions: map(), filter() and reduce()*.

We'll look at subclassing the built-in `list` class, by creating a class, `Samples`, which extends `list`. You'll need to implement the following methods in your new class.

`__init__`(*self, * args*)
: Save a sequence of samples. It could, at this time, also precompute a number of useful values, like the sum, count, min and max of this set of data. When no data is provided, these values would be set to `None`.

`__str__`(*self*)
: Return string with a summary of the data. An example is a string like `"%d values, min %g, max %g, mean %g"` with the number of data elements, the minimum, the maximum and the mean. The superclass, `list`, `__repr__()` function will return the raw data.

`mean`(*self*)
: Returns the sum divided by the count.

`mode`(*self*)
: Return the most popular of the sample values. Below we've provided an algorithm that can be used to locate the mode of a sequence of samples.

  For information on computing the mode, see *Exercises*.

`median`(*self*)
: The median is the value in the middle of the sequence. First, sort the sequence. If there is an odd number of elements, pick the middle-most element. If there is an even number of elements, average the two elements that are mid-most.

`variance`(*self*)
: For each sample, compute the difference between the sample and the mean, square this value, and sum these squares. The number of samples minus 1 is the *degrees of freedom*. The sum, divided by the degrees of freedom, is the variance. Note that you need two samples to meaningfully compute a variance.

`stdev`(*self*)
: The square root of the variance.

Note that the `list` superclass already works correctly with the built-in `min()` and `max()` functions. In this case, this consequence of using inheritance instead of wrapping turns out to be an advantage.

24.9.2 Shuffling Method for the `Deck` class

Shuffling is a matter of taking existing cards and putting them into other positions. There are a many ways of doing this. We'll need to try both to see which is faster. In essence, we need to create a polymorphic family of classes that we can use to measure performance.

Shuffling Variation 1 - Exchange

For `i` in range 0 to the number of cards

Generate a random number `r` in the range 0 to the number of cards.

Use Multiple Assignement to swap cards at position `i` and `r`.

Shuffling Variation 2 - Build

Create an empty result sequence, `s`.

While there are cards in the source `self.cards` sequence.

Generate a random number `r` in the range 0 to the number of cards.

Append card `r` to the result sequence; delete object `r` from the source `self.cards` sequence. The `pop()` method of a sequence can return a selected element and delete it from a sequence nicely.

Replace `self.cards` with the result sequence, `s` .

Shuffling Variation 3 - Sort

Create a key function which actually returns a random value.

Use the `sort()` method of a `list` with this random key-like function.

```
self.cards.sort( key=aRandomKeyFunction )
```

Shuffling Variation 4 - random.shuffle

The `random` module has a `shuffle()` method which can be used as follows.

```
random.shuffle( self.cards )
```

Of these four algorithms, which is fastest? The best way to test these is to create four separate subclasses of `Deck`, each of which provides a different implementation of the `shuffle()` method. A main program can then create an instance of each variation on `Deck` and do several hundred shuffles.

We can create a timer using the `time` module. The `time.clock()` function will provide an accurate time stamp. The difference between two calls to `time.clock()` is the elapsed time. Because shuffling is fast, we'll do it 100 times to get a time that's large enough to be accurate.

Because all of our variations on `Deck` are polymorphic, our main program should look something like the following.

```
d1= DeckExch()
d2= DeckBuild()
d3= DeckSortRandom()
d4= DeckShuffle()
for deck in ( d1, d2, d3, d4 ):
    start= time.clock()
    for i in range(100):
        d.shuffle()
    finish= time.clock()
```

24.9.3 Encapsulation

The Shuffling exercise built several alternate solutions to a problem. We are free to implement an algorithm with no change to the interface of `Deck`. This is a important effect of the principal of encapsulation: a class and the clients that use that class are only coupled together by an interface defined by method functions.

There are a variety of possible dependencies between a class and its clients.

- **Interface Method Functions**. A client can depend on method functions specifically designated as an interface to a class. In Python, we can define internal methods by prefixing their names with '_'. Other names (without the leading '_') define the public interface.
- **All Method Functions**. A client can depend on all method functions of a class. This removes the complexity of hidden, internal methods.
- **Instance Variables**. A client can depend on instance variables in addition to method functions. This can remove the need to write method functions that simply return the value of an instance variable.
- **Global Variables**. Both classes share global variables. The Python **global** statement is one way to accomplish this.
- **Implementation**. A client can depend on the specific algorithm being executed by a class. A client method can have expectations of how a class is implemented.

What are the advantages and disadvantages of each kind of dependency?

24.9.4 Class Responsibilities

Assigning responsibility to class can be challenging. A number of reasons can be used to justify the functions and instance variables that are combined in a single class.

- **Convenience**. A class is defined to do things because – well – it's convenient to write the program that way.
- **Similar Operations**. A class is defined because it does all input, all output, or all calculations.
- **Similar Time**. A class is defined to handle all initialization, all processing or all final cleanup.
- **Sequence**. We identify some operations which are performed in a simple sequence and bundle these into a single class.
- **Common Data**. A class is defined because it has the operations which isolate a data structure or algorithm.

What are the possible differences between theses? What are the advantages and disadvantages of each?

24.10 Style Notes

Classes are perhaps the most important organizational tool for Python programming. Python software is often designed as a set of interacting classes. There are several conventions for naming and documenting class definitions.

It is important to note that the suite within a class definition is typically indented four spaces. It is often best to set your text editor with tab stops every four spaces. This will usually yield the right kind of layout. Each function's suite is similarly indented four spaces, as are the suites within compound statements.

Blank lines are used sparingly; most typically a single blank line will separate each function definition within the class. A lengthy class definition, with a number of one-liner set-get accessor functions may group the accessors together without any intervening blank lines.

Class names are typically `MixedCase` with a leading uppercase letter. Members of the class (method functions and attributes) typically begin with a lowercase letter. Class names are also, typically singular nouns. We don't define `People` , we define `Person`. A collection might be a PersonList or PersonSet.

Note that the following naming conventions are honored by Python:

'`single_trailing_underscore_`' Used to make a variable names different from a similar Python reserved word. For example: '`range_`' is a legal variable name, where '`range`' would not be legal.

'`_single_leading_underscore`' Used to make variable or method names hidden. This conceals them from the `dir()` function.

'`__double_leading_underscore`' Class-private names. Use this to assure that a method function is not used directly by clients of a class.

'`__double_leading_and_trailing_underscore__`' These are essentialy reserved by Python for its own internals.

Docstring Recommendations. The first line of a class body is the docstring; this provides an overview of the class. It should summarize the responsibilities and collaborators of the class. It should summarize the public methods and instance variables.

Individual method functions are each documented in their own docstrings. Tools like Sphinx and Epydoc will look for the `__init__()` docstring as part of summarizing a class.

When defining a subclass, be sure to mention the specific features added (or removed) by the subclass. There are two basic cases: overriding and extending. When overriding a superclass method function, the subclass has replaced the superclass function. When extending a superclass function, the subclass method will call the superclass function to perform some of the work. The override-extend distinctions must be made clear in the docstring.

When initializing instance variables in the `__init__()` function, a string placed after the assignment statement can serve as a definition of the variable.

RST Docstring. The most widely-used technique is to write reStructuredText (RST) markup in the docstrings. This is extracted and formatted by tools like Sphinx and epydoc.

For information on RST formatting, see **PEP 287**, as well as http://docutils.sourceforge.net/.

```
class Dice( object ):
    """Model two dice used for craps.  Relies on Die class.

    :ivar theDice: tuple with two Die instances

    ..  method:: roll

        roll dice and return total
    """
    def __init__(self):
        """Create a new pair of dice."""
        self.theDice = ( Die(), Die() )
    def roll(self):
        """Roll the dice and return the sum.

        :returns: number
        """
        [ d.roll() for d in self.theDice ]
        t = sum( theDice )
        return t
```

Generally, we have been omitting a complete docstring header on each class in the interest of saving some space for the kind of small examples presented in the text.

CHAPTER

TWENTYFIVE

SOME DESIGN PATTERNS

The best way to learn object-oriented design is to look at patterns for common solutions to ubiquitous problems. These patterns are often described with a synopsis that gives you several essential features. The writer of a pattern will describe a programming context, the specific problem, the forces that lead to various kinds of solutions, a solution that optimizes the competing forces, and any consequences of choosing this solution.

There are a number of outstanding books on patterns. We'll pick a few key patterns from one of the books, and develop representative classes in some depth. The idea is to add a few additional Python programming techniques, along with a number of class design techniques.

Most of these patterns come from the "Gang of Four" design patterns book, *Design Patterns: Elements of Reusable Object-Oriented Software* [Gamma95]. We'll look at a few design patterns that illustrate some useful Python programming techniques.

Factory This is a pattern for designing a class which is used as a factory for a family of other classes. This allows a client program to use a very flexible and extensible "Factory" to create necessary objects.

State This is a pattern for desiging a hierarchy of classes that describes states (or status) and state-specific processing or data.

Strategy This is a pattern that helps create a class that supports an extension in the form of alternative strategies for implementing methods.

25.1 Factory

When we add subclasses to a class hierarchy, we may also need to rearrange the statements where objects are created. To provide a flexible implementation, it is generally a good idea to centralize all of the object creation statements into a single extendable class. When we extend the subclass hierarchy we can also create a relevant subclass of the centralized object creation class.

The design pattern for this kind of centralized object creator can be called a Factory. It contains the details for creating an instance of each of the various subclasses.

In the next section, *Components, Modules and Packages*, we'll look at how to package a class hierarchy in a module. Often the classes and the factory object are bundled into one seamless module. Further, as the module evolves and improves, we need to preserve the factory which creates instances of other classes in the module. Creating a class with a factory method helps us control the evolution of a module. If we omit the **Factory** class, then everyone who uses our module has to rewrite their programs when we change our class hierarchy.

Extending the Card Class Hierarchy. We'll extend the `Card` class hierarchy, introduced in *Inheritance*. That original design had three classes: `Card`, `FaceCard` and `AceCard`.

While this seems complete for basic Blackjack, we may need to extend these classes. For example, if we are going to simulate a common card counting technique, we'll need to separate 2-6 from 7-9, leading to two more subclasses. Adding subclasses can easily ripple through an application, leading to numerous additional, sometimes complex changes. We would have to look for each place where the various subclasses of cards were created. The *Factory* design pattern, however, provides a handy solution to this problem.

An object of a class based on the *Factory* pattern creates instances of other classes. This saves having to place creation decisions throughout a complex program. Instead, all of the creation decision-making is centralized in the factory class.

For our card example, we can define a `CardFactory` that creates new instances of `Card` (or the appropriate subclass.)

```
class CardFactory( object ):
    def newCard( self, rank, suit ):
        if rank == 1:
            return Ace( rank, suit )
        elif rank in [ 11, 12, 13 ]:
            return FaceCard( rank, suit )
        else:
            return Card( rank, suit )
```

We can simplify our version of `Deck` using this factory.

```
class Deck( object ):
    def __init__( self ):
        factory= CardFactory()
        self.cards = [ factory.newCard( rank+1, suit )
            for suit in range(4)
                for rank in range(13) ]
     Rest of the class is the same
```

Tip: Centralized Object Creation

While it may seem like overhead to centralize object creation in factory objects, it has a number of benefits.

First, and foremost, centralizing object creation makes it easy to locate the one place where objects are constructed, and fix the constructor. Having object construction scattered around an application means that time is spent searching for and fixing things that are, in a way, redundant.

Additionally, centralized object creation is the norm for larger applications. When we break down an application into the data model, the view objects and the control objects, we find at least two kinds of factories. The data model elements are often created by fetching from a database, or parsing an input file. The control objects are part of our application that are created during initialization, based on configuration parameters, or created as the program runs based on user inputs.

Finally, it makes evolution of the application possible when we are creating a new version of a factory rather than tracking down numerous creators scattered around an application. We can assure ourselves that the old factory is still available and still passes all the unit tests. The new factory creates the new objects for the new features of the application software.

Extending the Factory. By using this kind of Factory method design pattern, we can more easily create new subclasses of Card. When we create new subclasses, we do three things:

1. Extend the `Card` class hierarchy to define the additional subclasses.

2. Extend the `CardFactory` creation rules to create instances of the new subclasses. This is usually done by creating a new subclass of the factory.
3. Extend or update `Deck` to use the new factory. We can either create a new subclass of `Deck`, or make the factory object a parameter to `Deck`.

Let's create some new subclasses of `Card` for card counting. These will subdivide the number cards into low, neutral and high ranges. We'll also need to subclass our existing `FaceCard` and `Ace` classes to add this new method.

```
class CardHi( Card ):
    """Used for 10."""
    def count( self ): return -1
class CardLo( Card ):
    """Used for 3, 4, 5, 6, 7."""
    def count( self ): return +1
class CardNeutral( Card ):
    """Used for 2, 8, 9."""
    def count( self ): return 0
class FaceCount( FaceCard ):
    """Used for J, Q and K"""
    def count( self ): return -1
class AceCount( Ace ):
    """Used for A"""
    def count( self ): return -1
```

A counting subclass of `Hand` can sum the `count()` values of all `Card` instances to get the count of the deck so far.

Once we have our new subclasses, we can create a subclass of `CardFactory` to include these new subclasses of `Card`. We'll call this new class `HiLoCountFactory`. This new subclass will define a new version of the `newCard()` method that creates appropriate objects.

By using default values for parameters, we can make this factory option transparent. We can design `Deck` to use the original `CardFactory` by default. We can also design `Deck` to accept an optional `CardFactory` object, which would tailor the `Deck` for a particular player strategy.

```
class Deck( object ):
    def __init__( self, factory=CardFactory() ):
        self.cards = [ factory.newCard( rank+1, suit )
            for suit in range(4)
                for rank in range(13) ]
     Rest of the class is the same
```

The Overall Main Program. Now we can have main programs that look something like the following.

```
d1 = Deck()
d2 = Deck(HiLoCountFactory())
```

In this case, `d1` is a `Deck` using the original definitions, ignoring the subclasses for card counting. The `d2` `Deck` is built using a different factory and has cards that include a particular card counting strategy.

We can now introduce variant card-counting schemes by introducing further subclasses of `Card` and `CardFactory`. To pick a particular set of card definitions, the application creates an instance of one of the available subclasses of `CardFactory`. Since all subclasses have the same `newCard()` method, the various objects are interchangeable. Any `CardFactory` object can be used by `Deck` to produce a valid deck of cards.

This evolution of a design via new subclasses is a very important technique of object-oriented programming. If we add features via subclasses, we are sure that the original definitions have not been disturbed. We can be completely confident that adding a new feature to a program will not break old features.

25.2 State

Objects have state changes. Often the processing that an object performs depends on the state. In non-object-oriented programming languages, this state-specific processing is accomplished with long, and sometimes complex series of **if** statements. The *State* design pattern gives us an alternative design.

As an example, the game of Craps has two states. A player's first dice roll is called a *come out* roll. Depending on the number rolled, the player immediately wins, immediately loses, or the game transitions to a *point* roll. The game stays in the point roll state until the player makes their point or crap out with a seven. The following table provides a complete picture of the state changes and the dice rolls that cause those changes.

Table 25.1: Craps State Change Rules

State	Roll	Bet Resolution	Next State
Point Off; the Come Out Roll; only Pass and Don't Pass bets allowed.	2, 3, 12	"Craps": Pass bets lose, Don't Pass bets win.	Point Off
	7, 11	"Winner": Pass bets win, Don't Pass bets lose.	Point Off
	4, 5, 6, 8, 9, 10	No Resolution	Point On the number rolled, p.
Point On; any additional bets may be placed.	2, 3, 12	No Resolution	Point still on
	11	No Resolution	Point still on
	7	"Loser": all bets lose. The table is cleared.	Point Off
	Point, p	"Winner": point is made, Pass bets win, Don't Pass bets lose.	Point Off
	Non-p number	Nothing; Come bets are activated	Point still on

The *State* design pattern is essential to almost all kinds of programs. The root cause of the hideous complexity that characterizes many programs is the failure to properly use the *State* design pattern.

The `Craps` Class. The overall game of craps can be represented in an object of class `Craps`. A `Craps` object would have a `play1Round()` function to initialize the game in the come out roll state, roll dice, pay off bets, and possibly change states.

Following the *State* design pattern, we will delegate state-specific processing to an object that represents just attributes and behaviors unique to each state of the game. We pan to create a `CrapsState` class with two subclasses: `CrapsStateComeOutRoll` and `CrapsStatePointRoll`.

The overall `Craps` object will pass the dice roll to the `CrapsState` object for evaluation. The `CrapsState` object calls methods in the original `Craps` object to pay or collect when there is a win or loss. The `CrapsState` object can also return an object for the next state. Additionally, the `CrapsState` object will have to indicate then the game actually ends.

We'll look at the `Craps` object to see the context in which the various subclasses of `CrapsState` must operate.

craps.py

```
import dice
class Craps( object ):
    """Simple game of craps."""
    def __init__( self ):
        self.state= None
        self.dice= dice.Dice()
        self.playing= False
    def play1Round( self ):
        """Play one round of craps until win or lose."""
        self.state= CrapsStateComeOutRoll()
        self.playing= True
        while self.playing:
           self.dice.roll()
           self.state= self.state.evaluate( self, self.dice )
    def win( self ):
        """Used by CrapsState when the roll was a winner."""
        print "winner"
        self.playing= False
    def lose( self ):
        """Used by CrapsState when the roll was a loser."""
        print "loser"
        self.playing= False
```

1. The `Craps` class constructor, `__init__()`, creates three instance variables: `state`, `dice` and `playing`. The `state` variable will contain an instance of `CrapsState`, either a `CrapsStateComeOutRoll` or a `CrapsStatePointRoll`. The `dice` variable contains an instance of the class `Dice`, defined in *Class Definition: the class Statement*. The `playing` variable is a simple switch that is `True` while we the game is playing and `False` when the game is over.

2. The `play1Round()` method sets the `state` to `CrapsStateComeOutRoll`, and sets the `playing` variable to indicate that the game is in progress. The basic loop is to roll the dice and the evaluate the dice.

   This method calls the state-specific `evaluate()` function of the current `CrapsState` object. We give this method a reference to overall game, via the `Craps` object. That reference allows the `CrapsState` to call the `win()` or `lose()` method in the `Craps` object. The `evaluate()` method of `CrapsState` is also given the `Dice` object, so it can get the number rolled from the dice. Some propositions (called "hardways") require that both dice be equal; for this reason we pass the actual dice to `evaluate()`, not just the total.

3. When the `win()` or `lose()` method is called, the game ends. These methods can be called by the the `evaluate()` method of the current `CrapsState`. The `playing` variable is set to `False` so that the game's loop will end.

The `CrapsState` Class Hierarchy. Each subclass of `CrapsState` has a different version of the `evaluate()` operation. Each version embodies one specific set of rules. This generally leads to a nice simplification of those rules; the rules can be stripped down to simple **if** statements that evaluate the dice in one state only. No additional **if** statements are required to determine what state the game is in.

```
class CrapsState( object ):
    """Superclass for states of a craps game."""
    def evaluate( self, crapsGame, dice ):
        raise NotImplementedError
    def __str__( self ):
        return self.__doc__
```

The `CrapsState` superclass defines any features that are common to all the states. One common feature is the definition of the `evaluate()` method. The body of the method is uniquely defined by each subclass. We provide a definition here as a formal place-holder for each subclass to override. In Java, we would declare the class and this function as abstract. Python lacks this formalism, but it is still good practice to include a placeholder.

Subclasses for Each State. The following two classes define the unique evaluation rules for the two game states. These are subclasses of `CrapsState` and inherit the common operations from the superclass.

```
class CrapsStateComeOutRoll ( CrapsState ):
    """Come out roll rules."""
    def evaluate( self, crapsGame, dice ):
        if dice.total() in [ 7, 11 ]:
            crapsGame.win()
            return self
        elif dice.total() in [ 2, 3, 12 ]:
            crapsGame.lose()
            return self
        return CrapsStatePointRoll( dice.total() )
```

The `CrapsStateComeOutRoll` provides an `evaluate()` function that defines the come out roll rules. If the roll is an immediate win (7 or 11), it calls back to the `Craps` object to use the `win()` method. If the roll is an immediate loss (2, 3 or 12), it calls back to the `Craps` object to use the `lose()` method. In all cases, it returns an object which is the next state; this might be the same instance of `CrapsStateComeOutRoll` or a new instance of `CrapsStatePointRoll`.

```
class CrapsStatePointRoll ( CrapsState ):
    """Point roll rules."""
    def __init__( self, point ):
        self.point= point
    def evaluate( self, crapsGame, dice ):
        if dice.total() == 7:
            crapsGame.lose()
            return None
        if dice.total() == self.point:
            crapsGame.win()
            return None
        return self
```

The `CrapsStatePointRoll` provides an `evaluate()` method that defines the point roll rules. If a seven was rolled, the game is a loss, and this method calls back to the `Craps` object to use the `lose()` method, which end the game. If the point was rolled, the game is a winner, and this method calls back to the `Craps` object to use the `win()` method. In all cases, it returns an object which is the next state. This might be the same instance of `CrapsStatePointRoll ` ` or a new instance of :class:`CrapsStateComeOutRoll`.

Extending the State Design. While the game of craps doesn't have any more states, we can see how additional states are added. First, a new state subclass is defined. Then, the main object class and the other states are updated to use the new state.

An additional feature of the state pattern is its ability to handle state-specific conditions as well as state-specific processing. Continuing the example of craps, the only bets allowed on the come out roll are pass and don't pass bets. All other bets are allowed on the point rolls.

We can implement this state-specific condition by adding a `validBet()` method to the `Craps` class. This will return `True` if the bet is valid for the given game state. It will return `False` if the bet is not valid. Since this is a state-specific condition, the actual processing must be delegated to the `CrapsState` subclasses.

25.3 Strategy

Objects can often have variant algorithms. The usual textbook example is an object that has two choices for an algorithm, one of which is slow, but uses little memory, and the other is fast, but requires a lot of storage for all that speed. In our examples, we can use the *Strategy* pattern to isolate the details of a betting strategy from the rest of a casino game simulation. This will allow us to freely add new betting strategies without disrupting the simulation.

One strategy in Roulette is to always bet on black. Another strategy is to wait, counting red spins and bet on black after we've seen six or more reds in a row. These are two alternate player strategies. We can separate these betting decision algorithms from other features of player.

We don't want to create an entire subclass of player to reflect this choice of algorithms. The Strategy design pattern helps us break something rather complex, like a Player, into separate pieces. The essential features are in one object, and the algorithm(s) that might change are in separate strategy object(s). The essential features are defined in the core class, the other features are strategies that are used by the core class. We can then create many alternate algorithms as subclasses of the plug-in Strategy class. At run time, we decide which strategy object to plug into the core object.

The Two Approaches. As mentioned in *Design Approaches*, we have two approaches for extending an existing class: wrapping and inheritance. From an overall view of the collection of classes, the Strategy design emphasizes wrapping. Our core class is a kind of wrapper around the plug-in strategy object. The strategy alternatives, however, usually form a proper class hierarchy and are all polymorphic.

Let's look at a contrived, but simple example. We have two variant algorithms for simulating the roll of two dice. One is quick and dirty and the other more flexible, but slower.

First, we create the basic `Dice` class, leaving out the details of the algorithm. Another object, the strategy object, will hold the algorithm

```
class Dice( object ):
    def __init__( self, strategy ):
        self.strategy= strategy
        self.lastRoll= None
    def roll( self ):
        self.lastRoll= self.strategy.roll()
        return self.lastRoll
    def total( self ):
        return reduce( lambda a,b:a+b, self.lastRoll, 0 )
```

The `Dice` class rolls the dice, and saves the roll in an instance variable, `lastRoll`, so that a client object can examine the last roll. The `total()` method computes the total rolled on the dice, irrespective of the actual strategy used.

The Strategy Class Hierarchy. When an instance of the `Dice` class is created, it must be given a strategy object to which we have delegated the detailed algorithm. A strategy object must have the expected interface. The easiest way to be sure it has the proper interface is to make each alternative a subclass of a strategy superclass.

```
import random
class DiceStrategy( object ):
    def roll( self ):
        raise NotImplementedError
```

The `DiceStrategy` class is the superclass for all dice strategies. It shows the basic method function that all subclasses must override. We'll define two subclasses that provide alternate strategies for rolling dice.

The first, `DiceStrategy1` is simple.

```
class DiceStrategy1( DiceStrategy ):
    def roll( self ):
        return ( random.randrange(6)+1, random.randrange(6)+1 )
```

This `DiceStrategy1` class simply uses the `random` module to create a tuple of two numbers in the proper range and with the proper distribution.

The second alternate strategy, `DiceStrategy2`, is quite complex.

```
class DiceStrategy2( DiceStrategy ):
    class Die:
        def __init__( self, sides=6 ):
            self.sides= sides
        def roll( self ):
            return random.randrange(self.sides)+1
    def __init__( self, set=2, faces=6 ):
        self.dice = tuple( DiceStrategy2.Die(faces) for d in range(set) )
    def roll( self ):
        return tuple( x.roll() for x in self.dice )
```

This `DiceStrategy2` class has an internal class definition, `Die` that simulates a single die with an arbitrary number of faces. An instance variable, `sides` shows the number of sides for the die; the default number of sides is six. The `roll()` method returns are random number in the correct range.

The `DiceStrategy2` class creates a number of instances of `Die` objects in the instance variable `dice`. The default is to create two instances of `Die` objects that have six faces, giving us the standard set of dice for craps. The `roll()` function creates a tuple by applying a `roll()` method to each of the `Die` objects in `self.dice`.

Creating Dice with a Plug-In Strategy. We can now create a set of dice with either of these strategies.

```
dice1= Dice( DiceStrategy1() )
dice2 = Dice( DiceStrategy2() )
```

The `dice1` instance of Dice uses an instance of the `DiceStrategy1` class. This strategy object is used to constuct the instance of `Dice`. The `dice2` variable is created in a similar manner, using an instance of the `DiceStrategy2` class.

Both `dice1` and `dice2` are of the same class, `Dice`, but use different algorithms to achieve their results. This technique gives us tremendous flexibility in designing a program.

Multiple Patterns. Construction of objects using the strategy pattern works well with a *Factory* pattern, touched on in *Factory*. We could, for instance, use a Factory Method to decode input parameters or command-line options. This give us something like the following.

```
class MakeDice( object ):
    def newDice( self, strategyChoice ):
        if strategyChoice == 1:
            strat= DiceStrategy1()
        else:
            strat= DiceStrategy2()
        return Dice( strat )
```

This allows a program to create the Dice with something like the following.

```
dice = MakeDice().newDice(  :replaceable:`someInputOption` )
```

When we add new strategies, we can also subclass the `MakeDice` class to include those new strategy alternatives.

25.4 Design Pattern Exercises

25.4.1 Alternate Counting Strategy

A simple card counting strategy in Blackjack is to score +1 for cards of rank 3 to 7, 0 for cards of rank 2, 8 and 9 and -1 for cards 10 to King and Ace. The updates to the `Card` class hierarchy are shown in the text.

Create a subclass of `CardFactory`, which replaces `newCard()` with a version that creates the correct subclass of `Card`, based on the rank.

25.4.2 Six Reds

A common strategy in Roulette is to wait until six reds in a row are spun and then start betting on only black. There are three player betting states: waiting, counting and betting.

A full simulation will require a `RouletteGame` class to spin the wheel and resolve bets, a `Wheel` object to produce a sequence of random spins, and a `Table` to hold the individual bets. We'd also need a class to represent the `Bet` s. We'll skim over the full game and try to focus on the player and player states.

A `Player` has a *stake* which is their current pool of money. The `RouletteGame` offers the `Player` an opportunity to bet, and informs the player of the resulting spin of the wheel. The `Player` uses a `SixRedsState` to count reds and bet on black.

The various `SixRedsState` classes have two methods, a `bet()` method decides to bet or not bet, and an `outcome()` method that records the outcome of the previous spin. Each class implements these methods differently, because each class represents a different state of the player's betting policy.

counting In the counting state, the player is counting the number of reds in a row. If a red was spun and the count is < 6, add one to a red counter and stay in this state. If a red is spun and the count is $= 6$, add one to a red counter and transition to the betting state. If black or green is spun, reset the count to zero.

:betting [In the betting state, the player is] betting on black. In a more advanced version, the player would also increase their bet for each red count over six. If a red was spun, add one to a red counter and stay in the betting state. If black was spun, transition to the counting state. If green was spun, transition to the counting state.

> **Caution:** Caution
> We'll focus on the `SixRedsState` design. We won't spend time on the actual betting or payouts. For now, we can simply log wins and losses with a **print** statement.

First, build a simple `Player` class, that has the following methods.

class `Player()`

`__init__`(*self, stake*)
Sets the player's initial stake. For now, we won't do much with this. In other player strategies, however, this may influence the betting.

More importantly, this will set the initial betting state of Counting.

`__str__`(*self*)
Returns a string that includes the current stake and state information for the player.

`getBet`(*self*)
: This will use the current state to determine what bet (if any) to place.

`outcome`(*self, spin*)
: This will provide the color information to the current state. It will also update the player's betting state with a state object returned the current state. Generally, each state will simple return a copy of itself. However, the counting state object will return a betting state object when six reds have been seen in a row.

Second, create a rudimentary `RouletteGame` that looks something like the following.

class `RouletteGame`()

`__init__`(*self, player*)
: A `RouletteGame` is given a `Player` instance when it is constructed.

`__str__`(*self*)
: It's not clear what we'd display. Maybe the player? Maybe the last spin of the wheel?

`play1Round`(*self*)
: The `play1Round()` method gets a bet from the `Player` object, spins the wheel, and reports the spin back to the `Player` object. A more complete simulation would also resolve the bets, and increase the player's stake with any winnings.

  Note that calling the `Player`'s `outcome()` method does two things. First, it provides the spin to the player

`playRounds`(*self, rounds=12*)
: A simple loop that calls '`self.play1Round`' as many times as required.

For guidance on designing the `Wheel` used by the `RouletteGame`, see *Class Variables* and *Function Definition: The def and return Statements*.

State Class Hierarchy. The best approach is to get the essential features of `RouletteGame`, `Wheel` and `Player` to work. Rather than write a complete version of the player's `getBet()` and `outcome()` methods, we can use simple place-holder methods that simply print out the status information. Once we have these objects collaborating, then the three states can be introduced.

The superclass, `SixRedsState`, as well as the two subclasses, would all be similar to the following.

class `SixRedsState`()

`__init__`(*self, player*)
: The superclass initialization saves the player object. Some subclasses will initialize a count to zero.

`__str__`(*self*)
: The superclass `__str__()` method should return a `NotImplemented` value, to indicate that the superclass was used improperly.

`getBet`(*self*)
: The `getBet()` method either returns `None` in the waiting and counting states, or returns a bet on red in the betting state. The superclass can return `None`, since that's a handy default behavior.

`outcome`(*self, spin*)
: The `outcome()` method is given a tuple with a number and a color. Based on the rules given above, each subclass of `SixRedsState` will do slightly different things. The superclass can return `NotImplemented`.

We need to create two subclasses of `SixRedState` :

SixRedCounting In this state, the `getBet()` method returns `None` ; this behavior is defined by the superclass, so we don't need to implement this method. The `outcome()` method checks the spin. If it is Red, this object increments the count by one. If it is black it resets the

count to zero. If the count is six, return an instance of `SixRedBetting` . Otherwise, return `self` as the next state.

SixRedBetting In this state, the `getBet()` method returns a bet on Black; for now, this can be the string `"Black"`. The `outcome()` method checks the spin. If it is Red, this object increments the count by one and returns `self`. If the spin is black it returns an instance of `SixRedCounting`. This will stop the betting and start counting.

Once we have the various states designed, the `Player` can then be revised to initialize itself with an instance of the wating class, and then delegate the `getBet()` request from the game to the state object, and delegate the `outcome()` information from the game to the state object.

25.4.3 Roulette Wheel Alternatives

There are several possible implementations of the basic Roulette wheel. One variation simply uses `random.randrange()` to generate numbers in the range of 0 to 37, and treats 37 as double zero. To separate double zero from zero, it's best to use character string results.

Another strategy is to create a sequence of 38 strings ('00', '0', '1', etc.) and use `random.choice()` to pick a number from the sequence.

Create a superclass for `WheelStrategy` and two subclasses with these variant algorithms.

Create a class for `Wheel` which uses an instance of `WheelStrategy` to get the basic number. This class for `Wheel` should also determine whether the number is red, black or green. The `Wheel` class `spin()` method should return a tuple with the number and the color.

Create a simple test program to create an instance of `Wheel` with an instance of `WheelStrategy`. Collect 1000 spins and print the frequency distribution.

25.4.4 Shuffling Alternatives

Shuffling rearranges a deck or shoe of multiple decks; there are many possible algorithms. First, you will need a `Card` class to keep basic rank and suit information. Next, you will need a basic `Deck` class to hold cards. See *Playing Cards and Decks* for additional details.

We looked at shuffling in an earlier exercise, but packaged it as part of the `Deck` class, not as a separate strategy. See *Advanced Class Definition Exercises*. We can rework those exercises to separate shuffing from `Deck`.

The `Deck` class must have a `shuffle()` function; but this should simply call a method of the shuffle strategy object. Because the `Deck` is a collection of `Card` s, the `Deck` object should be passed to the shuffle strategy. The call would like something like this:

```
class Deck( object ):
    Other parts of Deck

def shuffle( self ): self.shuffleStrategy.shuffle( self )
```

Create a superclass for shuffle strategies. Create a subclass for each of the following algorithms:

- For each card position in the deck, exchange it with a card position selected randomly
- For even-numbered card position (positions 0, 2, 4, 6, etc.) exchange it with an odd-numbered card position, selected randomly (random.choice from 1, 3, 5, 7, 9, etc.)
- Swap two randomly-selected positions; do this 52 times

Create a simple test program that creates a `Deck` with each of the available a `Shuffle` strategy objects.

25.4.5 Shuffling Quality

An open issue in the shuffling exercise is the statistical quality of the shuffling actually performed. Statistical tests of random sequences are subtle, and more advanced than we can cover in this set of exercises. What we want to test is that each card is equally likely to land in each position of the deck.

We can create a dictionary, with the key of each card, and the item associated with that key is a list of positions in which the card occured. We can evaluate a shuffle algorithm as follows.

Test A Shuffle

Setup. Create a `Deck` .

Create an empty dictionary, `positions` for recording card positions.

For each `Card` in the `Deck`, insert the `Card` in the `positions` dictionary; the value associated with the `Card` is a unique empty `list` used to record the positions at which this `Card` is found.

For Each Strategy. Perform the following evaluation for an instance of each `Shuffle` class, *s*.

> **Create Deck**. Set the `Deck`'s current shuffle strategy to *s*.
>
> **Shuffle**. Shuffle the `Deck`.
>
> **Record All Positions**. For each card in the deck, *d*.
>
> > **Record Card Position**. Locate the `Card`'s position list in the `positions` dictionary; append the position of this `Card` to the list in the `positions` dictionary.

Chi-Squared. The chi-squared statistical test can be used to compare the actual frequency histogram to the expected frequency histogram. If you shuffle each deck 520 times, a given card should appear in each of the positions approximately 10 times. Ideally, the distribution is close to flat, but not exactly.

The chi-squared test compares sequence of actual frequencies, *a*, and a sequence of expected frequencies, *e*. It returns the chi-squared metric for the comparison of these two sequences. Both sequences must be the same length and represent frequencies in the same order.

$$\chi^2 = \sum_{0 \le i \le n} \frac{(a_i - e_i)^2}{e_i}$$

We can use the built-in `zip()` function to interleave the two lists, creating a sequence of tuples of '`( actual, expected )`'. This sequence of tuples can be used with the multiple-assignment **for** loop to assign a value from actual to one variable, and a value from expected to another variable. This allows a simple, elegant **for** statement to drive the basic comparison function.

CHAPTER

TWENTYSIX

CREATING OR EXTENDING DATA TYPES

When we use an operator, like + or *, what happens depends on the types of the objects involved. When we say '`c*2`', the value depends on the type of `c` . If `c` is numeric, then 2 may have to be converted to the same type of number as `c`, and the answer will be a number. If, however, `c` is a sequence, the result is a new sequence.

```
>>> c=8.0
>>> c*2
16.0
>>> c="8.0"
>>> c*2
'8.08.0'
>>> c=(8,0)
>>> c*2
(8, 0, 8, 0)
```

The selection of appropriate behavior is accomplished by the relatively simple mechanism of *special method names* within Python. Each class of objects, either built-in or created by a programmer, can provide the required special method names to create the intimate relationship between the class, the built-in functions and the mathematical operators.

We'll look at the general principles in *Semantics of Special Methods*.

If you provide special methods, you can make your class behave like a built-in class. Your class can participate seamlessly with built-in Python functions like `str()`, `len()`, `repr()`. These are basic special methods, covered in *Basic Special Methods*. We'll look at some special attributes in *Special Attribute Names*.

Your class can also participate with the usual mathematical operators like '`+`' and '`*`'. We'll look at this in *Numeric Type Special Methods*.

Additionally, your class could also use the collection operators in a manner similar to a `dict`, `set`, `tuple` or `list`. We'll look at this in *Collection Special Method Names*, *Collection Special Method Names for Iterators and Iterable*, *Collection Special Method Names for Sequences*, *Collection Special Method Names for Sets* and *Collection Special Method Names for Mappings*.

We'll look at a few examples in *Mapping Example* and *Iterator Examples*.

We'll look at special names for handling attributes are handled in *Attributes, Properties and Descriptors*.

Additionally, we can extend built-in classes. We do this by extending some of the special methods to do additional or different things. We'll examine this in *Extending Built-In Classes*.

26.1 Semantics of Special Methods

Python has a number of language features that interact with the built-in data types. For example, objects of all built-in types can be converted to strings. You can use the built-in `str()` function to perform these conversions. The `str()` function invokes the `__str__()` special method of the given object. In effect, '`str(a)`' is evaluated as '`a.__str__()`'.

When you create your own class, you must supply the specially-named method, `__str__()`, that the built-in `str()` function can use to successfully convert your classes values to strings. The default implementation of `__str__()` is pretty lame; you'll always want to override it.

In *Special Method Names* we introduced a few special method names. We looked at `__init__()`, which is evaluated implicitly when an object is created. We looked at `__str__()`, which is used by the `str()` function and `__repr__()` that is used by the `repr()` function.

A huge number of Python features work through these special method names. When you provide appropriate special methods for your class, it behaves more like a built-in class.

You may be suspicious that the special method name `__str__()` matches the built-in function `str()`. There is no simple, obvious rule. Many of the built-in functions invoke specially-named methods of the class that are similar. The operators and other special symbols, however, can't have a simple rule for pairing operators with special method names. You'll have to actually read the documentation for built-in functions (*Library Reference*, section 2.1) and special method names (*Language Reference*, section 3.3) to understand all of the relationships.

Categories of Special Method Names. The special methods fall into several broad categories. The categories are defined by the kind of behavior your class should exhibit.

Basic Object Behaviors A number of special method names make your object behave like oher built-in objects. These special methods make your class respond to `str()`, `repr()` and various comparison operators. This also includes methods that allow your object to respond to the `hash()` function, which allows instances of your class to be a key to a mapping.

Numeric Behaviors These special methods allow your class to respond to the artithmetic operators: '`+`', '`-`', '`*`', '`/`', '`%`', '`**`', '`<<`', '`>>`', **and**, **or** and **not**. When you implement these special methods, your class will behave like the built-in numeric types.

Container Behaviors If your new class is a container (or a collection), there are a number of methods required so that your class can behave like the built-in collection types (sequence, set, mapping). Section 3.4.5 of the Python Language Reference calls them "containers". However, we'll call them collections below.

Iterator Behavior An iterator has a unique protcol. The **for** statement requires an `__iter__()` method to product an iterator for an iterable object. The iterator must provide the `next()` method to actually do the iteration. While this isn't tied to a collection, it's commonly used with collections, so we'll show this with the collection special names below.

Attribute Handling Behavior Some special methods customize how your class responds to the `.` operator for manpulating attributes. For example, when you evaluate `object.attr`. This is commonly used when attribute manipulation is more complex than simply locating an attribute that was defined by `__init__()`.

Function Behavior You can make your object behave like a function. When you define the method `__call__()`, your object is *callable* , and can be used as if it was a function.

Statement Interaction There are a few special methods required by statements.

The **for** statement requires an `__iter__()` method to product an iterator for an iterable object. The iterator object must implement a `next()` method.

The **with** statement requires `__enter__()` and `__exit__()` methods.

26.2 Basic Special Methods

In addition to `__init__()` and `__str__()` there are a number of methods which are appropriate for classes of all kinds.

`__init__`(*self, args...*)
: Called when a new instance of the class is created. Note that this overrides any superclass `__init__()` method; to do superclass initialization first, you must evaluate the superclass `__init__()` like this: '`super( class, self ).__init__( args... )`'. The `super()` function identifies the superclass of your class, *class*.

`__del__`(*self*)
: Called when the this object is no longer referenced anywhere in the running program; the object is about to be removed by garbage collection. This is rarely used. Note that this is called as part of Python garbage collection; it is not called by the **del** statement.

`__repr__`(*self*)
: Called by the `repr()` built-in function. Typically, the string returned by this will look like a valid Python expression to reconstruct the object.

`__str__`(*self*)
: Called by the `str()` built-in function. This is called implicitly by the **print** statement (and `print()` function) to convert an object to a convenient, "pretty" string representation.

`__eq__`(*self, other*)
: Called by '`==`'.

`__ne__`(*self, other*)
: Called by '`!=`'.

`__lt__`(*self, other*)
: Called by '`<`'.

`__le__`(*self, other*)
: Called by '`<=`'.

`__gt__`(*self, other*)
: Called by '`>`'.

`__ge__`(*self, other*)
: Called by '`>=`'.

`__hash__`(*self*)
: Called during dictionary operations, and by the built-in function `hash()` to transform an object to a unique 32-bit integer hash value. Objects which compare equal should also have the same hash value. If a class does not define a `__eq__()` method it should not define a `__hash__()` operation either. Classes with mutable objects can define `__eq__()` but should not define `__hash__()`, or objects would move around in the dictionary.

`__nonzero__`(*self*)
: Called during truth value testing; must return 0 or 1. If this method is not defined, and `__len__()` is defined, then `__len__()` is called based on the assumption that this is a collection. If neither function is defined, all values are considered `True`.

26.3 Special Attribute Names

As part of creating a class definition, Python adds a number of special attributes. These are informational in nature, and cannot not be easily be changed except by redefining the class or function, or reimporting the module.

___class___ This object's class name. The class has a `__name__` attribute which is the name of the class.

___module___ The module in which the class was defined.

___dict___ The dictionary which contains the object's attributes and methods.

___bases___ The base classes for this class. These are also called superclasses.

___doc___ The documentation string. This is part of the response produced by the `help()` function.

Here's an example of how the class docstring is used to produce the `help()` results for a class.

```
import random
print random.Random.__doc__
help(random.Random)
```

26.4 Numeric Type Special Methods

When creating a new numeric data type, you must provide definitions for the essential mathematical and logical operators. When we write an expression using the usual '`+`', '`-`', '`*`', '`/`', '`//`', '`%`', or '`**`', Python transforms this to method function calls.

Consider the following:

```
v1= MyClass(10,20)
v2= MyClass(20,40)
x = v1 + v2
```

In this case, Python will evaluate line 3 as if you had written:

```
x = v1.__add__( v2 )
```

Every arithmetic operator is transformed into a method function call. By defining the numeric special methods, your class willwork with the built-in arithmetic operators. There are, however, some subtleties to this.

Forward, Reverse and In-Place Method Functions. There are as many as three variant methods required to implement each operation. For example, '`*`' is implemented by `__mul__()`, `__rmul__()` and `__imul__()`. There are forward and reverse special methods so that you can assure that your operator is properly commutative. There is an in-place special method so that you can implement augmented assignment efficiently (see *Augmented Assignment*).

You don't need to implement all three versions. If you implement just the forward version, and your program does nothing too odd or unusual, everything will work out well. The reverse name is used for special situations that involve objects of multiple classes.

Python makes two attempts to locate an appropriate method function for an operator. First, it tries a class based on the left-hand operand using the "forward" name. If no suitable special method is found, it tries the the right-hand operand, using the "reverse" name.

Additionally, we can return the special value `NotImplemented` to indicate that a specific version of a method function is not implemented. This will cause Python to skip this method function and move on to an alternative.

Consider the following:

```
v1= MyClass(10,20)
x = v1 * 14
y = 28 * v1
```

Both lines 2 and 3 require conversions between the built-in integer type and `MyClass`. For line 2, the forward name is used. The expression '`v1*14`' is evaluated as if it was

```
x = v1.__mul__( 14 )
```

For line 3, the reverse name is used. The expression '`28*v1`' is evaluated as if it was

```
y = v1.__rmul__( 28 )
```

Note: Python 3 and Coercion

Historically, as Python has evolved, so have the ins and outs of argument coercion from data type to data type. We've omitted the real details of the coercion rules.

In Python 3.0, the older notion of type coercion and the `coerce()` function will be dropped altogether, so we'll focus on the enduring features that will be preserved.

Section 3.4.8 of the *Python Language Reference* covers this in more detail; along with the caveat that the Python 2 rules have gotten too complex.

The Operator Algorithm. The algorithm for determing what happens with '`x op y`' is approximately as follows.

Note that a special method function can return the value `NotImplemented`. This indicates that the operation can't work directly only the values, and another operation should be chosen. The rules provide for a number of alternative operations, this allows a class to be designed in a way that will cooperate successfully with potential future subclasses.

1. The expression '`string % anything`' is a special case and is handled first. This assures us that the value of *anything* is left untouched by any other rules. Generally, it is a tuple or a dictionary, and should be left as such.

2. If this is an augmented assignment statement (known as an in-place operator, e.g., '`variable $= anything`') for some operator, '`$`'. If the left operand implements `__iXopX__()`, then that `__iXopX__()` special method is invoked without any coercion. These in-place operators permit you to do an efficient udpate the left operand object instead of creating a new object.

3. As a special case, the two operators are '`superclass XopX subclass`', then the right operand (the subclass) `__rXopX__()` method is tried first. If this is not implemented or returns `NotImplemented` then the the left operand (the superclass) `__XopX__()` method is used. This is done so that a subclass can completely override binary operators, even for built-in types.

4. For '`x op y`', '`x.__op__(y)`' is tried first. If this is not implemented or returns `NotImplemented` , '`y.__rop__(x)`' is tried second.

The following functions are the "forward" operations, used to implement the associated expressions.

method function	original expression
`__add__(other)()`	'self + other'
`__sub__(other)()`	'self - other'
`__mul__(other)()`	'self * other'
`__div__(other)()`	'self / other' classical Python 2 division
`__truediv__(other)()`	'self / other' when 'from __future__ import division' or Python 3
`__floordiv__(other)()`	'self // other'
`__mod__(other)()`	'self % other'
`__divmod__(other)()`	'divmod(self, other)'
`__pow__(other [, modulo] )()`	'self ** other'
`__lshift__(other)()`	'self << other'
`__rshift__(other)()`	'self >> other'
`__and__(other)()`	'self & other'
`__or__(other)()`	'self | other'
`__xor__(other)()`	'self ^ other'

The method functions in this group are used to resolve operators by attempting them using a reversed sense.

method function	original expression
`__radd__(other)()`	'other + self'
`__rsub__(other)()`	'other - self'
`__rmul__(other)()`	'other * self'
`__rdiv__(other)()`	'other / self' classical Python 2 division
`__rtruediv__(other)()`	'other / self' when 'from __future__ import division' or Python 3
`__rfloordiv__(other)()`	'other // self'
`__rmod__(other)()`	'other % self'
`__rdivmod__(other)()`	'divmod(other, self)'
`__rpow__(other [,modulo])()`	'other ** self'
`__rlshift__(other)()`	'other << self'
`__rrshift__(other)()`	'other >> self'
`__rand__(other)()`	'other & self'
`__ror__(other)()`	'other | self'
`__rxor__(other)()`	'other ^ self'

The method functions in this group are used to resolve operators by attempting them using an incremental sense.

method function	original expression
`__iadd__(other)()`	'self += other'
`__isub__(other)()`	'self -= other'
`__imul__(other)()`	'self *= other'
`__idiv__(other)()`	'self /= other' classical Python 2 division
`__itruediv__(other)()`	'self /= other' when 'from __future__ import division' or Python 3
`__ifloordiv__(other)()`	'self //= other'
`__imod__(other)()`	'self %= other'
`__ipow__(other [,modulo])()`	'self **= other'
`__ilshift__(other)()`	'self <<= other'
`__irshift__(other)()`	'self >>= other'
`__iand__(other)()`	'self &= other'
`__ior__(other)()`	'self |= other'
`__ixor__(other)()`	'self ^= other'

The method functions in the following group implement the basic unary operators.

method function	original expression
`__neg__()`	'`- self`'
`__pos__()`	'`+ self`'
`__abs__()`	'`abs( self )`'
`__invert__()`	'`~ self`'
`__complex__()`	'`complex( self )`'
`__int__()`	'`int( self )`'
`__long__()`	'`long( self )`'
`__float__()`	'`float( self )`'
`__oct__()`	'`oct( self )`'
`__hex__()`	'`hex( self )`'
`__index__()`	'`sequence[self]`', usually as part of a slicing operation which required integers

Rational Number Example. Consider a small example of a number-like class. The *Rational Numbers* exercise in *Classes* describes the basic structure of a class to handle rational math, where every number is represented as a fraction. We'll add some of the special methods required to make this a proper numeric type. We'll finish this in the exercises.

```
class Rational( object ):
    def __init__( self, num, denom= 1L ):
        self.n= long(num)
        self.d= long(denom)
    def __add__( self, other ):
        return Rational( self.n*other.d + other.n*self.d,
        self.d*other.d )
    def __str__( self ):
        return "%d/%d" % ( self.n, self.d )
```

This class has enough methods defined to allow us to add fractions as follows:

```
>>> x = Rational( 3, 4 )
>>> y = Rational( 1, 3 )
>>> x + y
7/12
```

In order to complete this class, we would need to provide most of the rest of the basic special method names (there is almost never a need to provide a definition for `__del__()`). We would also complete the numeric special method names.

Additionally, we would have to provide correct algorithms that reduced fractions, plus an additional conversion to respond with a mixed number instead of an improper fraction. We'll revisit this in the exercises.

Conversions From Other Types. For your class to be used successfully, your new numeric type should work in conjunction with existing Python types. You will need to use the `isinstance()` function to examine the arguments and make appropriate conversions.

Consider the following expressions:

```
x = Rational( 22, 7 )
y = x+3
z = x+0.5
```

Our original `__add__()` method assumed that the *other* object is a `Rational` object. But in this case, we've provided `int` and `float` values for *other*. Generally, numeric classes must be implemented with tests for various other data types and appropriate conversions.

We have to use the isinstance() function to perform checks like the following: 'isinstance(other, int)'. This allows us to detect the various Python built-in types.

Function Reference vs. Function Call

In this case, we are using a reference to the 'int' function; we are not evaluating the int() function. If we incorrectly said 'isinstance(other, int())', we would be attempting to evaluate the int() function without providing an argument; this is clearly illegal.

If the result of 'isinstance(other, types)' is True in any of the following cases, some type of simple conversion should be done, if possible.

- **complex**. 'isinstance(other, complex)'. You may want to raise an exception here, since it's hard to see how to make rational fractions and complex numbers conformable. If this is a common situation in your application, you might need to write an even more sophisticated class that implements complex numbers as a kind of rational fraction. Another choice is to write a version of the abs() function of the complex number, which creates a proper rational fraction for the complex magnitude of the given value.
- **float**. 'isinstance(other, float)'. One choice is to truncate the value of other to long , using the built-in long() function and treat it as a whole number, the other choice is to determine a fraction that approximates the floating point value.
- **int or long**. 'isinstance(other, (int,long))'. Any of these means that the other value is clearly the numerator of a fraction, with a denominator of 1.
- **string**. 'isinstance(other, basestring)'. We might try to convert the other value to a long using the built-in long() function. If the conversion fails, we could try a float. The exception that's thrown from any of the attempted conversions will make the error obvious.

  The basestring type, by the way, is the superclass for ASCII strings (str) and Unicode strings (unicode).
- **Rational**. 'isinstance(other, Rational)'. This indicates that the other value is an instance of our Rational class; we can do the processing as expected, knowing that the object has all the methods and attributes we need.

Here is a version of __sub__() with an example of type checking. If the *other* argument is an instance of the class Rational, we can perform the subtract operation. Otherwise, we attempt to convert the *other* argument to an instance of Rational and attempt the subtraction between two Rationals.

```
def __sub__( self, other ):
    if isinstance(other,Rational):
        return Rational( self.n*other.d - other.n*self.d, self.d*other.d )
    else:
        return self - Rational(long(other))
```

An alternative to the last line of code is the following.

```
return Rational( self.n-long(other)*self.d, self.d )
```

While this second version performs somewhat quicker, it expresses the basic rational addition algorithm twice, once in the **if:** suite and again in the **else:** suite. A principle of object oriented programming is to maximize reuse and minimize restating an algorithm. My preference is to state the algorithm exactly once and reuse it as much as possible.

Reverse Operators. In many cases, Python will reverse the two operands, and use a function like __rsub__() or __rdiv__(). For example:

```
def __rsub__( self, other ):
    if isinstance(other,Rational):
       return Rational( other.n*self.d - self.n*other.d,
       self.d*other.d )
    else:
        return Rational(long(other)) - self
```

You can explore this behavior with short test programs like the following:

```
x = Rational( 3,4 )
print x-5
print 5-x
```

26.5 Collection Special Method Names

The various collection special method names can be organized several different ways. Above, in *Semantics of Special Methods* we claimed that a bunch of special method names were related to "container" and "iterator" behavior. These categories from the language reference don't tell the whole story.

Python gives us additional tools to create classes that behave like the built-in collection classes. We can use the abstract base classes in the `collections` module to jump-start our definition of new types of collections.

Each abstract base class (ABC) in the `collections` module provides a common feature (or set of features) with the method functions that are required to implement that feature. In some cases, the features build on each other, and a number of method functions are required.

Since each of the ABC classes is *abstract*, they're missing the implementation of one or more methods. To use these classes, you'll have to provide the necessary methods.

One very important consequence of using the collections base classes is that it creates standardized names for the various features. This simplifies the assertions that might be required when checking the argument values to a function or method function.

For more information, see section 9.3.1 of the Python Library Reference, as well as **PEP 3119**.

Some Foundational Definitions. We'll look at some foundational abstract classes first. Each of these defines a small group of fundamental features. We'll use this in the next section to build more sophisticated classes.

We'll look at the following:

- `Container`. What makes a container? The **in** test for membership. Extend this class to make objects of your class a container.
- `Hashable`. This makes something usable as a key for mappings or sets. Extend this class to make objects of your class a hashable key.
- `Sized`. This makes something report how many elements it has. Extend this class to make objects of your class respond to the `len()` function with a size.
- `Callable`. Extend this class to make objects of your class behave like a function.

class `Container()`
To be a Container object, the class must provide the `__contains__()` method.

`__contains__`(*self, value*)
Return true if the value is in the container.

This example is a little silly, but it shows a tuple-like container that secretly adds an additional item.

```
class BonusContainer( collections.Container ):
    def __init__( self, \*members ):
        self.members= members + ( 'SecretKey', )
    def __contains__( self, value ):
        return value in self.members
```

class Hashable()

To be a Hashable object, the class must provide the `__hash__()` method. This is a requirement for any object we might want to use as a key to a dictionary.

__hash__(*self*)

Return a hash for this Hashable object. The easiest wasy to compute a hash is to sume the hashes of the various elements.

Here's an example of a class that creates a hash, suitable for use in a dictionary.

```
class StockBlock( collections.Hashable ):
    def __init__( self, name, price, shares ):
        self.name= name
        self.price= price
        self.shares= shares
        self._hash= hash(self.name)+hash(self.price)+hash(self.shares)
    def __hash__( self ):
        return self._hash
```

class Sized()

To be a Sized object, the class must provide the `__len__()` method.

__len__(*self*)

Return the size of this collection. This is generally understood to be the nunber of items in the collection.

class Callable()

To be a Callable object, the class must provie the `__call__()` method.

Functions are callable objects, but we can also define a class that creates callable objects, similar to a function definition.

__call__(*self, parameters...*)

This method is called when the object is used as if it were a function. We might create and use callable object with something like the following.

```
callable_object = MyCallable()
callable_object( argument, values )
```

Here's an example of a callable class definition. We can use this to create callable objects that are – essentially – functions.

```
class TimesX( collections.Callable ):
    def __init__( self, factor ):
        self.factor= factor
    def __call__( self, argument ):
        return argument * self.factor
```

We can use this class to create callable objects as follows:

```
>>> times_2= TimesX(2)
>>> times_2( 5 )
10
>>> import math
>>> times_pi= TimesX(math.pi)
>>> times_pi( 3*3 )
28.274333882308138
```

1. We created a callable object, `times_2`, as an instance of `TimesX` with a factor of 2.
2. We applied our `times_2` function to a value of `5`.
3. We created a callable object, `times_pi`, as an instance of `TimesX` with a factor of `math.pi`.
4. We applied our `times_i` function to a value of '`3*3`'.

26.6 Collection Special Method Names for Iterators and Iterable

The following `collection` class definitions introduce special method names to make your class respond to the iterator protocols used by the **for** statement.

We'll look at defining iterable contains and iterators in depth in *Collection Special Method Names for Iterators and Iterable*.

class `Iterable()`
To be an Iterable object, the class must provide the `__iter__()` method.

`__iter__`(*self*)
Returns an Iterator for this Iterable object.

Generally, this will look like the following.

```
import collections
class  MyIterable( collections.Iterable ):

    # all the other methods of the MyIterable collection

    def __iter__( self ):
        return MyIteratorClass( self )
```

This means that we have a class that extends `collections.Iterator` which will control the iteration through the given `MyIterable` collection.

These two classes are sometimes called "friends", since the the Iterator often has deeper access to the Iterable.

class `Iterator()`
To be an Iterator object, the class must provide the `__next__()` method. Additionally, an Iterator is itself Iterable, so it must provide a `__iter__()` method.

Generally, the `__iter__()` method just does '`return self`'.

`__next__`(*self*)
Advance the iterator and either return the next object from the iterable container or raise an `StopIteration` exception.

Important: Python 3

The the Iterator method name of `__next__()` is focused on Python 3.

For Python 2 compatability, you might want to also defined `next()`.

```
def next( self ):
    return self.__next__()
```

`__iter__`(*self*)
Additionally an iterator will also provide a definition of the `__iter__()` special method name. This will simply return the iterator itself ('`return self`'). This prevents small problems with redundant calls to the `iter()` built-in function.

Note there are still more features of iterators. The Python Enhancement Proposal (**PEP 342**) describes some considerably more advanced features of iterators and the **yield** statement.

26.7 Collection Special Method Names for Sequences

The following `collection` class definitions introduce special method names to make your class behave like a Sequence (`tuple`) or a Mutable Sequence (`list`).

class `Sequence()`
A Sequence object (essentially a tuple) is based on three more fundamental definitions: Sized, Iterable and Container. As such, the class must define a number of methods including `__contains__()`, `__len__()`, `__iter__()`.

A Sequence must define a `__getitem__()` method.

Additionally, methods like `__reversed__()`, `index()` and `count()` are also sensible for this class. The `collections.Sequence` provides defaults for these methods.

Since we're talking about an object that's like a tuple or frozenset, there aren't any methods for updating or mutating the contents.

Note also, that Hashable isn't part of a Sequence. You might want to add Hashable if your Sequence can support a fixed hash value, suitable for use as dictionary key.

This class provides a default implementation of `__iter__()` that is based on using a range of values and calling `__getitem__()`.

`__getitem__`(*self, index*)
Return the value at the given index in the Sequence.

The `__getitem__()` method function should be prepared for the *key* to be either a simple integer or a `slice` object. When called with an integer, it returns an element of the sequence or raises `IndexError`.

A `slice` is a simple object with three attributes: `start`, `stop` and `step`. When called with a slice object, it returns another Sequence.

The following examples show common slice situations.

- The expression '`someSequence[1:5]`' is transformed to '`someSequence.__getitem__( slice(1,5) )`'. The `slice` object has the following attribute values: `key.start` = 1, `key.stop` = 5, `key.step` = `None`.
- The expression '`someSequence[2:8:2]`' is transformed to '`someSequence.__getitem__( slice(2,8,2) )`'. The `slice` object has the following attribute values: `key.start` = 2, `key.stop` = 8, `key.step` = 2.

- The expression 'someSequence[1:3,5:8]' is transformed into 'someSequence.__getitem__((slice(1,3), slice(5,8)))'. The *key* argument will be a tuple of slice objects.

Here's an example of a simple class that behaves like a tuple, with some restrictions.

```
import collections
class Point( collections.Sequence ):
    def __init__( self, x, y ):
        self.x= x
        self.y= y
    def __len__( self ):
        return 2
    def __contains__( self, key ):
        return self.x==key or self.y==key
    def __getitem__( self, position ):
        if position in ( 0, -2 ):
            return self.x
        elif position in ( 1, -1 ):
            return self.y
        else:
            raise IndexError
```

class MutableSequence()

A MutableSequence exteds a Sequence. It requires all of the Sequence methods to be defined. Plus it has some additional methods. To be mutable, it must have a way to update and remove items. The methods __setitem__(), __delitem__(), and insert() must be defined to update a MutableSequence.

There are of course, numerous additional methods that are provided by default. Any of the optional methods from Sequence, plus append(), reverse(), extend(), pop(), remove(), and __iadd__(). You can override these definitions if you want to improve their performance.

__getitem__(*self, index*)

Return the value at the given index in the Sequence.

__setitem__(*self, index, value*)

Replace the value at the given index in the Sequence

__delitem__(*self, index, value*)

Remove the value at the given index in the Sequence.

The __getitem__(), __setitem__() and __delitem__() method function should be prepared for the *index* to be either a simple integer, a slice object, or a tuple of slice objects.

insert(*self, index, value*)

Insert a new value before the given index in the Sequence.

26.8 Collection Special Method Names for Sets

The following collection class definitions introduce special method names to make your class behave like a Set (frozenset) or a MutableSet (set).

class Set()

A Set, like a basic Sequence, is based on three more fundamental definitions: Sized, Iterable, Container. The basic collections.Set is an immutable set; it's the basis for the built-in frozenset. A mutable set will build on this definition.

As such, the class must define a number of methods including __contains__(), __len__(), __iter__().

Since, generally, a set simply checks for membership, we don't need too much more.

The comparison operations (`__le__()`, `__lt__()`, `__eq__()`, `__ne__()`, `__gt__()`, `__ge__()`, `__and__()`, `__or__()`, `__sub__()`, `__xor__()`, and `isdisjoint()`) have default definitions. You can override these for performance reasons.

class `MutableSet()`
A MutableSet extends a Set. It requires all of the Set methods to be defined. Plus it has some additional methods. To be mutable, it must have the methods `add()` and `discard()` to update the MutableSet. The `collections.MutableSet` is is the basis for the built-in `set`.

The `collections.MutableSet` provides the following method functions `clear()`, `pop()`, `remove()`. These are based on our supplied `add()` and `discard()`

Also, the following operators are provided so that a MutableSet can be updated with another set: `__ior__()`, `__iand__()`, `__ixor__()`, and `__isub__()`.

`add`(*self, item*)
Updates the set to add the item, if it was not already a member.

`discard`(*self, item*)
Updates the set to remove the item, if it was a member. Does nothing if the member was not already in the set.

26.9 Collection Special Method Names for Mappings

The following `collection` class definitions introduce special method names to make your class behave like a Mapping or a MutableMapping (`dict`).

class `Mapping()`
A Mapping, like a basic Sequence, is based on three more fundamental definitions: Sized, Iterable, Container. The basic `collections.Mapping` is the definition of an immutable mapping. A mutable mapping (like a `dict`) will build on this definition.

As such, the class must define a number of methods including `__contains__()`, `__len__()`, `__iter__()`.

A Mapping must define a `__getitem__()` method.

Additionally, default methods will be provided for `__contains__()`, `keys()`, `items()`, `values()`, `get()`, `__eq__()`, and `__ne__()`. The equality test compares the list created by `items()` to assure that each item tuple has the same key and value.

`__getitem__`(*self, key*)
Returns the value corresponding to key, or raises `KeyError`.

class `MutableMapping()`
A MutableMapping exteds a Mapping. It requires all of the Set methods to be defined. Plus it has some additional methods. To be mutable, the methods `__setitem__()` and `__setitem__()` must be defined.

Also, methods are provided for `pop()`, `popitem()`, `clear()`, `update()`, and `setdefault()`

`__getitem__`(*self, key*)
Returns the value corresponding to key, or raises `KeyError`.

A `collections.defaultdict` does not raise an exception. For keys that don't exist, this version of a MutableMapping creates a default value and then returns that.

__setitem__(*self, key, value*)
Puts an item into the mapping; the item has the given key and value. If the key did not exist it is added. If the key did exist, the previous value is replaced.

__delitem__(*self, key*)
Removes an item from the mapping, or raises a KeyError if the item did not exist.

Beyond these two base classes, there are some additional classes that help you to define a "view" that's based on a mapping.

class KeysView()
An object of this class is built from an existing Mapping, and behaves like a Set that contains the keys from the exsting Mapping.

The methods from Sized (__len__()) and Set (__contains__() and __iter__()) are defined.

class ValuesView()
An object of this class is built from an existing Mapping, and behaves like a Set that contains the values from the exsting Mapping.

Unlike a proper Set, however, there may appear to be multiple copies of a given value.

The methods from Sized (__len__()) and Set (__contains__() and __iter__()) are defined.

class ItemsView()
An object of this class is built from an existing Mapping, and behaves like a Set that contains a sequence of (key, value) tuples from the exsting Mapping.

The methods from Sized (__len__()) and Set (__contains__() and __iter__()) are defined.

Note that __contains__() checks for the presence of a (key, value) 2-tuple.

26.10 Mapping Example

An immutable mapping is a kind of translation from key to value. The mapping is fixed when the object is created and cannot be updated.

Here's an example of a small class to define an immutable mapping that we're calling a Translation.

Note that our immutable mapping happens to have a plain old dict under the hood.

```
class Translation( collections.Mapping ):
    def __init__( self, ** kw ):
        self._map= kw
    def __len__( self ):
        return len(self._map)
    def __contains__( self, key ):
        return key in self._map
    def __iter__( self ):
        return iter(self._map)
    def __getitem__( self, key ):
        return self._map[key]
```

Here's a transcript of using our Translation class to create an object that translates some names to numeric values.

```
>>> c = Translation( red=0, green=1, blue=2 )
>>> c['red']
0
```

```
>>> c['white']
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "<stdin>", line 11, in __getitem__
KeyError: 'white'
>>> c['black']= 3
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: 'Translation' object does not support item assignment
>>> for nm in c:
...     print nm
...
blue
green
red
```

26.11 Iterator Examples

The built-in sequence types (`list`, `tuple`, `string`) all produce iterator objects for use by the **for** statement. The `set`, `frozenset`, `dict` and `file` objects also produce an iterator.

In addition to defining ordinary generator methods by using the **yield** statement, your classes can also produce iterator objects. This can make a program slightly simpler to read by assuring that loops are simple, obvious **for** statements.

Easy Iterators. When writing a collection-like class, you can simply write method functions that include the **yield** statement.

```
class Deck( object ):
    def __init__( self ):
        # Create the self.cards container.
    def deal( self ):
        self.shuffle()
        for c in self.cards:
            yield c
```

The `deal()` method is an iterator. We can use this iterator as follows.

```
d= Deck()
for card in d.deal():
    print c
```

This is the same technique covered in *Iterators and Generators*, except used with method functions instead of stand-alone functions.

Unique Iterator Classes. Generally, an iterator is an object we've designed to help us use a more complex container. Consequently, the container will usually contain a factory method which creates iterators associated with the container. A container will implement the special method `__iter__()` to emit an iterator properly configured to handle the container.

When we evaluate '`iter( someList )`', the object, *someList*, must return an iterator object ready to be used with a **for** statement. The way this works is the `iter()` function evaluates the `__iter__()` method function of the object, *someList*. The objects `__iter__()` method function creates the object to be used as an iterator. We'll do something similar in our own classes.

In the following example classes, we'll create a class which wraps a `list` and provides and a specialized iterator that yields only non-zero values of the collection.

```
import collections
class DataSamples( collections.Iterable, collections.Sized ):
    def __init__( self, aList=None ):
        self.values= [] if aList is None or aList
    def __iter__( self ):
        return NonZeroIter( self )
    def __len__( self ):
        return len( self.values )
    def __getitem__( self, index ):
        return self.values[index]
```

1. When we initialize a `DataSamples` instance, we save any provided sequence of values. This class behaves like a collection. We haven't provided all of the methods, however, in order to keep the example short. Clearly, to be `list`-like, we'll need to provide an `append()` method.
2. When we evaluate the `iter()` function for a `DataSamples` object, the `DataSamples` object will create a new, initialized `NonZeroIter`. Note that we provide the `DataSamples` object to the new `NonZeroIter`, this allows the iterator to process the collection properly.

```
class NonZeroIter( collections.Iterator ):
    def __init__( self, aDataSamples ):
        self.ds= aDataSamples
        self.pos= -1
    def __next__( self ):
        while self.pos+1 != len(self.ds) and self.ds[self.pos+1] == 0:
            self.pos += 1
        if self.pos+1 == len( self.ds ):
            raise StopIteration
        self.pos += 1
        return self.ds[self.pos]
    def next( self ):
        return self.__next__()
    def __iter__( self ):
        return self
```

1. When initialized, the `NonZeroIter` saves the collection that it works with. It also sets it's current state; in this instance, we have `pos` set to `-1`, just prior to the element we'll return.
2. The `next()` function of the iterator locates the next non-zero value. If there is no next value or no next non-zero value, it raises `StopIteration` to notify the **for** statement. Otherwise, it returns the next non-zero value. It updates its state to reflect the value just returned.
3. The `__iter__()` function of the iterator typically returns `self`.

We can make use of this iterator as follows.

```
ds = DataSamples( [0,1,2,0,3,0] )
for value in ds:
    print value
```

The **for** statement calls '`iter(ds)`' implicitly, which calls '`ds.__iter__()`', which creates the `NonZeroIter` instance. The **for** statement then calls the `next()` method of this iterator object to get the non-zero values from the `DataSamples` object. When the iterator finally raises the `StopIteration` exception, the **for** statement finishes normally.

26.12 Extending Built-In Classes

We can extend all of Python's built-in classes. This allows us to add or modify features of the data types that come with Python. This may save us from having to build a program from scratch.

Here's a quick example of a class which extends the built-in `list` class by adding a new method.

```
>>> class SumList( list ):
...     def sum( self ):
...             return sum( self )
...
>>> x= SumList( [1, 3, 4] )
>>> x
[1, 3, 4]
>>> x.sum()
8
>>> x.append( 5 )
>>> x.sum()
13
```

Clearly, we can extend a class like `list` with additiona; methods for various statistical calculations. Each function can be added as easily as the `SumList.sum()` function in the above example.

Here's an exmaple of extending a dictionary with simple statistical functions. We based on dictionary on `collections.defaultdict` because it makes it very simple to create a frequency table. See *Default Dictionaries* for more information on default dictionaries.

```
>>> from collections import defaultdict
>>> class StatDict( defaultdict ):
...     def __init__( self, valueList=None ):
...             super( StatDict, self ).__init__( int, valueList )
...     def sum( self ):
...             return sum(  k*self[k] for k in self  )
...
>>> x = StatDict( [ (2,1), (3,1), (4,2) ] )
>>> x.sum()
13
>>> x[5] += 1
>>> x.sum()
18
>>> x[5] += 1
>>> x.sum()
23
```

Each time we increment the frequency of a numeric value, the `defaultdict` will add the integer count automatically.

26.13 Special Method Name Exercises

26.13.1 Geometric Points

A 2-dimensional point is a coordinate pair, an x and y value. If we limit the range to the range 0 to 2**16, we can do a few extra operations quickly.

Develop the basic routines for `__init__()`, `__repr__()`, `__str__()`. The `__hash__()` function can simply combine x and y via '`x<<16+y`'.

Develop a test routine that creates a sequence of points.

Also, be sure to develop a test that uses points as keys in a dictionary.

26.13.2 Rational Numbers

Finish the `Rational` number class by adding all of the required special methods. The *Rational Numbers* exercise in *Classes* describes the basic structure of a class to handle rational math, where every number is represented as a fraction.

26.13.3 Currency and the Cash Drawer

Currency comes in denominations. For instance, US currency comes in $100, $50, $20, $10, $5, $1, $.50, $.25, $.10, $.05, and $.01 denominations. Parker Brothers Monopoly™game has currency in 500, 100, 50, 20, 10, 5 and 1. Prior to 1971, English currency had £50, £20, £10, £5, £1, shillings (1/12 of a pound) and pence (1/20 of a shilling). An amount of money can be represented as an appropriate tuple of integers, each of which represents the specific numbers of each denomination. For instance, one representation for $12.98 in US currency is '`(0, 0, 0, 1, 0, 2, 0, 3, 2, 0, 3)`'.

Each subclass of `Currency` has a specific mix of denominations. We might define subclasses for US currency, Monopoly currency or old English currency. These classes would differ in the list of currencies.

An object of class currency would be created with a specific mix of denominatioons. The superclass should include operations to add and subtract `Currency` objects. An `__iadd__( currency )()` method, for example would add the denominations in *currency* to this object's various denominations. An `__isub__( currency )()` method, for example would subtract the denominations in *currency* to this object's various denominations; in the event of attempting to subtract more than is available, the object would raise an exception.

Be sure to define the various conversions to float, int and long so that the total value of the collection of bills and coins can be reported easily.

An interesting problem is to translate a decimal amount into appropriate currency. Note that numbers like 0.10 don't have a precise floating-point representation; floating point numbers are based on powers of 2, and 0.10 can only be approximated by a finite-precision binary fraction. For US currency, it's best to work in pennies, representing $1.00 as `100`.

Develop a method which will translate a given target amount, t, into an appropriate mixture of currency denominations. In this case, we can iterate through the denominations from largest to smallest, determining the largest quantity, q of a denomination, d, such that $q \times d \leq t$. This version doesn't depend on the current value of the `Currency` object.

More Adanced Solution. A more advanced version is to create a `Currency` object with a given value; this would represent the money in a cash drawer, for example. A method of this object would make an amount of money from only the available currency in the cash drawer, or raise an exception if it could not be done.

In this case, we iterate through the denominations, d, from largest to smallest, determining the largest quantity, q, such that $q \times d \leq t$, consistent with available money in the cash drawer. If we don't have enough of a given denomination, it means that we will be using more of the smaller denominations.

One basic test case is to create a currency object with a large amount of money available for making change.

In the following example, we create a cash drawer with $804.55. We accept a payment of $10 as 1 $5, 4 $1, 3 $.25, 2 $.10 and 1 $.05. Then we accept a payment of $20, for a bill of $15.24, meaning we need to pay out $4.76 in change.

```
drawer = USCurrency( (5,2,6,5,5,5,5,5,5,5,5) )
drawer += USCurrency((0,0,0,0,1,4,0,3,2,1,0))
drawer += USCurrency((0,0,1,0,0,0,0,0,0,0,0))
drawer.payMoney( 4.76 )
```

Interestingly, if you have $186.91 (one of each bill and coin) you can find it almost impossible to make change. Confronted with impossible situations, this class should raise an `UnableToMakeChange` exception.

26.13.4 Sequences with Statistical Methods

Create a sequence class, `StatSeq` that can hold a sequence of data values. This class must be a subclass of `collections.MutableSequence` and define all of the usual sequence operators, including `__add__()`, `__radd__()`, `__iadd__()`, but not `__mul__()`.

The `__init__()` function should accept a sequence to initialize the collection. The various `__add__()` functions should append the values from a `StatSeq` instance as well as from any subclass of `collections.Sequence` (which includes `list` and `tuple`.)

Most importantly, this class shold define the usual statistical functions like mean and standard deviation, described in the exercises after *Tuples*, *Sequence Processing Functions: map(), filter() and reduce()* and *Sample Class with Statistical Methods* in *Classes*.

Since this class can be used everywhere a sequence is used, interface should match that of built-in sequences, but extra features are now readily available. For a test, something like the following should be used:

```
import random
samples = StatSeq( [ random.randrange(6) for i in range(100) ] )
print samples.mean()
s2= StatSeq()
for i in range(100):
    ss.append( random.randrange(6) )
    # Also allow s2 += [ random.randrange(6) ]
print s2.mean()
```

There are two approaches to this, both of which have pros and cons.

- Define a subclass of `list` with a few additional methods. This will be defined as '`class StatSeq( list ):`'.
- Define a new class (a subclass of `object`) that contains an internal list, and provides all of the sequence special methods. Some (like append) will be delegated to the internal list object. Others (like mean) will be performed by the StatSeq class itself. This will be defined as '`class StatSeq( object ):`'.

Note that the value of `mean()` does not have to be computed when it is requested. It is possible to simply track the changing sum of the sequence and length of the sequence during changes to the values of the sequence.

The sum and length are both set to zero by `__init__()`. The sum and length are incremented by every `__add__()`, `append()`, `insert()`. They are decremented by `pop()`, `remove()`, and and `__delitem__()`. Finally, there's a two-part change for `__setitem__()`: the old value is deducted and the new value is added.

This way the calculation of mean is simply a division operation.

Keeping track of sums and counts can also optimize mode and standard deviation. A similar optimization for median is particularly interesting, as it requires that the sample data is retained by this class in sorted order. This means that each insert must preserve the sorted data set so that the median value can be retrieved without first sorting the entire sequence of data. You can use the `bisect` module to do this.

There are a number of algorithms for maintaining the data set in sorted order. You can refer to Knuth's *The Art of Computer Programming* [Knuth73], and Cormen, Leiserson, Rivest *Introduction to Algorithms* [Cormen90] which cover this topic completely.

26.13.5 Chessboard Locations

A chessboard can be thought of as a mapping from location names to pieces. There are two common indexing schemes from chessboards: algebraic and descriptive. In algebraic notation the locations have a rank-file address of a number and a letter. In descriptive notation the file is given by the starting piece's file, rank and player's color.

See *Chess Game Notation* for an extension to this exercise.

The algebraic description of the chess board has *files* from a-h going from white's left to right. It has *ranks* from 1-8 going from white's side (1) to black's side (8). Board's are almost always shown with position a1 in the lower left-hand corner and h8 in the upper right, white starts at the bottom of the picture and black starts at the top.

In addition to the simplified algebraic notation, there is also a descriptive notation, which reflects each player's unique point of view. The descriptive board has a queen's side (white's left, files a-d) and a king's side (white's right, files e-h). Each rank is numbered starting from the player. White has ranks 1-8 going from white to black. Black, at the same time as ranks 1-8 going back toward white. Each of the 64 spaces on the board has two names, one from white's point of view and one from black's.

Translation from descriptive to algebraic is straight-forward. Given the player's color and a descriptive location, it can be translated to an algebraic location. The files translate through a relatively simple lookup to transform QR to a, QKt to b, QB to c, Q to d, K to e, KB to f, KKt to g, KR to h. The ranks translate through a simple calculation: white's ranks are already in algebraic notation; for black's rank of r, $9 - r$ is the algebraic location.

Create a class to represent a chess board. You'll need to support the special function names to make this a kind of mapping. The `__getitem__()` function will locate the contents of a space on the board. The `__setitem__()` function will place a piece at a space on the board. If the `key` to either function is algebraic (2 characters, lower case file from a-h and digit rank from 1-8), locate the position on the board. If the `key` is not algebraic, it should be translated to algebraic.

The codes for pieces include the piece name and color. Piece names are traditionally "p" or nothing for pawns, "R" for rook, "N" for knight, "B" for bishop, "Q" for queen and "K" for king. Pawns would be simply the color code "w" or "b". Other pieces would have two-character names: "Rb" for a black rook, "Qw" for the white queen.

The `__init__()` method should set the board in the standard starting position:

Table 26.1: Chess Starting Position

piece	algebraic	descriptive	piece code
white rooks	a1, h1	wQR1, wKR1	Rw
white knights	b1, g1	wQKt1, wKKt1	Nw
white bishop	c1, f1	wQB1, wKB	Bw
white queen	d1	wQ1	Qw
white king	e1	wK1	Kw
white pawns	a2-h2	wQR2-wKR2	w
black rooks	a8, h8	bQR1, bKR1	Rb
black knights	b8, g8	bQKt1, bKKt1	Nb
black bishops	c8, f8	bQB1, bKB1	Bb
black queen	d8	bQ1	Qb
black king	e8	bK1	Kb
black pawns	a7-a7	bQR2-bKR2	b

Here's a sample five-turn game. It includes a full description of each move, and includes the abbreviated chess game notation.

1. white pawn from e2 to e4; K2 to K5

   black pawn from e7 to e5; K2 to K5

2. white knight from g1 to f3; KKt1 to KB3

   black pawn from d7 to d6; Q2 to Q3

3. white pawn from d2 to d4; Q2 to Q4

   black bishop from c8 to g4; QB1 to KKt5

4. white pawn at d4 takes pawn at e5; Q4 to K5

   black bishop at g4 takes knight at f3; KKt5 to KB6

5. white Q at d1 takes bishop at f3; Q1 to KB3

   black pawn at d6 takes e5; Q3 to K4

The main program should be able to place and remove pieces with something like the following:

```
chess= Board()
# move pawn from white King 2 to King 5
chess['wK5']= chess['wK2']; chess['wK2']= ''
# move pawn from black King 2 to King 5
chess['bK5']= chess['bK2']; chess['bK2']= ''
# algebraic notation to print the board
for rank in [ '8', '7', '6', '5', '4', '3', '2', '1']:
    for file in [ 'a', 'b', 'c', 'd', 'e', 'f', 'g', 'h']:
        print "%5s" % board[file+rank],
    print
```

The algebraic output can be changed to the following, which some people find simpler.

```
for rank in ('8','7','6','5','4','3','2','1'):
    print "".join(
    [ "%5s" % board[file+rank]
        for file in ('a','b','c','d','e','f','g','h') ] )
```

You should also write a `move()` function to simplify creating the test game. A move typically consists of the piece name, the from position, the to position, plus optional notes regarding check and pawn promotions.

26.13.6 Relative Positions on a Chess Board

When decoding a log of a chess game in Short Algebraic Notation (SAN), it is often necessary to search for a piece that made a given move. We'll look at this problem in detail in *Chess Game Notation*.

There are actually a number of search algorithms, each constrained by the rules for moving a particular piece. For example, the knight makes a short "L"-shaped move and there are only 8 positions on the board from which a knight can start to end up at a given spot. The queen, on the other hand, moves horizontally, vertically or diagonally any distance, and there are as many as 24 starting positions for the queen to end up at a given spot.

This search is simplified by having iterators that know a few rules of chess and an give us a sequence of appropriate rank and file values. We'd like to be able to say something like the following.

```
piece, move, toPos = ( "Q", "x", "f3" )
for fromPos in aBoard.queenIter( toPos ):
    if aBoard[fromPos] == 'Q':
        print "Queen from", fromPos, "takes", aBoard[toPos], "at", toPos
```

We'll review a few chess definitions for this problem. You can also see *Chessboard Locations* in *Collection Special Method Names* for some additional background.

The algebraic description of the chess board has *files* from a-h going from white's left to right. It has *ranks* from 1-8 going from white's side (1) to black's side (8). Board's are almost always shown with position a1 in the lower left-hand corner and h8 in the upper right, white starts at the bottom of the picture and black starts at the top.

We need the following collection of special-purpose iterators.

- The `kingIter()` method has to enumerate the eight positions that surround the king.
- The `queenIter()` method has to enumerate all the positions in the same rank, the same file, and on the diagonals. Each of these must be examined from the queen's position moving toward the edge of the board. This search from the queen outward allows us to locate blocking pieces that would prevent the queen from making a particular move.
- The `bishopIter()` method has to enumerate all the positions on the diagonals. Each of these must be examined from the bishop's position moving toward the edge of the board.
- The `knightIter()` method has to enumerate the eight positions that surround the knight, reflecting the knight's peculiar move of 2 spaces on one axis and 1 space on the other axis. There are four combinations of two ranks and one file and four more combinations of two files and one rank from the ending position. As with the king, no piece can block a knight's move, so order doesn't matter.
- The `rookIter()` method has to enumerate all the positions in the same rank and the same file. Each of these must be examined from the rook's position moving toward the edge of the board.
- The `pawnIter()` method has to enumerate a fairly complex set of positions. Most pawn moves are limited to going forward one rank in the same file.

  Since we need to know which direction is forward, we need to know the color of the pawn. For white pawns, forward means the ranks increase from 2 to 8. For black pawns, then, forward means the ranks decrease from 7 down to 1.

  Pawn captures involve going forward one rank in an adjacent file. Further complicating the analysis is the ability for a pawn's first move to be two ranks instead of one.

We note that the queen's iterator is really a combination of the bishop and the rook. We'll look at the rook's iterator, because it is can be adapted to be a bishop iterator, and then those two combined to create the queen iterator.

Given a starting position with a rank of r and a file of f, we'll need to examine all ranks starting from r and moving toward the edge of the board. These are $r-1, r+1, r-2, r+2, r-3, r+3, ...$ Similarly, we need to examine all of the files starting from f and moving toward the edge of the board. These are $f-1, f+1, f-2, f+2, f-3, f+3, ...$

Before doing an comparison, we need to filter the file and rank combinations to assure that they are legal positions. Additionally, we need to stop looking when we've encountered a piece of our own color or an opposing piece that isn't the one we're searching for. These intervnening pieces "block" the intentended move.

CHAPTER

TWENTYSEVEN

ATTRIBUTES, PROPERTIES AND DESCRIPTORS

When we reference an attribute of an object with something like '`someObject.someAttr`', Python uses several special methods to get the `someAttr` attribute of the object.

In the simplest case, attributes are simply instance variables. But that's not the whole story. To see how we can control the meaning of attributes, we have to emphasize a distinction:

- An *attribute* is a name that appears after an object name. This is the syntactic construct. For example, '`someObj.name`'.
- An *instance variable* is an item in the internal `__dict__` of an object.

The default semantics of an attribute reference is to provide access to the instance variable. When we say '`someObj.name`', the default behavior is effectively '`someObj.__dict__['name']`'.

This is not the only meaning an attribute name can have.

In *Semantics of Attributes* we'll look at the various ways we can control what an attribute name means.

The easiest technique for controlling the meaning of an attribute name is to define a property. We'll look at this in *Properties*.

The most sophisticated technique is to define a descriptor. We'll look at this in *Descriptors*.

The most flexible technique is to override the special method names and take direct control over attribute processing. We'll look at this in *Attribute Access Exercises*.

27.1 Semantics of Attributes

Fundamentally, an object encapsulates data and processing via it's instance variables and method functions. Because of this encapsulation, we can think of a class definition as providing both an interface definition and an implementation that supports the defined interface.

In some languages, the attributes *are* the instance variables; an attribute can name expose the private state of the object. Consequently, some languages suggest that attributes should not be part of the interface. Further, some languages (C, C#, Java are examples) provide syntax to distinguish the public interface from the private implementation.

In Python, this distinction between interface and implementation is not heavily emphasized in the syntax, since it can often lead to wordy, complex programs. Most well-designed classes, however, tend to have a set of interface methods that form the interface for collaborating with objects of that class.

In Python, the method names and instance variables which begin with '_' are treated as part of the private implementation of the class. These names aren't shown in the `help()` function, for example. The remaining elements (without a leading '_') form the public interface.

Encapsulation There are two commonly-used design patterns for encapsulating an object's instance variables.

- **Getters and Setters**. This design pattern can insulate each instance variable with some method functions to get and set the value of that instance variable.

  When we do this, each access to an attribute of the object is via an explicit function: '`anObject.setPrice( someValue )`' and '`anObject.getPrice()`'.

- **Attributes**. We can insulate an instance variable with more sophisticated attribute access. In the case of Python, we have several techniques for handling attribute access.

Python Attributes. In Python, the attributes do not have to be instance variables.

- **Properties**. We can bind getter, setter (and deleter) functions with an attribute name, using the built-in `property()` function or '`@property`' decorator. When we do this, each reference to an attribute has the syntax of direct access to an instance variable, but it invokes the given method function.

  We'll look at this in *Properties*.

- **Descriptors**. We can implement getter, setter (and deleter) functions into a separate descriptor class. We then create an instance of this class as the object named by an attribute. When we do this, each reference to an attribute has the syntax of direct access to an instance variable, but it invokes a method function of the Descriptor object.

  We'll look at this in *Descriptors*.

- **Special Method Names**. We can override definitions for several special method names. There are several methods which plug into the standard algorithm. A fourth method, `__getattribute__()`, allows you to change attribute access in a fundamental way.

  We'll look at this in *Attribute Access Exercises*.

  > **Warning:** Caution
  > Changing attribute access in radical ways can interfere with how people understand the operation of your classes and objects. The default assumption is that an attribute is an instance variable. While we can fundamentally alter the meaning of a Python attribute, we need to be cautious about violating the default assumptions of people reading our software.

27.2 Properties

The `property()` function gives us a handy way to implement an attribute that is more than a simple reference to an instance variable.

Through the property function, we can assign a simple attribute name to parameter-less getter and setter method functions.

This allows us to create programs that look like the following example.

```
>>> oven= Temperature()
>>> oven.farenheit= 450
>>> oven.celsius
232.22222222222223
>>> oven.celsius= 175
```

```
>>> oven.farenheit
347.0
```

In this example, we set one attribute and the value of another attribute changes to mirror it precisely. We can do this by defining some method functions and binding them to attribute names.

Property Design Pattern. The Property design pattern has a number of method functions which are bound together with a single property name. The method functions can include any combination of a getter, a setter and a deleter.

To create a property, we define the instance variable and one or more method functions. This is identical with the *Getter and Setter* design pattern. To make a property, we provide these method functions to the `property()` function to bind the various methods to an attribute name.

Here's the definition of the `property()` function.

property(*fget, [fset, fdel, doc]*)

This binds the given method functions into a property definition. Usually the result value is assigned to an attribute of a class.

The `fget` parameter must be a getter function, of the form '`function(self)->value`'.

The `fset` parameter must be a setter function, of the form '`function(self,value)`'.

The `fdel` parameter must be a deleter function, of the form '`function(self)`'. This can be used to delete the attribute, and is evaluated in response to '`del object.attribute`'.

The `doc` parameter becomes the docstring for the attribute. If this is not provided the docstring from the getter function becomes the docstring for the property.

```
class SomeClass( object ):
    def getThis( self ):
        return self._hidden_variable * 2
    def setThis( self, value ):
        self._hidden_variable = float(value) / 2
    this= property( getThis, setThis )
```

This creates a property, named `this`: defined by two method functions `getThis()` and `setThis()`. The functions do a fairly silly calculation, but this shows how an attribute can embody a calculation.

The property function can also be used as a decorator. We'll look at decorators in detail in *Decorators*.

Here is a quick sample of the using the the `property()` with the decorato syntax instead of the function syntax.

```
class SomeClass( object ):
    @property
    def this( self ):
        return self._hidden_variable * 2
    @this.setter
    def this( self, value ):
        self._hidden_variable = float(value) / 2
```

Property Example. The following example shows a class definition with four method functions that are used to define two properties.

property.py

```
class Temperature( object ):
    def fget( self ):
        return self.celsius * 9 / 5 + 32
    def fset( self, value ):
        self.celsius= (float(value)-32) * 5 / 9
    farenheit= property( fget, fset )
    def cset( self, value ):
        self.cTemp= float(value)
    def cget( self ):
        return self.cTemp
    celsius= property( cget, cset, doc="Celsius temperature" )
```

1. We create the `farenheit` property from the `fget()` and `fset()` method functions. When we use the `farenheit` attribute on the left side of an assignment statement, Python will use the setter method. When we use this attribute in an expression, Python will use the getter method. We don't show a deleter method; it would be used when the attribute is used in a **del** statement.

2. We create the `celsius` property from the `cget()` and `cset()` method functions. When we use the `celsius` attribute on the left side of an assignment statement, Python will use the setter method. When we use this attribute in an expression, Python will use the getter method.

   The doc string provided for the `celsius` attribute is available as '`Temperature.celsius.__doc__`'.

27.3 Descriptors

A Descriptor is a class which provides the detailed get, set and delete control over an attribute of another object. This allows you to define attributes which are fairly complex objects in their own right. The idea is that we can use simple attribute references in a program, but those simple references are actually method functions of a descriptor object.

This allows us to create programs that look like the following example.

```
>>> oven= Temperature()
>>> oven.farenheit= 450
>>> oven.celsius
232.22222222222223
>>> oven.celsius= 175
>>> oven.farenheit
347.0
```

In this example, we set one attribute and the value of another attribute changes to mirror it precisely.

A common use for descriptors is in an object-oriented database (or an object-relational mapping). In a database context, getting an attribute value may require fetching data objects from the file system; this may involve creating and executing a query in a database.

This kind of "related-item fetch" operation will be shared widely among the persistent classes in an application. Rather than attempt to manage this shared functionality via inheritance of method functions, it's simpler to split it into a separate Descriptor class and use this descriptor to manage the access of related objects.

Descriptor Design Pattern. The Descriptor design pattern has two parts: an *Owner* and an attribute *Descriptor*. The Owner is usually a relatively complex object that uses one or more Descriptors for its

attributes. A Descriptor class defines get, set and delete methods for a class of attributes of the Owner. Each Descriptor object manages a specific attribute.

Note that Descriptors will tend to be reusable, generic classes of attributes. The Owner can have multiple instances of each Descriptor class to manage attributes with similar behaviors. Each Descriptor object is a unique instance of a Descriptor class, bound to a distinct attribute name when the Owner class is defined.

To be recognized as a Descriptor, a class must implement some combination of the following three methods.

`__get__`(*self, instance, owner*)
: The *instance* parameter is the `self` variable of object being accessed. The *owner* parameter is the owning class object. This method of the descriptor must return this attribute's value.

  If this descriptor implements a class level variable, the *instance* parameter can be ignored; the instance is irrelevant and may be `None`. The *owner* parameter refers to the class.

`__set__`(*self, instance, value*)
: The *instance* argument is the self variable of the object being updated. This method of the descriptor must set this attribute's value.

`__delete__`(*self, instance*)
: The *instance* argument is the self variable of the object being accessed. This method of the descriptor must delete this attribute's value.

Sometimes, a Descriptor class will also need an `__init__()` method function to initialize the descriptor's internal state. Less commonly, the descriptor may also need `__str__()` or `__repr__()` method functions to display the instance variable correctly.

You must also make a design decision when defining a descriptor. You must determine where the underlying instance variable is contained. You have two choices.

- The Descriptor object has the instance variable. In this case, the descriptor object's `self` variable has the instance variable.

  This is common for attributes that can be updated.

- The Owner object contains the instance variable. In this case, the descriptor object must use the `instance` parameter to reference a value in the owning object.

  This is common for attributes that are "get-only".

Descriptor Example. Here's a simple example of an object with two attributes defined by descriptors. One descriptor (`Celsius`) contains it's own value. The other desriptor (`Farenheit`), depends on the `Celsius` value, showing how attributes can be "linked" so that a change to one directly changes the other.

descriptor.py

```
class Celsius( object ):
    """Fundamental Temperature Descriptor."""
    def __init__( self, value=0.0 ):
        self.value= float(value)
    def __get__( self, instance, owner ):
        return self.value
    def __set__( self, instance, value ):
        self.value= float(value)

class Farenheit( object ):
    """Requires that the owner have a ``celsius`` attribute."""
```

```
    def __get__( self, instance, owner ):
        return instance.celsius * 9 / 5 + 32
    def __set__( self, instance, value ):
        instance.celsius= (float(value)-32) * 5 / 9

class Temperature( object ):
    celsius= Celsius()
    farenheit= Farenheit()
```

1. We've defined a `Celsius` descriptor. The Celsius descriptor has an `__init__()` method which defines the attribute's value. The Celsius descriptor implements the `__get__()` method to return the current value of the attribute, and a `__set__()` method to change the value of this attribute.

2. The `Farenheit` descriptor implements a number of conversions based on the value of the celsius attribute. The `__get__()` method converts the internal value from Celsius to Farenheit. The `__set__()` method converts the supplied value (in Farenheit) to Celsius.

   In a way, the `Farenheit` descriptor is an "observer" of the owning objects's `celsius` attribute.

3. The owner class, `Temperature` has two attributes, both of which are managed by descriptors. One attribute, `celsius`, uses an instance of the `Celsius` descriptor. The other attribute, `farenheit`, uses an instance of the `Fareheit` descriptor. When we use one of these attributes in an assignment statement, the descriptor's `__set__()` method is used. When we use one of these attributes in an expression, the descriptor's `__get__()` method is used. We didn't show a `__delete__()` method; this would be used when the attribute is used in a **del** statement.

Let's look at what happens when we set an attribute value, for example, using '`oven.farenheit= 450`' . In this case, the `farenheit` attribute is a Descriptor with a `__set__()` method. This `__set__()` method is evaluated with `instance` set to the object which is being modified (the `oven` variable) and owner set to the `Temperature` class. The `__set__()` method computes the celsius value, and provides that to the celsius attribute of the instance. The Celsius descriptor simply saves the value.

When we get an attribute value, for example, using '`oven.celsius`', the following happens. Since `celsius` is a Descriptor with a `__get__()` method, this method is evaluated, and returns the celsius temperature.

27.4 Attribute Handling Special Method Names

Fundamentally, attribute access works through a few special method names. Python has a default approach: it checks the object for an instance variable that has the attribute's name before using these attribute handling methods.

Because Python uses these methods when an attribute is not already an instance variable, you can easily create infinite recursion. This can happen if you write '`self.someAttr`' inside the body of a `__getattr__()` or `__setattr__()` method **and** the attribute is not in the object's `__dict__`, Python will use the `__getattr__()` or `__setattr__()` method to resolve the name. Oops.

Within `__getattr__()` and `__setattr__()`, you have to use the internal `__dict__` explicitly.

These are the low-level attribute access methods.

`__getattr__`(*self, name*)
: Returns a value for an attibute when the name is not an instance attribute nor is it found in any of the parent classes. *name* is the attribute name. This method returns the attribute value or raises an `AttributeError` exception.

`__setattr__`(*self, name, value*)
: Assigns a value to an attribute. *name* is the attribute name, *value* is the value to assign to it.

Note that if you naively do '`self.name= value`' in this method, you will have an infinite recursion of `__setattr__()` calls.

To access the internal dictionary of attributes, `__dict__`, you have to use the following: '`self.__dict__[name] = value`'.

`__delattr__`(*self, name*)
Delete the named attribute from the object. *name* is the attribute name.

`__getattribute__`(*self, name*)
Low-level access to a named attribute. If you provide this, it replaces the default approach of searching for an attribute and then using `__getattr__()` if the named attribute isn't an instance variable of the class.

If you want to extend the default approach, you must explicitly evaluate the superclass `__getattribute__()` method with '`super( Class,self ).__getattribute__( name )`'. This only works for classes which are derived from `object`.

27.5 Attribute Access Exercises

1. **Rework Previous Exercises**. Refer to exercises for previous chapters (*Class Definition Exercises*, *Advanced Class Definition Exercises*, *Design Pattern Exercises*, *Special Method Name Exercises*). Rework these exercises to manage attributes with getters and setters. Use the property function to bind a pair of getter and setter functions to an attribute name. The following examples show the "before" and "after" of this kind of transformation.

```
class SomeClass( object ):
    def __init__( self, someValue ):
        self.myValue= someValue
```

When we introduce the getter and setter method functions, we should also rename the original attribute to make it private. When we define the property, we can use the original attribute's name. In effect, this set of transformations leaves the class interface unchanged. We have added the ability to do additional processing around attribute get and set operations.

```
class SomeClass( object ):
    def __init__( self, someValue ):
        self._myValue= someValue
    def getMyValue( self ):
        return self._myValue
    def setMyvalue( self, someValue ):
        self._myValue= someValue
    myValue= property( getMyValue, setMyValue )
```

The class interface should not change when you replace an attibute with a property. The original unit tests should still work perfectly.

2. **Rework Previous Exercises**. Refer to exercises for previous chapters (*Class Definition Exercises*, *Advanced Class Definition Exercises*, *Design Pattern Exercises*, *Special Method Name Exercises*). Rework these exercises to manage attributes with Descriptors. Define a Descriptor class with `__get__()` and `__set__()` methods for an attribute. Replace the attribute with an instance of the Descriptor.

When we introduce a descriptor, our class should look something like the following.

```
class ValueDescr( object ):
    def __set__( self, instance, value ):
        instance.value= value
    def __get__( self, instance, owner ):
        return instance.value

class SomeClass( object ):
    def __init__( self, someValue ):
        self.myValue= ValueDescr()
```

The class interface should not change when you replace an attibute with a descriptor. The original unit tests should still work perfectly.

3. **Tradeoffs and Design Decisions**. What is the advantage of Python's preference for referring to attributes directly instead of through getter and setter method functions?

   What is the advantage of having an attribute bound to a property or descriptor instead of an instance variable?

   What are the potential problems with the indirection created by properties or descriptors?

CHAPTER

TWENTYEIGHT

DECORATORS

In addition to object-oriented programming, Python also supports an approach called *Aspect-Oriented Programming* . Object-oriented programming focuses on structure and behavior of individual objects. Aspect-oriented programming refines object design techniques by defining aspects which are common across a number of classes or methods.

The focus of aspect-oriented programming is consistency. Toward this end Python allows us to define "decorators" which we can apply to class definitions and method definitions and create consistency.

We have to note that decorators can easily be overused. The issue is to strike a balance between the obvious programming in the class definition and the not-obvious programming in the decorator. Generally, decorators should be transparently simple and so obvious that they hardly bear explanation.

We'll look at what a decorator is in *Semantics of Decorators*.

We'll look at some built-in decorators in *Built-in Decorators*.

In *Defining Decorators* we'll look at defining our own decorators.

It is possible to create some rather sophisticated decorators. We'll look at the issues surrounding this in *Defining Complex Decorators*.

28.1 Semantics of Decorators

Essentially, a decorator is a function that is applied to another function. The purpose of a decorator is to transform the function definition we wrote (the argument function) into another (more complex) function definition. When Python applies a decorator to a function definition, a new function object is returned by the decorator.

The idea of decorators is to allow us to factor out some common aspects of several functions or method functions. We can then write a simpler form of each function and have the common aspect inserted into the function by the decorator.

When we say

```
@theDecorator
def someFunction( anArg ):
    pass # some function body
```

We are doing the following:

1. We defined an argument function, `someFunction()`.

2. Python applied the decorator function, `theDecorator()`, to our argument function. The decorator function will return a value; this should be some kind of callable object, either a class with a `__call__()` method or a function.

3. Python binds the result of the decorator evaluation to the original function name, `someFunction()`. In effect, we have a more sophisticated version of `someFunction()` created for us by the `theDecorator()` function.

Cross-Cutting Concerns. The aspects that makes sense for decorators are aspects that are truly common. These are sometimes called *cross-cutting concerns* because they cut across multiple functions or multiple classes.

Generally, decorators fall into a number of common categories.

- **Simplifying Class Definitions**. One common need is to create a method function which applies to the class-level attributes, not the instance variables of an object. For information on class-level variables, see *Class Variables*.

  The '`@staticmethod`' decorator helps us build method functions that apply to the class, not a specific object. See *Static Methods and Class Method*.

  Additionally, we may want to create a class function which applies to the class as a whole. To declare this kind of method function, the built-in '`@classmethod`' decorator can be used.

  If you look at the Python Wiki page for decorators (http://wiki.python.org/moin/PythonDecoratorLibrary), you can find several examples of decorators that help define properties for managing attributes.

- **Debugging**. There are several popular decorators to help with debugging. Decorators can be used to automatically log function arguments, function entrance and exit. The idea is that the decorator "wraps" your method function with additional statements to record details of the method function.

  One of the more interesting uses for decorators is to introduce some elements of type safety into Python. The Python Wiki page shows decorators which can provide some type checking for method functions where this is essential.

  Additionally, Python borrows the concept of *deprecation* from Java. A deprecated function is one that will be removed in a future version of the module, class or framework. We can define a decorator that uses the Python `warnings` module to create warning messages when the deprecated function is used.

- **Handling Database Transactions**. In some frameworks, like Django (http://www.djangoproject.org), decorators are used to simplify definition of database transactions. Rather than write explicit statements to begin and end a transaction, you can provide a decorator which wraps your method function with the necessary additional processing.

- **Authorization**. Web Security stands on several legs; two of those legs are authentication and authorization. Authentication is a serious problem involving transmission and validation of usernames and passwords or other credentials. It's beyond the scope of this book. Once we know who the user is, the next question is what are they authorized to do? Decorators are commonly used web frameworks to specify the authorization required for each function.

28.2 Built-in Decorators

Python has a few built-in decorators.

`staticmethod`(*function*)
: The '`@staticmethod`' decorator modifies a method function so that it does not use any `self` variable. The method function will not have access to a specific instance of the class.

This kind of method is part of a class, but can only be used when qualified by the class name or an instance variable.

For an example of a static method, see *Static Methods and Class Method*.

`classmethod`(*function*)
The '`@classmethod`' decorator modifies a method function so that it receives the class object as the first parameter instead of an instance of the class. This method function wil have access to the class object itself.

`property`(*fget, [fset, fdel, doc]*)
The '`@property`' decorator modifies from one to three method functions to be a properties of the class. The returned method functions invokes the given getter, setter and/or deleter functions when the attribute is referenced.

Here's a contrived example of using introspection to display some features of a object's class.

introspection.py

```
import types

class SelfDocumenting( object ):
    @classmethod
    def getMethods( aClass ):
        return [ (n,v.__doc__) for n,v in aClass.__dict__.items()
                 if type(v) == types.FunctionType ]
    def help( self ):
        """Part of the self-documenting framework"""
        print self.getMethods()

class SomeClass( SelfDocumenting ):
    attr= "Some class Value"
    def __init__( self ):
        """Create a new Instance"""
        self.instVar= "some instance value"
    def __str__( self ):
        """Display an instance"""
        return "%s %s" % ( self.attr, self.instVar )
```

1. We import the `types` module to help us distinguish among the various elements of a class definition.
2. We define a superclass that includes two methods. The classmethod, `getMethods()`, introspects a class, looking for the method functions. The ordinary instance method, `help()`, uses the introspection to print a list of functions defined by a class.
3. We use the '`@classmethod`' decorator to modify the `getMethods()` function. Making the `getMethods()` into a class method means that the first argument will be the class object itself, not an instance.
4. Every subclass of `SelfDocumenting` can print a list of method functions using a `help()` method.

Here's an example of creating a class and calling the help method we defined. The result of the `getMethods()` method function is a list of tuples with method function names and docstrings.

```
>>> ac= SomeClass()
>>> ac.help()
[('__str__', 'Display an instance'), ('__init__', 'Create a new Instance')]
```

28.3 Defining Decorators

A decorator is a function which accepts a function and returns a new function. Since it's a function, we must provide three pieces of information: the name of the decorator, a parameter, and a suite of statements that creates and returns the resulting function.

The suite of statements in a decorator will generally include a function **def** statement to create the new function and a **return** statement.

A common alternative is to include a **class** definition statement . If a class definition is used, that class must define a callable object by including a definition for the `__call__()` method and (usually) being a subclass of `collections.Callable`.

There are two kinds of decorators, decorators without arguments and decorators with arguments. In the first case, the operation of the decorator is very simple. In the case where the decorator accepts areguments the definition of the decorator is rather obscure, we'll return to this in *Defining Complex Decorators*.

A simple decorator has the following outline:

```
def myDecorator( argumentFunction ):
    def resultFunction( \*args, \*\*keywords ):
        enhanced processing including a call to argumentFunction
    resultFunction.__doc__= argumentFunction.__doc__
    return resultFunction
```

In some cases, we may replace the result function definition with a result class definition to create a callable class.

Here's a simple decorator that we can use for debugging. This will log function entry, exit and exceptions.

trace.py

```
def trace( aFunc ):
    """Trace entry, exit and exceptions."""
    def loggedFunc( \*args, \*\*kw ):
        print "enter", aFunc.__name__
        try:
            result= aFunc( \*args, \*\*kw )
        except Exception, e:
            print "exception", aFunc.__name__, e
            raise
        print "exit", aFunc.__name__
        return result
    loggedFunc.__name__= aFunc.__name__
    loggedFunc.__doc__= aFunc.__doc__
    return loggedFunc
```

1. The result function, `loggedFunc()`, is built when the decorator executes. This creates a fresh, new function for each use of the decorator.
2. Within the result function, we evaluate the original function. Note that we simply pass the argument values from the evaluation of the result function to the original function.
3. We move the original function's docstring and name to the result function. This assures us that the result function looks like the original function.

Here's a class which uses our '`@trace`' decorator.

trace_client.py

```
class MyClass( object ):
    @trace
    def __init__( self, someValue ):
        """Create a MyClass instance."""
        self.value= someValue
    @trace
    def doSomething( self, anotherValue ):
        """Update a value."""
        self.value += anotherValue
```

Our class definition includes two traced function definitions. Here's an example of using this class with the traced functions. When we evaulate one of the traced methods it logs the entry and exit events for us. Additionally, our decorated function usees the original method function of the class to do the real work.

```
>>> mc= MyClass( 23 )
enter __init__
exit __init__
>>> mc.doSomething( 15 )
enter doSomething
exit doSomething
>>> mc.value
38
```

28.4 Defining Complex Decorators

A decorator transforms an argument function definition into a result function definition. In addition to a function, we can also provide argument values to a decorator. These more complex decorators involve a two-step dance that creates an intermediate function as well as the final result function.

The first step evaluates the abstract decorator to create a concrete decorator. The second step applies the concrete decorator to the argument function. This second step is what a simple decorator does.

Assume we have some qualified decorator, for example '`@debug( flag )`', where flag can be `True` to enable debugging and `False` to disable debugging. Assume we provide the following function definition.

```
debugOption= True
class MyClass( object ):
    @debug( debugOption )
    def someMethod( self, args ):
         real work
```

Here's what happens when Python creates the definition of the `someMethod()` function.

1. Defines the argument function, `someMethod()`.
2. Evaluate the abstract decorator '`debug( debugOption )`' to create a concrete decorator based on the argument value.
3. Apply the concrete decorator the the argument function, `someMethod()`.
4. The result of the concrete decorator is the result function, which is given the name `someMethod()`.

Here's an example of one of these more complex decorators. Note that these complex decorators work by creating and return a concrete decorators. Python then applies the concrete decorators to the argument function; this does the work of transforming the argument function to the result function.

debug.py

```
def debug( theSetting ):
    def concreteDescriptor( aFunc ):
        if theSetting:
            def debugFunc( *args, **kw ):
                print "enter", aFunc.__name__
                return aFunc( *args, **kw )
            debugFunc.__name__= aFunc.__name__
            debugFunc.__doc__= aFunc.__doc__
            return debugFunc
        else:
            return aFunc
    return concreteDescriptor
```

1. This is the concrete decorators, which is created from the argument, `theSetting`.
2. If `theSetting` is `True`, the concrete decorator will create the result function named `debugFunc()`, which prints a message and then uses the argument function.
3. If `theSetting` is `False`, the concrete descriptor will simply return the argument function without any overhead.

28.5 Decorator Exercises

1. **Merge the** '`@trace`' **and** '`@debug`' **decorators**. Combine the features of the '`@trace`' decorator with the parameterization of the '`@debug`' decorator. This should create a better '`@trace`' decorator which can be enabled or disabled simply.
2. **Create a** '`@timing`' **decorator**. Similar to the parameterized '`@debug`' decorator, the '`@timing`' decorator can be turned on or off with a single parameter. This decorator prints a small timing summary.

CHAPTER

TWENTYNINE

MANAGING CONTEXTS: THE WITH STATEMENT

Many objects manage resources, and must impose a rigid protocol on use of that resource.

For example, a file object in Python acquires and releases OS files, which may be associated with devices or network interfaces. We looked at the way that `file` objects can be managed by the **with** statement in *File Statements*.

In this section, we'll look at ways in which the new **with** statement will simplify file or database processing. We will look at the kinds of object design considerations which are required to create your own objects that work well with the **with** statement.

Important: Legacy

In versions of Python prior to 2.6, we must enable the **with** statement by using the following statement.

```
from __future__ import with_statement
```

29.1 Semantics of a Context

While most use of the **with** statement involve acquiring and releasing specific resources – like OS files – the statement can be applied somewhat more generally. To make the statement more widely applicable, Python works with a *context*. A context is not limited to acquiring and releasing a file or database connection. A context could be a web transaction, a user's logged-in session, a particular transaction or any other stateful condition.

Generally, a context is a state which must endure for one or more statements, has a specific method for entering the state and has a specific method for exiting the state. Further, a context's exit must be done with the defined method irrespective of any exceptions that might occur within the context.

Database operations often center on transactions which must either be completed (to move the database to a new, iternally consistent state,) or rolled back to reset the database to a prior consistent state. In this case, exceptions must be tolerated so that the database server can be instructed to commit the transaction or roll it back.

We'll also use a context to be sure that a file is closed, or a lock is released. We can also use a context to be sure that the user interface is reset properly when a user switches their focus or an error occurs in a complex interaction.

The design pattern has two elements: a *Context Manager* and a *Working Object*. The Context Manager is used by the **with** statement to enter and exit the context. One thing that can happen when entering a

context is that a Working Object is created as part of the entry process. The Working Object is often used for files and databases where we interact with the context. The Working Object isn't always necessary; for example acquiring and releasing locks is done entirely by the Context Manager.

29.2 Using a Context

There are a few Python library classes which provide context information that is used by the **with** statement. The most commonly-used class is the `file` class.

There are two forms of the **with** statement. In the first, the context object does not provide a context-specific object to work with. In the second, the context provides us an object to be used within the context.

```
with context :
    suite


with context as variable :
    suite
```

We'll look at the second form, since that is how the `file` class works. A `file` object is a kind of context manager, and responds to the protocol defined by the **with** statement.

When we open a file for processing, we are creating a context. When we leave that context, we want to be sure that the file is properly closed. Here's the standard example of how this is used.

```
with file('someData.txt','r') as theFile:
   for aLine in theFile:
       print aLine
# the file was closed by the context manager
```

1. We create the file, which can be used as a context manager. The **with** statement enters the context, which returns a file object that we can use for input and output purposes. The **as** clause specifies that the working object is assigned to `theFile`.
2. This is a pretty typical **for** statement that reads each line of a file.
3. The **with** statement also exits the context, irrespective of the presence or absence of exceptions. In the case of a `file` context manager, this will close the file.

In the previous example, we saw that the file factory function is used to create a context manager. This is possible because a file has several interfaces: it is a context manager as well as being a working file object. This is potentially confusing because it conflate file context manager with the working file object. However, it also

This has the advantage of making the **with** statement optional. In some simple applications, improperly closed files have few real consequences, and the carefully managed context of a **with** statement isn't necessary.

29.3 Defining a Context Manager Function

One easy way to create a context manager is to write a function that handles the acquisition and release of an important resource.

The `contextlib` module provides a handy decorator that transforms a simple generator function into a context manager.

Conceptually, you'll break your function into two phases:

- The `__enter__()` phase acquires the resources. This is written as statements from the start of the function's suite to up to the one and only **yield** statement. The value that is yielded is the value that's used in the **as** clause.

  Once the function yields this value, then the **with** statement's suite starts processing.

  If an exception occurs anywhere in the **with** statement, it will be raised by the **yield** statement, and must be handled by the function to assure that resources are released properly.

- The `__exit__()` phase releases resources. This is written as statements after the **yield** statement.

Here's an example of a context manager that manages a subclass of `file`. The `FileWithCount` has an extra method that will append a summary line that shows if everything has gone properly.

We'll manage this object so that we are assured that file either has a summary, or is removed from the directory.

```
import os

class FileWithCount( file ):
    def __init__( self, *args, **kw ):
        super( FileWithCount, self ).__init__( *args, **kw )
        self.count= 0
    def write( self, data ):
        super( FileWithCount, self ).write( data )
        self.count += data.count('\n' )
    def writelines( self, dataList ):
        for d in dataList:
            self.write( d )
    def summarize( self ):
        super( FileWithCount, self ).write( "\n:count:`%d`\n" % self.count )
```

1. We defined a `FileWithCount` class that adds a line-counting feature to the built-in `file` type.
2. Note that we're defining a subclass of `file` that adds features. For the most part, we simply pass the arguments to the superclass method functions.
3. The `write()` method counts the number of newline characters written to the file.
4. The `summarize()` method appends a label with final count to the end of the file.

Here's a context manager that uses our `FileWithCount` class.

```
from contextlib import contextmanager

@contextmanager
def file_with_count( *args, **kw ):
    # The __enter__ processing
    try:
        counted_file=  FileWithCount( *args, **kw )
        yield counted_file
        # The __exit__ processing -- if everything's ok
        counted_file.summarize()
        counted_file.close()
    except:
        # The __exit__ processing -- if there as an exception
        counted_file.close()
        os.remove( counted_file.name )
        raise
```

1. We defined a context manager function, `file_with_count()` that builds an instance of `FileWithCount` and yields it to a **with** statement.
2. If everything works normally, the '`counted_file.summarize()`' statement is executed.
3. If there is an exception, then the '`counted_file.close()`' statement is executed, and the file is removed via '`os.remove()`'. The is removed so that incomplete files are not left around to confuse other application programs or users.

Here's an example of using this context manager to create a temporary directory.

```
with file_with_count( "file.data", "w" ) as results:
    results.write( "this\nthat\n" )
```

This yields a file with the following content.

```
MacBook-5:Python-2.6 slott$ cat file.data
this
that

:count:`2`
```

The final '`:count:`' line is written automatically by the context manager, simplifying our application.

29.4 Defining a Context Manager Class

In some cases, a class is both the working object and the context manager. The `file` class is the central example of this. The two do not have to be tied together. It's clearer if we'll look at creating a context manager that is separate from the working object first.

A Context Manager must implement two methods to collaborate properly with the **with** statement.

`__enter__`(*self*)
: This method is called on entry to the **with** statement. The value returned by this method function will be the value assigned to the **as** variable.

`__exit__`(*self, exc_type, exc_val, exc_tb*)
: This method is called on exit from the **with** statement. If the `exc_type`, `exc_val` or `exc_tb` parameters have values other than `None`, then an exception occured.

  - A return value of `False` will propagate the exception after `__exit__()` finishes.
  - A return value of `True` will suppress any exception and finish normally.

  If the `exc_type`, `exc_val` or `exc_tb` parameters have values of `None`, then this is a normal conclusion of the **with** statement. The method should return `True`.

Here is a context manager class, named `FileCountManager`, which incorporates the `FileWithCount` class, shown above. To be a context manager, this class implements the required `__enter__()` and `__exit__()` methods.

```
class FileCountManager( object ):
    def __init__( self, *args, **kw ):
        self.theFile= FileWithCount( *args, **kw )
    def __enter__( self ):
        return self.theFile
    def __exit__( self, exc_type, exc_val, exc_tb ):
        if  exc_type is not None:
```

```
            # Exception occurred
            self.theFile.close()
            os.remove( self.theFile.name )
            return False # Will raise the exception
        self.theFile.summarize()
        self.theFile.close()
        return True # Everything's okay
```

1. The `__enter__()` method creates the `FileWithCount` and returns it so that the **as** clause will assign this to a variable.
2. The `__exit__()` method checks to see if it is ending with an exception.

   In case of an exception, we close the file and remove it. We also return `False` to permit the exception to propagate outside the **with** statement.

   If there was no exception, then the :class:FileWithCount.summarize‘ is used to write the summary and the file is closed.

The overall main program can have the following structure. We don't need to make special arrangements in the main program to be sure that the log is finalized correctly. We have delegated those special arrangements to the context manager object, leaving us with an uncluttered main program.

```
with FileCountManager( "file.data", "w" ) as results:
    results.write( "this\nthat\n" )
```

29.5 Context Manager Exercises

1. **Build a class with it's own manager**. Merge the methods from `FileCountManager` into `FileWithCount` to create a single class which does both sets of features.
2. **List with a Checksum**. A crypto application works with lists, but only lists that have a checksum of the values in a list of numbers.

   Define a class, `ManageChecksum`, which removes and replaces the last element in a non-empty list.

   - The `__init__()` method accepts a single parameter which is a list or MutableSequence object.
   - On `__entry__()`, given a zero-length list, return the list object.
   - On `__entry__()`, given a list with 1 or more elements, pop the last element. Assert that this is the cryptological checksum of the values of the other elements. Return this updated list.
   - On `__exit__()`, comput cryptological checksum of the elements and append this checksum to the list.

   For now, our cryptological checksum can be the simple sum, created with `sum()`. As an advanced exercise, look at using `hashlib` to put a better checksum on the list.

   You should be able to do the following kinds of test.

   ```
   crypto_list = []
   with ManageChecksum( crypto_list ) as theList:
       theList.extend( [5, 7, 11] )
       assert theList == [5, 7, 11] # no checksum in the with statement
       theList.append( 13 )
   assert theList[:-1] == [5, 7, 11, 13] # checksum was added to prevent tampering
   with ManageChecksum( crypto_list) as theList:
   ```

```
    theList.pop( 0 )
assert theList[:-1] == [7, 11, 13]
```

Inside the **with** statement, the list is an ordinary list.

Outside the **with** statement, the list has an anti-tampering checksum appended.

Part V

Components, Modules and Packages

Organization and Deployment

The basic Python language is rich with features. These include several sophisticated built-in data types (*Data Structures*), numerous basic statments (*Language Basics*), a variety of common arithmetic operators and a library of built-in functions. In order to keep the basic Python kernel small, relatively feature features are built-in. A small kernel means that Python interpreters can be provided in a variety of software application, extending functionality of the application without bloating due to a large and complex command language.

The more powerful and sophisticated features of Python are separated into extension modules. There are several advantages to this. First, it allows each program to load only the relevant modules, speeding start-up. Second, it allows additional modules to be added easily. Third, it allows a module to be replaced, allowing you to choose among competing solutions to a problem.

The second point above, easily adding modules, is something that needs to be emphasized. In the Python community, this is called the *batteries included* principle. The ideal is to make Python directly applicable to just about any practical problem you may have.

Some modules have already been covered in other chapters. In *The math Module* we covered `math` and `random` modules. In *Strings* we covered the `string` module.

Overview of this part. This part will cover selected features of a few modules. The objective is to introduce some of the power of key Python modules and show how the modules are used to support software development. This isn't a reference, or even a complete guide to these modules. The standard Python Library documentation and other books describe all available modules in detail. Remember that Python is an open-source project: in some cases, you'll have to read the module's source to see what it really does and how it works.

This part provides a general overview of how to create Python modules in *Modules*. We'll distinguish package and module in *Packages*.

We'll overview the Python Library in *The Python Library*.

Module Details. We cover several essential modules in some detail.

- *Complex Strings: the re Module* covers *regular expressions*, which you can use to do string matching and parsing.
- *Dates and Times: the time and datetime Modules* covers how to handle the vagaries of our calendar with the `time` and `datetime` modules.
- We'll cover many aspects of file handling in *File Handling Modules*; this includes modules like: `sys`, `glob`, `fnmatch`, `fileinput`, `os`, `os.path`, `tempfile`, and `shutil`.
- We'll also look at modules for reading and writing files in various formats in *File Formats: CSV, Tab, XML, Logs and Others*.
  - *Comma-Separated Values: The csv Module* will cover Comma Separated Values (CSV) files.
  - Tab-delimited files, however, are a simpler problem, and don't require a separate module.
  - *Property Files and Configuration (or .INI) Files: The ConfigParser Module* will cover parsing Configuration files, sometimes called `.INI` files. An `.INI` file is not the best way to handle configurations, but this technique is common enough that we need to show it.
  - *Fixed Format Files, A COBOL Legacy: The codecs Module* will cover ways to handle COBOL files which are in a "fixed length" format, using EBCDIC data instead of the more common ASCII or Unicode.
  - *XML Files: The xml.etree and xml.sax Modules* will cover the techniques for parsing XML files.

Programs – The Ultimate Modules. In a sense a top-level program is a module that does something useful. It's important understand "programs" as being reusable modules. Eventually most really useful programs get rewritten and merged into larger, more sophisticated programs.

In *Programs: Standing Alone* this part covers modules essential for creating polished, complete stand-alone programs. This includes the `getopt` and `optparse` modules.

The final chapter, *Architecture: Clients, Servers, the Internet and the World Wide Web* covers integration among programs using the client-server programming model. This includes a number of modules that are essential for creating networked programs.

- We can use the HTTP protocol with a number of modules covered in *The World Wide Web and the HTTP protocol*.
- We can use the REST to create or use web services. This is covered in *Web Services*.
- Using *Writing Web Clients: The urllib2 Module*, we can leverage a number of protocols to read a file located anywhere on the World-Wide Web via their Uniform Resource Locator (URL).
- If none of these protocols are suitable, we can invent our own, using the low-level socket module, covered in *Socket Programming*.

CHAPTER

THIRTY

MODULES

A *module* allows us to group Python classes, functions and global variables. Modules are one level of composition of a large program from discrete components. The modules we design in one context can often be reused to solve other problems.

In *Module Semantics* we describe the basic semantics of modules. In *Module Definition* we describe how to define a module. We'll show how to use a module with the **import** statement in *Module Use: The import Statement*. A module must be found on the search path, we'll briefly talk about ways to control this in *Finding Modules: The Path*.

There are number of variations on the **import** statement; we'll look at these in *Variations on An import Theme*. We'll also look at the **exec** statement in *The exec Statement*. This chapter ends with some style notes in *Style Notes*.

30.1 Module Semantics

A *module* is a file that contains Python programming. A module can be brought into another program via the **import** statement, or it can be executed directly as the main script of an application program. There are two purposes for modules; some files may do both.

- A *library module* is expected to contain definitions of classes, functions and module variables. If it does anything beyond this, it is generally hard to understand and harder to use properly.
- A *script* (or application or "main" module) does the useful work of an application. It will have up to three disctinct elements: imports of any modules on which it depeds, main function definitions, a script that does the real work. It generally uses library modules.

Modules give us a larger-scale structure to our programs. We see the following levels of Python programming:

- The individual statement. A statement makes a specific state change by changing the value of a variable. State changes are what advance our program from its initial state to the desired ending state.
- Multiple statements are combined in a function. Functions are designed to be an indivisible, atomic unit of work. Functions can be easily combined with other functions, but never taken apart. Functions may be as simple as a single statement. While functions could be complex, it's important that they be easily understood, and this limits their complexity. A well-chosen function name helps to clarify the processing.
- Multiple functions and related data are used to define a class of objects. To be useful, a class must have a narrowly defined set of responsibilities. These responsibilities are characterized by the class attributes and behaviors.

- Multiple closely-related classes, functions and variables are combined into modules. The module name is the file name. A module should provide a closely related set of classes and functions. Sometimes, a module will package a set of closely related functions.
- Modules can be combined into packages. The directory structure defines the packages and their constituent modules. Additionally, packages contain some additional files that Python uses to locate all of the elements of the package.
- The user-oriented application program depend on modules or packages.

The application – the functionality that the user perceives – is usually the top-most "executable" script that does the useful work. The relationship between shell commands (or desktop icons, or web links) that a user sees and the packaging of components that implement those commands can be murky. For example, a single application file may have multiple aliases, making it appear like independed commands. A single script can process multiple command-line options.

The application-level view, since it is presented to the user, must focused on usability: the shell commands or icons the user sees. The design of modules and packages sould be focused on maintenance and adaptability. The modules are the files that you, the developer, must use to keep the software understandable.

Components: Class and Module. A class is a container for attributes, method functions, and nested class definitions. Similarly, a module can also contain attributes, functions and class definitions.

A module is different from a class in several ways. First, a module is a physical file; it is the unit of software construction and configuration management. A class is defined within a file. Additionally, a class definition allows us to create a number of class instances, or objects. A module, on other hand, can only have a single instance. Python will only import a module one time; any additional requests to import a module have no effect. Any variables defined by the module, similarly, will only have a single instance.

Beyond this technical distinction, we generally understand modules to be the big, easy-to-understand components out of which are applications are built. A class is a finer-grained piece of functionality, which usually captures a small, very tightly bound collection of attribute and operations.

30.2 Module Definition

A module is a file; the name of the module is the file name. The `.py` extension on the file name is required by the operating system, and gracefully ignored by Python. We can create a file named `roulette.py`, include numerous definitions of classes and functions related to the game of roulette.

Note that a module name must be a valid Python name. Operating system file names don't have the same restrictions on their names. The rules for variable names are in *Variables*. A module's name is limited to letters, digits and '`_`'s.

Standard file systems are case-sensitive. Filenames are traditionally all lower-case. Consequently, most Python module file names are all lower-case letters.

Note that the Windows filesystem has very complex file naming rules in which there are long versions of names and short versions of names. Further, Windows is flexible regarding case matching of file names. It helps to avoid these problems by using relatively short, all lower-case filenames in Windows, also.

The first line of a module is usually a '`#!`' comment; this is typically '`#!/usr/bin/env python`'. The next few lines are a triple-quoted module doc string that defines the contents of the module file. As with other Python doc strings, the first line of the string is a summary of the module. This is followed by a more complete definition of the module's contents, purpose and usage.

Also, a module may include the `__all__` variable. This lists the names which are created by an '`from module import *`'. Absent the `__all__` variable, all names that don't begin with '`_`' are created.

Example. For example, we can create the following module, called `dice.py`.

dice.py

```
#!/usr/bin/env python
"""dice - basic definitions for Die and Dice.
Die - a single die
Dice - a collection of one or more dice
roll - a function to roll a pair of dice"""
from random import *

class Die( object ):
    """Simulate a 6-sided die."""
    def __init__( self ):
        self.value= None
    def roll( self ):
        self.value= randrange(6)+1
    def total( self ):
        return self.value

class Dice:
    """Simulate a pair of 6-sided dice."""
    def __init__( self ):
        self.value = ( Die(), Die() )
    def roll( self ):
        map( lambda d: d.roll(), self.value )
    def dice( self ):
        return tuple( [d.value for d in self.value] )

pair= Dice()

def roll():
    pair.roll()
    return pair.dice()
```

1. A "main" script file must include the shell escape to run nicely in a Posix or Mac OS environment. Other files, even if they aren't main scripts, can include this to mark them as Python.
2. Our docstring is a minimal summary. Well-written docstrings provide more information on the classes, variables and functions that are defined by the module.
3. Many modules depends on other modules. Note that Python optimizes these imports; if some other module has already imported a given module, it is simply made available to our module. If the module has not been imported already, it is imported for use by our module.
4. As is typical of many modules, this module provides some class definitions.
5. This module defines a module-global variable, `pair`. This variable is part of the module; it appears global to all classes and functions within this module. It is also available to every client of this module. Since this variable is part of the module, every client is sharing a single variable.
6. This module defines a handy function, `roll()`, which uses the module global variable, `pair`.

Conspicuous by its absence is any main script to do anything more useful than create a single module global variable. This module is a pure library module.

30.3 Module Use: The import Statement

Since a module is just a Python file, there are two ways to use a module. We can **import** the module, to make use of it's definitions, or we can execute it as a script file to have it do useful work. We started looking at execution of scripts back in *Script Mode*, and have been using it heavily.

We looked briefly at the **import** statement in *Using Modules*. There are several variations on this statement that we'll look at in the next section. In this section, we'll look at more features of the **import** statement.

The essential import statement has the following syntax:

```
import module
```

The module name is the Python file name with the `.py` file extension removed.

Python does the following.

1. Search the global namespace for the module. If the module exists, it had already been imported; for the basic **import**, nothing more needs to be done.
2. If the module doesn't exist, search the Python path for a file; the file name is the module name plus the `.py` extension. The search path has a default value, and can be modified by command-line arguments and by environment variables. If the module name can't be found anywhere on the path, an `ImportError` exception is raised.
3. If the file was found, create the module's new, unique namespace; this is the container in which the module's definitions and module-level variables will be created. Execute the statements in the module, using the module's namespace to store the variables and definitions.

   We'll look a little more closely at namespaces below.

The most important effect of importing a module is that the Python definitions from the module are now part of the running Python environment. Each class, function or variable defined in the module is available for use. Since these objects are contained in the module's namespace, The names of those elements must be qualified by the module's name.

In the following example, we import the `dice` module. Python will search for module `dice`, then for the file `dice.py` from which to create the module. After importing, create an instance of the `Dice` class and called that instance `craps`. We qualified the class name with the module name: '`dice.Dice`'.

```
>>> import dice
>>> craps= dice.Dice()
>>> craps.roll()
>>> craps.dice()
(3, 5)
```

Namespaces. Python maintains a number of local namespaces and one global namespace. A unique local namespace is used when evaluating each function or method function. In effect, a variable created in a function's namespace is private to that function; it only exists only while the function executes.

Typically, when a module is imported, the module's namespace is the only thing created in the global namespace. All of the module's objects are inside the module's namespace.

You can explore this by using the built-in `dir()` function. Do the following sequence of steps.

1. Create a small module file (like the `dice.py` example, above).
2. Start a fresh command-line Python interpreter in the same directory as your module file. Starting the intepreter in the same directory is the simplest way to be sure that your module will be found by the **import** statement.

3. Evalute '`dir()`' to see what is in the initial global namespace.
4. Import your module.
5. Evaluate '`dir()`' to see what got added to the namespace.
6. Evaluate '`dir(your module)`' to see what's in your module's namespace.

Scripts and Modules. There are two ways to use a Python file. We can execute it as a script or we can import it as a library module. We need to keep this distinction clear when we create our Python applications. The file that a user executes will do useful work, and must be a script of some kind. This script can be an icon that the user double-clicked, or a command that the user typed at a command prompt; in either case, a single Python script initiates the processing.

A file that is imported will provide definitions. We'll emphasize this distinction.

Important: Bad Behavior

The standard expectation is that a library module will contain only definitions. Some modules create module global variables; this must be fully documented. It is bad behavior for an imported module to attempt to do any real work beyond creating definitions. Any real work that a library module does makes reuse of that module nearly impossible.

Importing a module means the module file is executed. This creates is an inherent, but important ambiguity. A given file can be used as a script or used as a library; any file can be used either way. Here's the complete set of alternatives.

- **A top-level script**. You execute a script with the **Run Module** menu item in IDLE. You can also execute a script from your operating system command prompt. For example, '`python file.py`' will execute the given file as a script. Also, you can set up most operating systems so that entering **file.py** at the command prompt will execute the file as a script. Also, you can set up most GUI's so that double-clicking the `file.py` icon will launch Python and execute the given file as a script.
- **import**. You can import a library module. As described above, Python will not import a module more than once. If the module was not previously imported, Python creates a namespace and executes the file. The namespace is saved.
- **exec**. Python's **exec** statement is similar to the **import** statement, with an important difference: The **exec** statement executes a file in the current namespace. The **exec** statement doesn't create a new namespace. We'll look at this in *The exec Statement*.

The Main-Import Switch. Since a file can be used as script or library, we can intentionally create files that are both. We can create a script which can also be used as a library. And we can create a library which has a useful behavior when used as a script. This promotes reuse of libraries.

Python provides a global variable that helps to differentiate between a main program script and a module library module. The global `__name__` variable is equal to `"__main__"` when the initial (or "top-level" or "outermost" or "main") file is being processed. When you have an executable script, and you run that script from the command line, that script sees `__name__` equal to `"__main__"`. However, when an import is in process, the `__name__` variable is the name of the module being imported.

As an example, we can make use of this to provide stand-alone unit testing for a library module. When we write a module that is primarily definitional, we can have it execute it's own unit tests when it is used as a main program. This makes testing a library module simple: we import it and it runs its unit test. We do this by examining the `__name__` variable.

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

When some other script imports a module (for example, named `dice.py`), the `__name__` variable is `"dice"` and nothing special is done. When testing, however, we can execute the module by itself; in this case the `__name__` variable is `"__main__"` and the test function is executed.

30.4 Finding Modules: The Path

For modules to be available for use, the Python interpreter must be able to locate the module file. Python has a set of directories in which it looks for module files. This set of directories is called the *search path*, and is analogous to the **PATH** environment variable used by an operating system to locate an executable file.

Python's search path is built from a number of sources:

- **PYTHONHOME** is used to define directories that are part of the Python installation. If this environment variable is not defined, then a standard directory structure is used. For Windows, the standard location is based on the directory into which Python is installed. For most Linux environments, Python is installed under `/usr/local`, and the libraries can be found there. For Mac OS, the home directory is under `/Library/Frameworks/Python.framework`.
- **PYTHONPATH** is used to add directories to the path. This environment variable is formatted like the OS **PATH** variable, with a series of filenames separated by '`:`'s (or '`;`'s for Windows).
- Script Directory. If you run a Python script, that script's directory is placed first on the search path so that locally-defined moules will be used instead of built-in modules of the same name.
- The `site` module's locations are also added. (This can be disabled by starting Python with the '`-S`' option.) The `site` module will use the **PYTHONHOME** location(s) to create up to four additional directories. Generally, the most interesting one is the `site-packages` directory. This directory is a handy place to put additional modules you've downloaded. Additionally, this directory can contain `.pth` files. The `site` module reads `.pth` files and puts the named directories onto the search path.

The search path is defined by the `path` variable in the `sys` module. If we '`import sys`', we can display `sys.path`. This is very handy for debugging. When debugging shell scripts, it can help to run '`python -c 'import sys; print sys.path'`' just to see parts of the Python environment settings.

Installing a module, then, is a matter of assuring that the module appears on the search path. There are four central methods for doing this.

- Some packages will suggest you create a directory and place the package in that directory. This may be done by downloading and unzipping a file. It may be done by using Subversion and sychronizing your subversion copy with the copy on a server. Either way, you will likely only need to create an operating system link to this directory and place that link in `site-packages` directory.
- Some packages will suggest you download (or use subversion) to create a temporary copy. They will provide you with a script – typically based on `setup.py` – which moves files into the correct locations. This is called the `distutils` distribution. This will generally copy the module files to the `site-packages` directory.
- Some packages will rely on `setuptools`. This is a package from the http://peak.telecommunity.com/DevCenter/setuptools Python Enterprise Application Kit that extends `distuils` to further automates download and installation. This tool, also, works by moving the working library modules to the `site-packages` directory.
- Extending the search path. Either set the **PYTHONPATH** environment variable, or put `.pth` files in the site-packages directory.

Tip: Windows Environment

In the Windows environment, the **Python_Path** symbol in the Windows registry is also used to locate modules. This, however, is not portable or standardized, so try to avoid using it.

30.5 Variations on An import Theme

There are several variations on the **import** statement. We looked at these briefly in *The math Module*. In this section, we'll cover the variations available on the **import** statement.

- Basic Import. This is covered in *Module Use: The import Statement*.
- Import As. This allows us to import a module, and assign it a new name.
- From Module Import Names. This allows us to import a module, making some names part of the global namespace.
- Combined From and As import.

30.5.1 Import As

A useful variation in the **import** statement is to rename a module using the **as** clause.

```
import module as name
```

This module renaming is used in two situations.

- We have two or more interchangable versions of a module.
- The module name is rather long and painful to type.

There are number of situations where we have interchangable versions of a module. One example is the built-in `os` module. This module gives us a number of functions that behave identically on most major operating systems. The way this is done is to create a number of variant implementations of these functions, and then use as appropriate **as** clause to give them a platform-neutral name.

Here's a summary of how the `os` module uses **import as**.

```
if 'posix' in _names:
    import posixpath as path
elif 'nt' in _names:
    import ntpath as path
elif 'mac' in _names:
    import macpath as path
```

After this **if** -statement, one of the various platform-specific modules will have been imported, and it will have the platform-independent name of `os.path`.

In the case of some modules, the name is rather long. For example, `sqlalchemy` is long and easy to misspell. It's somewhat simpler to use the following technique.

```
import sqlalchemy as sa
db= sa.create_engine('sqlite:///file.db')
```

This allows us to use `sa` as the module name.

30.5.2 From Module Import Names

Two other variations on the **import** statement introduce selected names from the module into the local namespace. One form picks specific names to make global.

```
from module import name ⟨ , ... ⟩
```

This version of **import** adds a step after the module is imported. It adds the given list of names into the local namespace, making them available without using the module name as a qualifier.

For example:

```
from math import sin, cos, tan
print dir(math)
['__doc__', '__name__', 'acos', 'asin', 'atan', 'atan2', 'ceil', 'cos',
'cosh', 'e', 'exp', 'fabs', 'floor', 'fmod', 'frexp', 'hypot', 'ldexp',
'log', 'log10', 'modf', 'pi', 'pow', 'sin', 'sinh', 'sqrt', 'tan',
'tanh']
print locals()
{'math': <module 'math' (built-in)>, '__doc__': None,
'__version__': '1.0',
'__file__': 'Macintosh HD:SWdev:Jack:Python:Mac:Tools:IDE:PythonIDE.py',
'__name__': '__main__',
'__builtins__': <module '__builtin__' (built-in)>,
'inspect': <function inspect at 0x0d084310>,
'sin': <built-in function sin>, 'cos': <built-in function cos>,
'tan': <built-in function tan>}
```

In this example, the `locals()` value shows that the `sin()`, `cos()` and `tan()` functions are now directly part of the namespace. We can use these functions without referring to the math module. We can evaluate '`sin(0.7854)`', rather than having to say '`math.sin(0.7854)`'.

This is discouraged because it tends to conceal the origin of objects.

Another variation on **import** makes all names in the module part of the local namespace. This import has the form:

```
from module import *
```

This makes all names from the module available in the local namespace.

30.5.3 Import and Rename

Finally, we can combine the **from** and **as** options to both import selected items and provide more understandable names for them.

We can say things like:

```
from module importname as  name
```

In this case, we're both concealing the source of the item and it's original name. We'd best have a very good reason for this. Think of the confusion that can be caused by

```
from math import sqrt as sin
```

This must be used cautiously to prevent creating more problems than it appears to solve.

30.6 The exec Statement

The **import** statement, in effect, executes the module file. Typically, the files we import are defined as sequences of definitions. Since our main program often begins with a series of **import** statements, these modules are imported into the global namespace. Python also optimizes the modules brought in by the **import** statement so that they are only imported once.

The **exec** statement can execute a file, a string of Python code, as well as a `code` created by the `compile()` function. Unlike the **import** statement, it doesn't optimize module definitions or create and save a new namespace.

```
exec  expression
```

The functions `eval()` and `execfile()` do essentially the same thing.

Warning: Fundamental Assumptions
The **exec** statement, `eval()` function and `execfile()` functions are dangerous tools. These break one of the Fundamental Assumptions: the source you are reading is the source that is being executed. A program that uses the **exec** statement or `eval()` function is incorprating other source statements into the program dynamically. This can be hard to follow, maintain or enhance.
Generally, the **exec** statement is something that must be used with some care. The most common use is to bring in a set of configuration parameters written as simple Python assignment statements. For example, we might use a file like the following as the configuration paramaters for a program.

```
db_server= "dbs_prod_01"
db_port= "3306"
db_name= "PROD"
```

30.7 Module Exercises

30.7.1 Refactor a Script

A very common situation is to take a script file apart and create a formal module of the definitions and a separate module of the script. If you refer back to your previous exercise scripts, you'll see that many of your files have definitions followed by a "main" script which demonstrates that your definitions actually work. When refactoring these, you'll need to separate the definitions from the test script.

Let's assume you have the following kind of script as the result of a previous exercise.

```
# Some Part 3 Exercise.
class X( object ):
    does something

class Y( X ):
    does something a little different

x1= X()
x1.someMethod()
y2= Y()
y2.someOtherMethod()
```

You'll need to create two files from this. The module will be the simplest to prepare, assume the file name is `myModule.py`

```
#!/usr/bin/env python
class X( object ):
    does something

class Y( X ):
    does something a little different
```

Your new new demonstation application will look like this because you will have to qualify the class and function names that are created by the module.

```
#!/usr/bin/env python
import myModule
x1= myModule.X()
x1.someMethod()
y2= myModule.Y()
y2.someOtherMethod()
```

Your original test script had an implicit assumption that the definitions and the test script were all in the same namespace. This will no longer be true. While you can finesse this by using '`from myNewModule import *`', this is not the best programming style. It is better to rewrite the test script to explicitly qualify names with the module name.

There are a number of related class definitions in previous exercises that can be used to create modules.

- Any of the exercises in *Class Definition Exercises* contains a number of related classes.
- The exercise in *Shuffling Method for the Deck class* has two parts: definitions of `Deck` and related material, and a procedure for comparing different shuffling algorithms. This should be repackaged to separate the performance measurement script from the basic definitions. You should be able to separate the `Deck` and the various shuffling strategies in a module separate from the performance measurement script.
- The simulation built in *State* can be formalized into two modules. The lowest-level module defines the basic game of Roulette including the `Wheel` and `RouletteGame`. Another module imports this and defines the `Player` and the states. Finally, the main script imports the game, the player and runs the simulation to produce a log of wins and losses.
- The rational number class, built in *Numeric Type Special Methods* can be formalized into a module. A script can import this module and demonstrate the various operations on rational numbers.
- The sequence with additional statistical methods, built in *Sample Class with Statistical Methods* can be formalized into a module. A script can import this module and demonstrate the various statistical operations on sample data.

30.7.2 Install a New Module

Create a simple module file with some definitions. Preferrably, this is a solution to *Refactor a Script*. Install the definitional part into the PYTHONPATH. Be sure to rename or remove the local version of this file. Be sure to use each installation method.

1. Move the module file to the site-packages directory. Be sure that it is removed (or renamed) in your local directory.
2. Move the module file to another directory and create a hard link (using the Linux ln or equivalent Windows utility) from site-packages to the other directory you created.

3. Remove the hard link and put a `.pth` file in the site-packages directory.
4. Remove the `.pth` file and update the PYTHONPATH environment variable to reference the new directory.

30.7.3 Planning for Maintenance and Upgrades

There are a number of module installation scenarios; each of these will require a different technique. Compare and contrast these techniques from several points of view: cost to deploy, security of the deployment, ease of debugging, and control over what the user experiences.

- You have to provide modules and an application on a number of desktop PC's. Python must be installed on each individual desktop. However, the application that uses Python could be put on a shared network drive. What are the pros and cons of installing a Python-based application locally versus on a network drive?
  - How would you handle the initial setup?
  - How would you handle an upgrade to Python itself? For example, how would you install Python 3.1 so as to preserve your modules and application?
  - How would you control an upgrade to a Python-based application? For example, you have a new module file that needs to be made available to all users.
- You have to provide modules and an application on a server, shared by a number of users. Python is installed on the server, as is the Python-based application. What security considerations should be put into place?
  - How would you handle initial installation of Python and your server-based application?
  - How would you handle an upgrade to Python on this shared server?
  - How would you control an upgrade to the Python-based application on this shared server?

30.8 Style Notes

Modules are a critical organizational tool for final delivery of Python programming. Python software is delivered as a set of module files. Often a large application will have one or more module files plus a main script that initiates the application. There are several conventions for naming and documenting module files.

Module names are python identifiers as well as file names. Consequently, they can only use "_" as a punctuation mark. Most modules have names that are mixedCase, beginning with lowercase letters. This conforms to the useage on most file systems. MacOS users would do well to keep their module names to a single word, and end with `.py`. This promotes portability to operating systems where file names are more typically single words. Windows, in particular, can have trouble with spaces in file names.

Some Python modules are a wrapper for a C-language module. In this case the C/C++ module is named in all lowercase and has a leading underscore (e.g. `_socket`).

A module's contents start with a docstring. After the docstring comes any version control information. The bulk of a module is typically a series of definitions for classes, exceptions and functions.

A module's docstring should begin with a one-line pithy summary of the module. This is usually followed by in inventory of the public classes, exceptions and functions this module creates. Detailed change history does not belong here, but in a separate block of comments or an additional docstring.

If you use **CVS** or **svn** to track the versions of your source files, following style is recommended. This makes the version information available as a string, and visible in the `.py` source as well as any `.pyc` working files.

```
"""My Demo Module.
This module is just a demonstration of some common styles."""
__version__ = "$Revision: 1.3$"
```

Note that the module's name will qualift everything created in the module, it is never necessary to have a prefix in front of each name inside the module to show its origin. For example, consider a module that contains classes and functions related to statistical analysis, called `stats.py`. The `stats` module might contain a class for tracking individual samples.

Poor Names. We don't include extra name prefixes like `statsSample` or `stats_sample`.

Better Names. We would call our internal sample class `Sample`. A client application that contains an **import stats** statement, would refer to the class as `stats.Sample`.

This needless over-qualification of names sometimes devolves to sillines, with class names beginning with `c_`, function names beginning with `f_`, the expected data type indicated with a letter, and the scope (global variables, local variables and function parameters) all identified with various leading and trailing letters. This is not done in Python programming. Class names begin with uppercase letters, functions begin with lowercase. Global variables are identified explicitly in **global** statements. Most functions are kept short enough that that the parameter names are quite obvious.

Any element of a module with a name that begins with `_single_leading_underscore` is not created in the namespace of the client module. When we use '`from stats import *`', these names that begin with _ are not inserted in the global namespace. While usable within the module, these names are not visible to client modules, making them the equivalent of Java's '`private`' declaration.

Errors and Exceptions. A common feature of modules is to create a module-wide exception class. The usuall approach looks like the following. Within a module, you would define an `Error` class as follows:

```
class Error( Exception ): pass
```

You can then raise your module-specific exception with the following.

```
raise Error, "additional notes"
```

A client module or program can then reference the module's exception in a **try** statement as `module.Error`. For example:

```
import aModule
try:
    aModule.aFunction()
except: aModule.Error, ex:
    print "problem", ex
    raise
```

With this style, the origin of the error is shown clearly.

CHAPTER

THIRTYONE

PACKAGES

A *package* is a collection of Python modules. Packages allow us to structure a collection of modules. In *Package Semantics* we describe the basic semantics of packages. In *Package Definition* we describe how to define a package. We'll look at using a package in *Package Use*.

31.1 Package Semantics

A *package* is a directory that contains modules. Having a directory of modules allows us to have modules contained within other modules. This allows us to use qualified module names, clarifying the organization of our software.

We can, for example, have several simulations of casino games. Rather than pile all of our various files into a single, flat directory, we might have the following kind of directory structure. (This isn't technically complete, it needs a few additional files.)

```
casino/
    craps/
        dice.py
        game.py
        player.py
    roulette/
        wheel.py
        game.py
        player.py
    blackjack/
        cards.py
        game.py
        player.py
    srategy/
        basic.py
        martingale.py
        bet1326.py
        cancellation.py
```

Given this directory structure, our overall simulation might include statements like the following.

```
import craps.game, craps.player
import strategy.basic as betting
class MyPlayer( craps.player.Player ):
    def __init__( self, stake, turns ):
        betting.initialize(self)
```

We imported the `game` and `player` modules from the `craps` package. We imported the `basic` module from the `strategy` package. We defined a new player based on a class named `Player` in the `craps.player` package.

We have a number of alternative betting strategies, all collected under the `strategy` package. When we import a particular betting strategy, we name the module `betting`. We can then change to a different betting strategy by changing the **import** statement.

There are two reasons for using a package of modules.

- There are a lot of modules, and the package structure clarifies the relationships among the modules. If we have several modules related to the game of craps, we might have the urge to create a craps_game.py module and a craps_player.py module. As soon as we start structuring the module names to show a relationship, we can use a package instead.
- There are alternative implementations, and the package contains polymorphic modules. In this case, we will often use an '`import package.alternative as interface`' kind of **import** statement. This is often used for interfaces and drivers to isolate the interface details and provide a uniform API to the rest of the Python application.

It is possible to go overboard in package structuring. The general rule is to keep the package structure relatively flat. Having only one module at the bottom of deeply-nested packages isn't really very informative or helpful.

31.2 Package Definition

In order for Python to make use of a directory as package, the directory must have a name that is a valid Python identifier and contain a special module named `__init__`. Valid Python names are composed of letters, digits and underscores. See *Variables* for more information.

The `__init__` module is often an empty file, `__init__.py` in the package directory. Nothing else is required to make a directory into a package. The `__init__.py` file, however, is essential. Without it, you'll get an `ImportError`.

For example, consider a number of modules related to the definition of cards. We might have the following files.

```
cards/
    __init__.py
    standard.py
    blackjack.py
    poker.py
```

The `cards.standard` module would provide the base definition of card as an object with suit and rank. The `cards.blackjack` module would provide the subclasses of cards that we looked at in *Blackjack Hands*. The `cards.poker` module would provided the subclasses of cards that we looked at in *Poker Hands*.

The cards.blackjack module and the cards.poker module should both import the cards.standard module to get the base definition for the `Card` and `Deck` classes.

The `__init__` module. The `__init__` module is the "initialization" module in a package. It is processed the first time that a package name is encountered in an **import** statement. In effect, it initializes Python's understanding of the package. Since it is always loaded, it is also effectively the default module in a package. There are a number of consequences to this.

- We can import the package, without naming a specific module. In this case we've imported just the initialization module, `__init__`. If this is part of our design, we'll put some kind of default or top-level definitions in the `__init__` module.

- We can import a specific module from the package. In this case, we also import the initialization module along with the requested module. In this case, the `__init__` module can provide additional definitions; or it can simply be empty.

In our cards example, above, we would do well to make the `__init__` module define the basic `Card` and `Deck` classes. If we import the package, `cards`, we get the default module, `__init__` , which gives us `cards.Card` and `cards.Deck`. If we import a specific module like `cards.blackjack` , we get the `__init__` module plus the named module within the package.

31.3 Package Use

If the `__init__` module in a package is empty, the package is little more than a collection of module files. In this case, we don't generally make direct use of a package. We merely mention it in an import statement: '`import cards.poker`'.

On other hand, if the `__init__` module has some definitions, we can import the package itself. Importing a package just imports the `__init__` module from the package directory. In this case, we mention the package in an import statement: '`import cards`'.

Even if the `__init__` module has some definitions in it, we can always import a specific module from within the package. Indeed, it is possible for the `__init__` module in a package is to do things like adjust the search path prior to locating individual module files.

31.4 Package Exercises

1. **Create a Package**. In the previous chapter's exercises (see *Refactor a Script*) are some suggestions for creating a simple module. The modules decribed in that exercise are so small that adding modules does not seem necessary. However, it's the best example of how packages arise when solving practical problems.

   Pick a module that you've already created. Add a second file with a few simple classes that do little real work. These are best described as "Hello World" classes, since they don't do anything more useful than provide a simple response to indicate that the module was imported correctly.

   Create a packge directory with the necessary `__init__.py` file.

   Create a demonstration script which imports and exercises both modules from this package.

31.5 Style Notes

Since a package, like a module, is both a file system location and a Python construct, the name must be a valid Python name, using just letters, numbers and '_''s. Additionally, some file systems are cavalier about maintaining the original case of the filename. The old Mac OS (pre Mac OS X), and many of the old Windows variants would casually alter the case of filenames.

Consequently, package and module names should be all lower case. This way, there is no ambiguity about the intended case of the module name.

Package structures should be relatively flat. The general rule is to keep the package structure relatively flat. Having only one module at the bottom of deeply-nested packages isn't really very informative or helpful. While it may seem like '`import casino.games.definitions.tablegames.dicegames.craps`' leaves lots of room for expansion, there just aren't enough casino games to make this immensely deep structure usable.

Packages are generally used for two things:

- Collecting related modules together in a directory to simplify installation, maintenenace and documentation.
- Defining alternative implementations as simply as possible.

If all of your modules are more-or-less unique, then a package structure isn't going to help. Similarly, if you don't have alternate implementations of some driver or interface, a package structure isn't useful.

CHAPTER

THIRTYTWO

THE PYTHON LIBRARY

Consistent with the Pythonic "Batteries Included" philopsophy of Python, there are hundreds of extension modules. It can be difficult to match a programming need with a specific module. The *Python Library Reference* document can be hard to pick through to locate an appropriate module. We'll start at the top of the library organization and work our way down to a useful subset of the tremendous wealth that is Python.

In *Overview of the Python Library* we'll take a very high level overview of what's in the Python library. We'll closely at the 50 or so most useful modules in *Most Useful Library Sections*.

32.1 Overview of the Python Library

The *Python Library Reference* organizes modules into the following sections. The current version of the Library documentation strives to prsent the modules with the most useful near the front of the list. The first 23 chapters, plus chapter 26 are the most useful. From chapter 24 and below (except for chapter 26), the modules are too highly specialized to cover in this book.

1. Introduction
2. Built-in Objects. This chapter provides complete documentation of the built-in functions, exceptions and constants.
3. Built-in Types. All of the data types we've looked at are documented completely in this chapter of the library reference. Of course, there are additional types in the Python reference that we haven't looked at.
4. String Services. This chapter includes almost a dozen modules for various kinds of string and text handling. This includes regular expression pattern matching, Unicode codecs and other string-processing modules.
5. Data Types. This chapter has almost 20 modules providing additional data types, including `datetime`.
6. Numeric and Mathematical Modules. This chapter describes `math`, `decimal` and `random` modules.
7. Internet Data Handling. One secret behind the internet is the use of standardized sophisticated data objects, like email messages with attachments. This chapter covers over a dozen modules for handling data passed through the internet.
8. Structured Markup Processing Tools. XML, HTML and SGML are all markup languages. This chapter covers tools for parsing these languages to separate the content from the markup.
9. File Formats. This chapter covers modules for parsing files in format like Comma Separated Values (CSV).
10. Cryptographic Services. This chapter has modules which can be used to develop and compare secure message hashes.

11. File and Directory Access. This chapter of the Library Reference covers many of the modules we'll look at in *File Handling Modules*.
12. Data Compression and Archiving. This chapter describes modules for reading and writing zip files, tar files and BZ2 files. We'll cover these modules in *File Handling Modules*, also.
13. Data Persistence. Objects can be written to files, sockets or databases so that they can persist beyond the processing of one specific program. This chapter covers a number of packages for pickling objects so they are preserved. The SQLite 3 relational database is also described in this module.
14. Generic Operating System Services. An Operating System provides a number of services to our application programs, including access to devices and files, consistent notions of time, ways to handle command-line options, logging, and handling operating system errors. We'll look some of these modules in *Programs: Standing Alone*.
15. Optional Operating System Services. This section includes operating system services that are common to most Linux variants, but not always available in Windows.
16. Unix Specific Services. There are a number of Unix and Linux-specific features provided by these modules.
17. Interprocess Communication and Networking. Larger and more complex application programs often consist of multiple, cooperating components. The World Wide Web, specifically, is based on the interaction between client and server programs. This chapter describes modules that provide a basis for communcating among the OS processes that execute our programs.
18. Internet Protocols and Support. This chapter describes over two dozen modules that process a wide variety of internet-related data structures. This varies from the relatively simple processing of URL's to the relatively complex processing of XML-based Remote Procedure Calls (XML-RPC).
19. Multimedia Services. Multimedia includes sounds and images; these modules can be used to manipulate sound or image files.
20. Graphical User Interfaces with Tk. The Tkinter module is one way to build a graphical desktop application. The GTK libraries are also widely used to build richly interactive desktop applications; to make use of them, you'll need to download the pyGTK package.
21. Internationalization. These packages help you separating your message strings from the rest of your application program. You can then translate your messages and provide language-specific variants of your software.
22. Program Frameworks. These are modules to help build command-line applications.
23. Development Tools. These modules are essential to creating polished, high-quality software: they support the creation of usable documents and reliable tests for Python programs.
24. The Python Debugger
25. The Python Profilers
26. Python Runtime Services. This chapter describes the `sys` module, which provides a number of useful objects.
27. Custom Python Interpreters
28. Restricted Execution
29. Importing Modules
30. Python Language Services
31. Python compiler package
32. Abstract Syntax Trees

33. Miscellaneous Services
34. SGI IRIX Specific Services
35. SunOS Specific Services
36. MS Windows Specific Services

32.2 Most Useful Library Sections

This section will overview about 50 of the most useful libary modules. These modules are proven technology, widely used, heavily tested and constantly improved. The time spent learning these modules will reduce the time it takes you to build an application that does useful work.

We'll dig more deeply into just a few of these modules in subsequent chapters.

Tip: Lessons Learned

As a consultant, we've seen far too many programmers writing modules which overlap these. There are two causes: ignorance and hubris. In this section, we hope to tackle the ignorance cause.

Python includes a large number of pre-built modules. The more you know about these, the less programming you have to do.

Hubris sometimes comes from the feeling that the library module doesn't fit our unique problem well enough to justify studying the library module. In other languages we can't read the library module to see what it *really* does. In Python, however, the documentation is only an introduction; we're encouraged to actually read the library module. This is called the *"Use the Source, Luke"* principle.

We find that hubris is most closely associated with calendrical calcuations. It isn't clear why programmers invest so much time and effort writing buggy calendrical calculations. Python provides many modules for dealing with times, dates and the calendar.

8. String Services. The String Services modules contains string-related functions or classes. See *Strings* for more information on strings.

re The `re` module is the core of text pattern recognition and processing. A *regular expression* is a formula that specifies how to recognize and parse strings. The `re` module is described in detail in *Complex Strings: the re Module*.

struct The avowed purpose of the `struct` module is to allow a Python program to access C-language API's; it packs and unpacks C-language struct object. It turns out that this module can also help you deal with files in packed binary formats.

difflib The `difflib` module contains the essential algorithms for comparing two sequences, usually sequences of lines of text. This has algorithms similar to those used by the Unix **diff** command (the Window **COMP** command).

StringIO

cStringIO There are two variations on `StringIO` which provide file-like objects that read from or write to a string buffer. The `StringIO` module defines the class `StringIO` , from which subclasses can be derived. The `cStringIO` module provides a high-speed C-language implementation that can't be subclassed.

Note that these modules have atypical mixed-case names.

textwrap This is a module to format plain text. While the word-wrapping task is sometimes handled by word processors, you may need this in other kinds of programs. Plain text files are still the most portable, standard way to provide a document.

codecs This module has hundreds of text encodings. This includes the vast array of Windows code pages and the Macintosh code pages. The most commonly used are the various Unicode schemes (utf-16 and utf-8). However, there are also a number of codecs for translating between strings of text and arrays of bytes. These schemes include base-64, zip compression, bz2 compression, various quoting rules, and even the simple rot_13 substitution cipher.

9. Data Types. The Data Types modules implement a number of widely-used data structures. These aren't as useful as sequences, dictionaries or strings – which are built-in to the language. These data types include dates, general collections, arrays, and schedule events. This module includes modules for searching lists, copying structures or producing a nicely formatted output for a complex structure.

datetime The `datetime` handles details of the calendar, including dates and times. Additionally, the `time` module provides some more basic functions for time and date processing. We'll cover both modules in detail in *Dates and Times: the time and datetime Modules*.

These modules mean that you never need to attempt your own calendrical calculations. One of the important lessons learned in the late 90's was that many programmers love to tackle calendrical calculations, but their efforts had to be tested and reworked prior to January 1, 2000, because of innumerable small problems.

calendar This module contains routines for displaying and working with the calendar. This can help you determine the day of the week on which a month starts and ends; it can count leap days in an interval of years, etc.

collections This package contains some handy data types, plus the Abstract Base Classes that we use for defining our own collections. Data types include the `collections.deque` – a "double-ended queue" – that can be used as stack (LIFO) or queue (FIFO). The `collections.defaultdict` class, which can return a default value instead of raising an exception for missing keys. The `collections.namedtuple` function helps us to create a small, specialized class that is a tuple with named positions.

We made use of this library in *Creating or Extending Data Types*.

bisect The `bisect` module contains the `bisect()` function to search a sorted list for a specific value. It also contains the `insort()` fucntion to insert an item into a list maintaining the sorted order. This module performs faster than simply appending values to a list and calling the `sort()` method of a list. This module's source is instructive as a lesson in well-crafted algorithms.

array The `array` module gives you a high-performance, highly compact collection of values. It isn't as flexible as a list or a tuple, but it is fast and takes up relatively little memory. This is helpful for processing media like image or sound files.

sched The `sched` module contains the definition for the `scheduler` class that builds a simple task scheduler. When a scheduler is contructed, it is given two user-supplied functions: one returns the "time" and the other executes a "delay" waiting for the time to arrive. For real-time scheduling, the `time` module `time()` and `sleep()` functions can be used. The scheduler has a main loop that calls the supplied time function and compares the current time with the time for scheduled tasks; it then calls the supplied a delay function for the difference in time. It runs the scheduled task, and calls the delay function with a duration of zero to release any resources.

Clearly, this simple algorithm is very versatile. By supplying custom time functions that work in minutes instead of seconds, and a delay function that does additional background processing while waiting for the scheduled time, a flexible task manager can be constructed.

copy The `copy` module contains functions for making copies of complex objects. This module contains a function to make a *shallow copy* of an object, where any objects contained within the parent are not copied, but references are inserted in the parent. It also contains a

function to make a *deep copy* of an object, where all objects contained within the parent object are duplicated.

Note that Python's simple assignment only creates a variable which is a label (or reference) to an object, not a duplicate copy. This module is the easiest way to create an independent copy.

pprint The `pprint` module contains some useful functions like `pprint.pprint()` for printing easy-to-read representations of nested lists and dictionaries. It also has a `PrettyPrinter` class from which you can make subclasses to customize the way in which lists or dictionaries or other objects are printed.

10. Numeric and Mathematical Modules. These modules include more specialized mathemathical functions and some additional numeric data types.

decimal The decimal module provides decimal-based arithmetic which correctly handles significant digits, rounding and other features common to currency amounts.

math The `math` module was covered in *The math Module*. It contains the math functions like sine, cosine and square root.

random The `random` module was covered in *The math Module*.

11. File and Directory Access. We'll look at many of these modules in *File Handling Modules*. These are the modules which are essential for handling data files.

os.path The `os.path` module is critical for creating portable Python programs. The popular operating systems (Linux, Windows and MacOS) each have different approaches to file names. A Python program that depends on `os.path` will behave more consistently in all environments.

fileinput The `fileinput` module helps your progam process a large number of files smoothly and simply.

glob

fnmatch The `glob` and `fnmatch` modules help a Windows program handle wild-card file names in a standard manner.

shutil The `shutil` module provides shell-like utilities for file copy, file rename, directory moves, etc. This module lets you write short, effective Pytthon programs that do things that are typically done by shell scripts.

Why use Python instead of the shell? Python is far easier to read, far more efficient, and far more capable of writing moderately sophisticated programs. Using Python saves you from having to write long, painful shell scripts.

12. Data Persistence. There are several issues related to making objects persistent. In Chapter 12 of the Python Reference, there are several modules that help deal with files in various kinds of formats. We'll talk about these modules in detail in *File Formats: CSV, Tab, XML, Logs and Others*.

There are several additional techniques for managing persistence. We can "pickle" or "shelve" an object. In this case, we don't define our file format in detail, instead we leave it to Python to persist our objects.

We can map our objects to a relational database. In this case, we'll use the SQL language to define our storage, create and retrieve our objects.

pickle

shelve The `pickle` and `shelve` modules are used to create persistent objects; objects that persist beyond the one-time execution of a Python program. The `pickle` module produces a serial text representation of any object, however complex; this can reconstitute an object from its text representation. The `shelve` module uses a `dbm` database to store and retrieve objects.

The `shelve` module is not a complete object-oriented database, as it lacks any transaction management capabilities.

sqlite3 This module provides access to the SQLite relational database. This database provides a significant subset of SQL language features, allowing us to build a relational database that's compatible with products like MySQL or Postgres.

13. Data Compression and Archiving. These modules handle the various file compression algorithms that are available. We'll look at these modules in *File Handling Modules*.

tarfile

zipfile These two modules create archive files, which contain a number of files that are bound together. The TAR format is not compressed, where the ZIP format is compressed. Often a TAR archive is compressed using GZIP to create a .tar.gz archive.

zlib

gzip

bz2 These modules emplioye different compression algorithms. They all have similar features to compress or uncompress files.

14. File Formats. These are modules for reading and writing files in a few of the amazing variety of file formats that are in common use. In addition to these common formats, modules in chapter 20, Structured Markup Processig Tools are also important.

csv The `csv` module helps you parse and create Comma-Separated Value (CSV) data files. This helps you exchange data with many desktop tools that produce or consume CSV files. We'll look at this in *Comma-Separated Values: The csv Module*.

ConfigParser Configuration files can take a number of forms. The simplest approach is to use a Python module as the configuration for a large, complex program. Sometimes configurations are encoded in XML.

Many Windows legacy programs use `.INI` files. The ConfigParser can gracefully parse these files.

15. Cryptographic Services. These modules aren't specifically encryption modules. Many popular encryption algorithms are protected by patents. Often, encryption requires compiled modules for performance reasons. These modules compute secure digests of messages using a variety of algorithms.

hashlib Compute a secure hash or digest of a message to ensure that it was not tampered with. The `hashlib.md5` class creates an MD5 hash, which is often used for validating that a downloaded file was recieved correctly and completely.

16. Generic Operating System Services. The following modules contain basic features that are common to all operating systems. Most of this commonality is acheived by using the C standard libraries. By using this module, you can be assured that your Python application will be portable to almost any operating system.

os The `os` (and `os.path`) modules provide access to a number of operating system features. The `os` module provides control over Processes, Files and Directories. We'll look at `os` and `os.path` in *The os Module* and *The os.path Module*.

time The `time` module provides basic functions for time and date processing. Additionally `datetime` handles details of the calendar more gracefully than `time` does. We'll cover both modules in detail in *Dates and Times: the time and datetime Modules*.

Having modules like `datetime` and `time` mean that you never need to attempt your own calendrical calculations. One of the important lessons learned in the late 90's was that many

programmers love to tackle calendrical calculations, but their efforts had to be tested and reworked because of innumerable small problems.

getopt

optparse A well-written program makes use of the command-line interface. It is configured through options and arguments, as well as properties files. We'll cover `optparse` in *Programs: Standing Alone*.

Command-line programs for Windows will also need to use the `glob` module to perform standard file-name globbing.

logging Often, you want a simple, standardized log for errors as well as debugging information. We'll look at logging in detail in *Log Files: The logging Module*.

17. Optional Operating System Services. This section includes less-common modules for handling threading other features that are more-or-less unavailable in Windows.

18. Interprocess Communication and Networking. This section includes modules for creating processes and doing simple *interprocess communication* (IPC) using the standard socket abstraction.

subprocess The `subprocess` module provides the class required to create a separate process. The standard approach is called *forking* a subprocess. Under Windows, similar functionality is provided.

Using this, you can write a Python program which can run any other program on your computer. This is very handy for automating complex tasks, and it allows you to replace clunky, difficult shell scripts with Python scripts.

socket This is a Python implementation of the standard socket library that supports the TCP/IP protocol.

19. Internet Data Handling. The Internet Data Handling modules contain a number of handy algorithms. A great deal of data is defined by the Internet Request for Comments (RFC). Since these effectively standardize data on the Internet, it helps to have modules already in place to process this standardized data. Most of these modules are specialized, but a few have much wider application.

mimify

base64

binascii

binhex

quopri

uu These modules all provide various kinds of conversions, ecapes or quoting so that binary data can be manipulated as safe, universal ASCII text. The number of these modules reflects the number of different clever solutions to the problem of packing binary data into ordinary email messages.

20. Structured Markup Processing Tools. The following modules contain algorithms for working with structured markup: Standard General Markup Lanaguage (SGML), Hypertext Markup Language (HTML) and Extensible Markup Language (XML). These modules simplify the parsing and analysis of complex documents. In addition to these modules, you may also need to use the CSV module for processing files; that's in chapter 9, File Formats.

htmllib Ordinary HTML documents can be examined with the `htmllib` module. This module based on the `sgmllib` module. The basic `HTMLParser` class definition is a superclass; you will typically override the various functions to do the appropriate processing for your application.

One problem with parsing HTML is that browsers – in order to conform with the applicable standards – must accept incorrect HTML. This means that many web sites publish HTML which is tolerated by browsers, but can't easily be parsed by `htmllib`. When confronted with serious horrors, consider downloading the Beautiful Soup module (http://www.crummy.com/software/BeautifulSoup/). This handles erroneous HTML more gracefully than `htmllib`.

xml.sax

xml.dom

xml.dom.minidom The `xml.sax` and `xml.dom` modules provide the classes necessary to conveniently read and process XML documents. A SAX parser separates the various types of content and passes a series of events the handler objects attached to the parser. A DOM parser decomposes the document into the Document Object Model (DOM).

The `xml.dom` module contains the classes which define an XML document's structure. The `xml.dom.minidom` module contains a parser which creates a DOM object.

Additionally, the `formatter` module, in chapter 24 (Miscellaneous Modules) goes along with these.

21. Internet Protocols and Support. The following modules contain algorithms for responding the several of the most common Internet protocols. These modules greatly simplify developing applications based on these protocols.

cgi The `cgi` module can be used for web server applications invoked as Common Gateway Interface (CGI) scripts. This allows you to put Python programming in the `cgi-bin` directory. When the web server invokes the CGI script, the Python interpreter is started and the Python script is executed.

wsgiref The Web Services Gateway Interface (WSGI) standard provides a much simpler framework for web applications and web services. See **PEP 333** for more information.

Essentially, this subsumes all of CGI, plus adds several features and a systematic way to compose larger applications from smaller components.

urllib

urllib2

urlparse These modules allow you to write relatively simple application programs which open a URL as if it were a standard Python file. The content can be read and perhaps parsed with the HTML or XML parser modules, described below. The `urllib` module depends on the `httplib`, `ftplib` and `gopherlib` modules. It will also open local files when the scheme of the URL is `file:`. The `urlparse` module includes the functions necessary to parse or assemble URL's. The `urllib2` module handles more complex situations where there is authentication or cookies involved.

httplib

ftplib

gopherlib The `httplib`, `ftplib` and `gopherlib` modules include relatively complete support for building client applications that use these protocols. Between the `html` module and `httplib` module, a simple character-oriented web browser or web content crawler can be built.

poplib

imaplib The `poplib` and `imaplib` modules allow you to build mail reader client applications. The `poplib` module is for mail clients using the Post-Office Protocol, POP3 (RFC 1725), to

extract mail from a mail server. The `imaplib` module is for mail servers using the Internet Message Access Protocol, IMAP4 (RFC 2060) to manage mail on an IMAP server.

nntplib The `nntplib` module allows you to build a network news reader. The newsgroups, like `comp.lang.python`, are processed by NNTP servers. You can build special-purpose news readers with this module.

SocketServer The `SocketServer` module provides the relatively advanced programming required to create TCP/IP or UDP/IP server applications. This is typically the core of a stand-alone application server.

SimpleHTTPServer

CGIHTPPServer

BaseHTTPServer The `SimpleHTTPServer` and `CGIHTTPServer` modules rely on the basic `BaseHTTPServer` and `SocketServer` modules to create a web server. The `SimpleHTTPServer` module provides the programming to handle basic URL requests. The `CGIHTTPServer` module adds the capability for running CGI scripts; it does this with the `fork()` and `exec()` functions of the `os` module, which are not necessarily supported on all platforms.

asyncore

asynchat The `asyncore` (and `asynchat`) modules help to build a time-sharing application server. When client requests can be handled quickly by the server, complex multi-threading and multi-processing aren't really necessary. Instead, this module simply dispatches each client communication to an appropriate handler function.

22. Multimedia Services. This is beyond the scope of this book.

23. Internationalization. A well-written application avoids including messages as literal strings within the program text. Instead, all messages, prompts, labels, etc., are kept as a separate resource. These separate string resources can then be translated.

locale The `locale` module fetches the current locale's date, time, number and currency formatting rules. This provides functions which will format and parse dates, times, numbers and currency amounts.

A user can change their locale with simple operating system settings, and your application can work consistently with all other programs.

24. Program Frameworks. We'll talk about a number of program-related issues in *Programs: Standing Alone* and *Architecture: Clients, Servers, the Internet and the World Wide Web*. Much of this goes beyond the standard Python library. Within the library are two modules that can help you create large, sophisticated command-line application programs.

cmd The `cmd` module contains a superclass useful for building the main command-reading loop of an interactive program. The standard features include printing a prompt, reading commands, providing help and providing a command history buffer. A subclass is expected to provide functions with names of the form `do_command()`. When the user enters a line beginning with `command`, the appropriate `do_command()` function is called.

shlex The `shlex` module can be used to tokenize input in a simple language similar to the Linux shell languages. This module defines a basic `shlex` class with parsing methods that can separate words, quotes strings and comments, and return them to the requesting program.

25. Graphical User Interfaces with Tk. This is beyond the scope of this book.

26. Development Tools. The testing tools are central to creating reliable, complete and correct software.

doctest When a function or a class docstring includes a snippet of interactive Python, the doctest module can use this snippet to confirm that the function or class works as advertised.

For example:

```
def myFunction( a, b ):
    """>>> myFunction( 2, 3 )
    6
    >>> myFunction( 5.0, 7.0 )
    35.0
    """
    return a * b
```

The '`>>> myFunction( 2, 3 )`' lines are parsed by doctest. They are evaluated, and the actual result compared with the docstring comment.

unittest This is more sophisticated testing framework in which you create TestCases which define a fixture, an operation and expected results.

2to3 This module is used to convert Python 2 files to Python 3.

Prior to using this, you should run your Python programs with the '`-3`' option to identify any potential incompatibilities. Once you've fixed all of the incompatibilities, you can confidently convert your program to Python 3.

Do not "tweak" the output from this conversion. If your converted program doesn't work under Python 3, it's almost always a problem with your original program playing fast and loose with Python rules.

In the unlikely event that this module cannot convert your program, you should probably rewrite your program to eliminate the "features" that are causing problems.

27. Debugging and Profiling. Debugging is an important skill, as is performance profiling. Much of this is beyond the scope of this book.

timeit This is a handy module that lets you get timing information to compare performance of alternative implementations of an algorithm.

28. Python Runtime Services. The Python Runtime Services modules are considered to support the Python runtime environment.

sys The `sys` module contains execution context information. It has the command-line arguments (in `sys.argv`) used to start the Python interpreter. It has the standard input, output and error file definitions. It has functions for retrieving exception information. It defines the platform, byte order, module search path and other basic facts. This is typically used by a main program to get run-time environment information.

Most of the remaining sections of the library, with one exception, are too advanced for this book.

- 1. Custom Python Interpreters
- 1. Restricted Execution
- 1. Importing Modules
- 1. Python Language Services
- 1. Python compiler package

34. Miscellaneous Services. This is a vague catch-all that only has one module.

formatter The `formatter` module can be used in conjunction with the HTML and XML parsers. A formatter instance depends on a writer instance that produces the final (formatted) output. It can also be used on its own to format text in different ways.

The HTML parser can produce a plain-text version of a web page. To do this, it uses the `formatter` module.

32.3 Library Exercises

1. **Why are there multiple versions of some packages**? Look at some places where there are two modules which clearly do the same or almost the same things. Examples include `time` and `datetime`, `urllib` and `urllib2`, `pickle` and `cPickle`, `StringIO` and `cStringIO`, `subprocess` and `popen2`, `getopt` and `optparse`.

   Why allow this duplication? Why not pick a "best" module and discard the others?

2. **Is it better to build an application around the library or simply design the application and ignore the library**? Assuming that we have some clear, detailed requirements, what is the benefit of time spent searching through the library? What if most library modules are a near-miss? Should we alter our design to leverage the library, or just write the program without considering the library?

3. **Which library modules are deprecated or disabled**? Why are these still documented in the library?

CHAPTER

THIRTYTHREE

COMPLEX STRINGS: THE `RE` MODULE

There are a number of related problems when processing strings. When we get strings as input from files, we need to recognize the input as meaningful. Once we're sure it's in the right form, we need to parse the inputs, sometimes we'll ahve to convert some parts into numbers (or other objects) for further use.

For example, a file may contain lines which are supposed to be like `"Birth Date: 3/8/85"` . We may need to determine if a given string has the right form. Then, we may need to break the string into individual elements for date processing.

We can accomplish these recognition, parsing and conversion operations with the `re` module in Python. A *regular expression* (RE) is a rule or pattern used for matching strings. It differs from the fairly simple "wild-card" rules used by many operating systems for naming files with a pattern. These simple operating system file-name matching rules are embodied in two simpler packages: `fnmatch` and `glob`.

We'll look at the semantics of a regular expression in *Semantics*. We'll look at the syntax for defining a RE in *Creating a Regular Expression*. In *Using a Regular Expression* we'll put the regular expression to use.

33.1 Semantics

One way to look at regular expressions is as a production rule for constructing strings. In principle, such a rule could describe an infinite number of strings. The real purpose is not to enumerate all of the strings described by the production rule, but to match a candidate string against the production rule to see if the rule could have constructed the given string.

For example, a rule could be `"aba"`. All strings of the form `"aba"` would match this simple rule. This rule produces only a single string. Determining a match between a given string and the one string produced by this rule is pretty simple.

A more complex rule could be `"ab*a"`. The `b*` means zero or more copies of `b`. This rule produces an infinite set of strings including `"aa"`, `"aba"`, `"abba"`, etc. It's a little more complex to see if a given string could have been produced by this rule.

The Python `re` module includes Python constructs for creating regular expressions (REs), matching candidate strings against RE's, and examining the details of the substrings that match. There is a lot of power and subtlety to this package. A complete treatment is beyond the scope of this book.

33.2 Creating a Regular Expression

There are a lot of options and clauses that can be used to create regular expressions. We can't pretend to cover them all in a single chapter. Instead, we'll cover the basics of creating and using RE's.

The full set of rules is given in section 8.2.1 Regular Expression Syntax of the *Python Library Reference* document. Additionally, there are many fine books devoted to this subject.

- **Any ordinary character, by itself, is an RE**. Example: '`"a"`' is an RE that matches the character `a` in the candidate string. While trivial, it is critical to know that each ordinary character is a stand-alone RE.

  Some characters have special meanings. We can *escape* that special meaning by using a '\' in front of them. For example, '`*`' is a special character, but '`\*`' escapes the special meaning and creates a single-character RE that matches the character '`*`'.

  Additionally, some ordinary characters can be made special with '\'. For instance '`\d`' is any digit, '`\s`' is any whitespace character. '`\D`' is any non-digit, '`\S`' is any non-whitespace character.

- **The character '.' is an RE that matches any single character**. Example: '`"x.z"`' is an RE that matches the strings like `xaz` or `xbz`, but doesn't match strings like `xabz`.

- **The brackets, '`"[...]"`', create a RE that matches any character between the [ ]'s**. Example: '`"x[abc]z"`' matches any of `xaz`, `xbz` or `xcz`. A range of characters can be specified using a '`-`', for example '`"x[1-9]z"`'. To include a '`-`', it must be first or last. '`^`' cannot be first. Multiple ranges are allowed, for example '`"x[A-Za-z]z"`' . Here's a common RE that matches a letter followed by a letter, digit or `_`: '`"[A-Za-z][A-Za-z1-9_]"`'.

- **The modified brackets, `"[^...]"`, create a regular expression that matches any character except those between the [ ]'s**. Example: '`"a[^xyz]b"`' matches strings like `a9b` and `a$b`, but don't match `axb`. As with '`[ ]`', a range can be specified and multiple ranges can be specified.

- **A regular expression can be formed from concatenating regular expressions**. Example: '`"a.b"`' is three regular expressions, the first matches `a`, the second matches any character, the third matches `b`.

- **A regular expression can be a group of regular expressions, formed with ()'s**. Example: '`"(ab)c"`' is a regular expression composed of two regular expressions: '`"(ab)"`' (which, in turn, is composed of two RE's) and '`"c"`'. '`()`'s also group RE's for extraction purposes. The elements matched within '`()`' are remembered by the regular expression processor and set aside in a `Match` object.

- **A regular expression can be repeated**. Several repeat constructs are available: '`"x*"`' repeats '`"x"`' zero or more times; '`"x+"`' repeats '`"x"`' 1 or more times; '`"x?"`' repeats '`"x"`' zero or once. Example: '`"1(abc)*2"`' matches '`12`' or '`1abc2`' or '`1abcabc2`', etc. The first match, against `12`, is often surprising; but there are zero copies of `abc` between `1` and `2`.

  The above ('`*`', '`+`' and '`?`') are called "greedy" repeats because they will match the longest string of repeats.

  There are versions which are not greedy: '`*?`', '`+?`' will match the shortest string of repeats .

- **The character `"^"` is an RE that only matches the beginning of the line**, **`"$"` is an RE that only matches the end of the line**. Example: `"^$"` matches a completely empty line.

Here are some examples.

```
r"[_A-Za-z][_A-Za-z1-9]*"
```

Matches a Python identifier. This embodies the rule of starting with a letter or '_', and containing any number of letters, digits or '_''s. Note that any number includes 0 occurances, so a single letter or '_' is a valid identifier.

```
r"^\s*import\s"
```

Matches a simple **import** statement. It matches the beginning of the line with ^ , zero or more whitespace characters with \s* , the sequence of letters import ; and one more whitespace character. This pattern will ignore the rest of the line.

```
r"^\s*from\s+[_A-Za-z][_A-Za-z1-9]*\s+import\s"
```

Matches a 'from module import' statement. As with the simple import, it matches the beginning of the line (^), zero or more whitespace characters (\s*), the sequence of letters from, a Python module name, one or more whitespace characters (\s+), the sequence import, and one more whitespace character.

```
r"(\d+):(\d+):(\d+\.?\d*)"
```

Matches a one or more digits, a :, one or more digits, a :, and digits followed by optional . and zero or more other digits. For example 20:07:13.2 would match, as would 13:04:05

Further, the ()'s group the digit strings for conversion and further processing. The resulting Match object will have four groups. 'group(0)' is the entire match; 'group(1)' will be the first string of digits.

```
r"def\s+([_A-Za-z][_A-Za-z1-9]*)\s+\([^)]*\):"
```

Matches Python function definition lines. It matches the letters def; a string of 1 or more whitespace characters (s); an identifier, surrounded by ()'s to capture the entire identifier as a match. It matches a (; we've used (to escape the meaning of (and make it an ordinary character. It matches a string of non-) characters, which would be the parameter list. The parameter list ends with a) ; we've used) to make escape the meaning of) and make it an ordinary character. Finally, we need tyo see the :.

33.3 Using a Regular Expression

There are several methods which are commonly used with regular expressions. The most common first step is to compile the RE definition string to make an Pattern object. The resulting Pattern object can then be used to match or search candidate strings. A successful match returns a Match object with details of the matching substring.

The re module provides the compile() function.

compile(*expr*)
: Create a Pattern object from an RE string, expr. The Pattern is used for all subsequent searching or matching operations. A Pattern has several methods, including match() and search().

Generally, raw string notation (r"pattern") is used to write a RE. This simplifies the \'s required. Without the raw notation, each \ in the string would have to be escaped by a \ , making it \\ . This rapidly gets cumbersome. There are some other options available for re.compile(), see the *Python Library Reference*, section 4.2, for more information.

The following methods are part of a Pattern object created by the re.compile() function.

match(*string*)
: Match the candidate string against the compiled regular expression (an instance of Pattern). Matching

means that the regular expression and the candidate string must match, starting at the beginning of the candidate string. A `Match` object is returned if there is match, otherwise `None` is returned.

`search`(*string*)
: Search a candidate string for the compiled regular expression (an instance of `Pattern`). Searching means that the regular expression must be found somewhere in the candidate string. A `Match` object is returned if the pattern is found, otherwise `None` is returned.

If `search()` or `match()` finds the pattern in the candidate string, a `Match` object is created to describe the part of the candidate string which matched. The following methods are part of a `Match` object.

`group`(*number*)
: Retrieve the string that matched a particular '`()`' grouping in the regular expression. Group zero is a tuple of everything that matched. Group 1 is the material that matched the first set of '`()`'s.

Here's a more complete example. This sample decodes a complex input value into fields and then computes a single result.

```
>>> import re
>>> raw_input= "20:07:13.2"
>>> hms_pat = re.compile( r'(\d+):(\d+):(\d+\.?\d*)' )
>>> hms_match= hms_pat.match( raw_input )
>>> hms_match.group( 0, 1, 2, 3 )
('20:07:13.2', '20', '07', '13.2')
>>>
>>> h,m,s= map( float, hms_match.group(1,2,3) )
>>> h
20.0
>>> m
7.0
>>>
>>> s
13.199999999999999
>>> seconds= ((h*60)+m)*60+s
>>> seconds
72433.199999999997
```

1. The **import** statement incorporates the `re` module.
2. The `raw_input` variable is sample input, perhaps from a file, perhaps from `input()`.
3. The `hms_pat` variable is the compiled regular expression object which matches three numbers, using '`"(d+)"`', separated by '`:`'s.

   The digit-sequence RE's are surround by ()'s so that the material that matched is returned as a group. This will lead to four groups: group 0 is everything that matched, groups 1, 2, and 3 are successive digit strings.
4. The `hms_match` variable is a `Match` object that indicates success or failure in matching. If `hms_match` is `None`, no match occurred. Otherwise, the `hms_match.group()` method will reveal the individually matched input items.
5. The statement that sets `h`, `m`, and `s` does three things. First is uses `hms_match.group()` to create a tuple of requested items. Each item in the tuple will be a string, so the `map()` function is used to apply the built-in `float()` function against each string to create a tuple of three numbers. Finally, this statement relies on the multiple-assignment feature to set all three variables at once. Finally, `seconds` is computed as the number of seconds past midnight for the given time stamp.

33.4 Regular Expression Exercises

1. **Parse Old Stock prices**. Create a function that will decode the old-style fractional stock price. The price can be a simple floating point number or it can be a fraction, for example, `4 5/8`.

   Develop two patterns, one for numbers with optional decimal places and another for a number with a space and a fraction. Write a function that accepts a string and checks both patterns, returning the correct decimal price for whole numbers (e.g., 14), decimal prices (e.g., 5.28) and fractional prices (`27 1/4`).

2. **Parse Dates**. Create a function that will decode a few common American date formats. For example, 3/18/87 is March 18, 1987. You might want to do 18-Mar-87 as an alternative format. Stick to two or three common formats; otherwise, this can become quite complex.

   Develop the required patterns for the candidate date formats. Write a function that accepts a string and checks all patterns. It will return the date as a tuple of (year, month, day).

CHAPTER

THIRTYFOUR

DATES AND TIMES: THE `TIME` AND `DATETIME` MODULES

When processing dates and times, we have a number of problems. Most of these problems stem from the irregularities and special cases in the units we use to measure time. We generally measure time in a number of compatible as well as incompatible units. For example, weeks, days, hours, minutes and seconds are generally compatible, with the exception of leap-second handling. Months, and years, however are incompatible with days and require sophisticated conversion.

Problems which mix month-oriented dates and numbers of days are particularly difficult. The number of days between two dates, or a date which is 90 days in the future are notoriously difficult to compute correctly.

We need to represent a point in time, a date, a time of day or a date-time stamp. We need to be able to do arithmetic on this point in time. And, we need to represent this point in time as a properly-punctuated string.

The `time` module contains a number of portable functions needed to format times and dates. The `datetime` module builds on this to provide a representation that is slightly more convenient for some things. We'll look at the definition of a moment in time in *Semantics: What is Time?*.

34.1 Semantics: What is Time?

The Gregorian calendar is extremely complex. Some of that complexity stems from trying to impose a fixed "year" on the wobbly, irregular orbit of our planet. There are several concesssions required to impose a calendar year with integer numbers of days that will match the astronomial year of approximately 365.2425 days. The Gregorian calendar's concession is the periodic addition of a leap day to approximate this fractional day. The error is just under .25, so one leap day each four years gets close to the actual duration of the year.

Some additional complexity stems from trying to break the year into a sequence of months. Fixed-length months don't work well because the year is 73 ×5 days long: there aren't many pleasant factors that divide this length. If the year were only 360 days long, we'd be able to create fixed-length months. The Gregorian calendar's concession to the individibility of the year is 12 months of 28, 29, 30 or 31 days in length.

We have several systems of units available to us for representing a point in time.

- Seconds are the least common denominator. We can easily derive hours and minutes from seconds. There are 24 ×60 ×60 = 86,400 seconds in a day. (Astronomers will periodically add a leap second, so this is not absolutely true.) We can use seconds as a simple representation for a point in time. We can pick some epoch and represent any other point in time as the number of seconds after the epoch. This makes arithmetic very simple. However, it's hard to read; what month contains second number 1,190,805,137?

- Days are another common denominator in the calendar. There are seven days in a week, and (usually) 86,400 seconds in day, so those conversions are simple. We can pick some epoch and represent any other point in time as the number of days after the epoch. This also makes arithmetic very simple. However, it's hard to read; what month contains day number 732,945?
- Months are serious problem. If we work with the conventional date triple of year, month, and day, we can't compute intervals between dates very well at all. We can't locate a date 90 days in the future without a rather complex algorithm.

Local Time. We also to have acknowledge the subtlety of local time and the potential differences between local standard time and local daylight time (or summer time). Since the clock shifts, some time numbers (1:30 AM, for example) will appear to repeat, this can require the timezone hint to decode the time number.

The more general solution is to do all work in UTC. Input is accepted and displayed in the current local time for the convenience of users. This has the advantage of being timezone neutral, and it makes time values monotonically increasing with no confusing repeats of a given time of day during the hour in which the clock is shifted.

The `time` Solution. The `time` module uses two different representations for a point in time, and provides numerous functions to help us convert back and forth between the two representations.

- A `float` seconds number. This is the UNIX internal representation for time. (The number is seconds past an epoch; the epoch happens to January 1st, 1970.) In this representation, a duration between points in time is also a `float` number.
- A `struct_time` object. This object has nine attributes for representing a point in time as a Gregorian calendar date and time. We'll look at this structure in detail below. In this representation, there is no representation for the duration between points in time. You need to convert back and forth between `struct_time` and seconds representations.

The `datetime` Solution. The `datetime` module contain all of the objects and methods required to correctly handle the sometimes obscure rules for the Gregorian calendar. Additionally, it is possible to use date information in the `datetime` to usefully conver among the world's calendars. For details on conversions between calendar systems, see *Calendrical Calculations* [Dershowitz97].

The `datetime` module has just one representation for a point in time. It assigns an ordinal number to each day. The numbers are based on an epochal date, and algorithms to derive the year, month and day information for that ordinal day number. Similarly, this class provides algorithms to convert a calendar date to an ordinal day number. (Note: the Gregorian calendar was not defined until 1582, all dates before the official adoption are termed *proleptic*. Further, the calendar was adopted at different times in different countries.)

There are four classes in this module that help us handle dates and times in a uniform and correct manner. We'll skip the more advanced topic of the `datetime.tzinfo` class.

`datetime.time` An instance of `datetime.time` has four attributes: hour, minute, second and microsecond. Additionally, it can also carry an instance of `tzinfo` which describes the time zone for this time.

`datetime.date` An instance of `datetime.date` has three attributes: year, month and day. There are a number of methods for creating `datetime.date` objects, and converting `datetime.date` objectss to various other forms, like floating-point timestamps, 9-tuples for use with the `time` module, and ordinal day numbers.

`datetime.datetime` An instance of `datetime.datetime` combines `datetime.date` and `datetime.time`. There are a number of methods for creating `datetime.datetime` objects, and converting `datetime.datetime` s to various other forms, like floating-point timestamps, 9-tuples for use with the `time` module, and ordinal day numbers.

`datetime.timedelta` A `datetime.timedelta` is the duration between two dates, times or datetimes. It has a value in days, seconds and microseconds. These can be added to or subtracted from dates, times

or datetimes to compute new dates, times or datetimes.

34.2 Some Class Definitions

A time.struct_time object behaves like an object as well as a tuple. You can access the attributes of the structure by position as well as by name. Note that this class has no methods of it's own; you manipulate these objects using functions in the `time` module.

tm_year The year. This will be a full four digit year, e.g. 1998.

tm_mon The month. This will be in the range of 1 to 12.

tm_mday The day of the month. This will be in the range of 1 to the number of days in the given month.

tm_hour The hour of the day, in the range 0 to 23.

tm_min The minutes of the hour, in the range 0 to 59.

tm_sec The seconds of the minute, in the range 0 to 61 because leap seconds may be included. Not all platforms support leap seconds.

tm_wday The day of the week. This will be in the range of 0 to 6. 0 is Monday, 6 is Sunday.

tm_yday The day of the year, in the range 1 to 366.

tm_isdst Is the time in local daylight savings time. 0 means that this is standard time; 1 means daylight time. If you are creating this object, you can provide -1; the `time.mktime()` can then determine DST based on the date and time.

We'll focus on the datetime.datetime class, since it includes `datetime.date` and `datetime.time`. This class has the following attributes.

MINYEAR

MAXYEAR These two attributes bracket the time span for which datetime works correctly. This is year 1 to year 9999, which covers the forseeable future as well as a proleptic past the predates the invention of the Gregorian calendar in 1582.

min

max The earliest and laterst representable `datetime`s. In effect these are '`datetime(MINYEAR, 1, 1, tzinfo=None)`' and '`(MAXYEAR, 12, 31, 23, 59, 59, 999999, tzinfo=None)`'.

resolution The smallest differences between `datetime`s. This is typically equaly to '`timedelta(microseconds=1)`'.

year The year. This will be a full four digit year, e.g. 1998. It will always be between `MINYEAR` and `MAXYEAR`, inclusive.

month The month. This will be in the range 1 to 12.

day The day. This will be in the range 1 to the number of days in the given month.

hour The hour. This will be in the range 0 to 23.

minute The minute. This will be in the range 0 to 59.

second The second. This will be in the range 0 to 59.

microsecond The microsecond (millionths of a second). This will in the range 0 to 999,999. Some platforms don't have a system clock which is this accurate. However, the SQL standard imposes this resolution on most date time values.

To get fractions of a second, you'll compute '`second+microsecond/1000000.`'

tzinfo The `datetime.tzinfo` object that was provided to the initial `datetime.datetime` constructor. Otherwise it will be `None`.

34.3 Creating a Date-Time

There are two use cases for creating `date` , `time`, `struct_time` or `datetime` instances. In the simplest case, we're asking our operating system for the current date-time or the date-time associated with some resource or event. In the more complex case, we are asking a user for input (perhaps on an interactive GUI, a web form, or reading a file prepared by a person); we are parsing some user-supplied values to see if they are a valid date-time and using that value.

From The OS. We often get time from the OS when we want the current time, or we want one of the timestamps associated with a system resource like a file or directory. Here's a sampling of techniques for getting a date-time.

`time()`
: Returns the current moment in time as a `float` seconds number. See *File Handling Modules* for examples of getting file timestamps; these are always a `float` seconds value. We'll often need to convert this to a `struct_time` or `datetime` object so that we can provide formatted output for users.

  The functions `time.localtime()` or `time.gmtime()` will convert this value to a `struct_time`. The class methods `datetime.datetime.fromtimestamp()`, and `datetime.datetime.utcfromtimestamp()` will create a `datetime` object from this time value.

  Then, we can use `time.strftime()` or `time.asctime()` to format and display the time.

`ctime()`
: Returns a string representation of the current time. These values aren't terribly useful for further calculation, but they are handy, standardized timestamp strings.

`asctime()`
: Returns a string representation of the current time. These values aren't terribly useful for further calculation, but they are handy, standardized timestamp strings.

`localtime()`
: When evaluated with no argument value, this will create a `struct_time` object from the current time. Since we can't do arithmetic with these values, we often need to convert them to something more useful.

  This time is converted to localtime using your current locale settings.

`gmtime()`
: When evaluated with no argument value, this will create a `struct_time` object from the current time. Since we can't do arithmetic with these values, we often need to convert them to something more useful.

  The `time.mktime()` function will convert the `struct_time` to a `float` seconds time.

  We have to use the `datetime.datetime` constructor to create a datetime from a `struct_time`. This can be long-winded, it will look like '`datetime.date( ts.tm_year, ts.tm_month, ts.tm_day )`'.

`today()`

`now()`

`utcnow()`
: All of these are class methods of the `datetime` class; the create a `datetime` object. The `today()` function uses the simple '`time.time()`' notion of the current moment and returns local time. The

`now()` function may use a higher-precision time, but it will be local time. The `utcnow()` function uses high-precision time, and returns UTC time, not local time.

We can't directly get a `float` seconds number number from a datetime value. However, we can do arithmetic directly with `datetime` values, making the `float` seconds value superflous.

We can get the `struct_time` value from a `datetime`, using the `timetuple()` or `utctimetuple()` method functions of the datetime object.

Getting Time From A User. Human-readable time information generally has to be parsed from one or more string values. Human-readable time can include any of the endless variety of formats in common use. This will include some combination of years, days, months, hours, minutes and seconds, and timezone names.

There are two general approaches to parsing time. In most cases, it is simplest to use `datetime.strptime()` to parse a string and create a datetime object. In other cases, we can use `time.strptime()`. In the most extreme case, we have to either use the `re` module (*Complex Strings: the re Module*), or some other string manipulation, and then create the date-time object directly.

`strptime`(*string, [format]*)
: This function will use the given format to attempt to parse the input string. If the value doesn't match the format, it will raise a `ValueError` exception. If the format is not a complete datetime, then defaults are filled in. The default year is 1900, the default month is 1 the default day is 1. The default time values are all zero.

  We'll look at the format string under the `time.strftime()` function, below.

`strptime`(*string, [format]*)
: This function will use the given format to attempt to parse the input string. If the value doesn't match the format, it will raise a `ValueError` exception. If the format is not a complete time, then defaults are filled in. The default year is 1900, the default month is 1 the default day is 1. The default time values are all zero.

  We'll look at the format string under the `time.strftime()` function, below.

`struct_time`(*9-tuple*)
: Creates a `struct_time` from a 9-valued tuple: '`(year, month, day, hour, minute, second, day of week, day of year, dst-flag)`'. Generally, you can supply 0 for day of week and day of year. The dst flag is 0 for standard time, 1 for daylight (or summer) time, and -1 when the date itself will define if the time is standard or daylight.

  This constructor does no validation; it will tolerate invalid values. If we use the `time.mktime()` function to do a conversion, this may raise an `OverflowError` if the time value is invalid.

  Typically, you'll build this 9-tuple from user-supplied inputs. We could parse a string using the `re` module, or we could be collecting input from fields in a GUI or the values entered in a web-based form. Then you attempt a `time.mktime()` conversion to see if it is valid.

`datetime`(*year, month, day, [hour, minute, second, microsecond, timezone]*)
: Creates a `datetime` from individual parameter values. Note that the time fields are optional; if omitted the time value is 0:00:00, which is midnight.

  This constructor will not tolerate a bad date. It will raise a `ValueError` for an invalid date.

34.4 Date-Time Calculations and Manipulations

There are two common classes of date-time calculations:

- Duration or interval calculations in days (or seconds), where the month, week and year boundaries don't matter. The `time` representation as a single floating-point number of seconds works well for this. Also, the `datetime` provides a `datetime.timedelta` that works well for this.
- Calendar calculations where the month, week of month and day of week matter. The `time` representation as a 9-element `struct_time` structure works well for this. Generally, we use `datetime.datetime` for this.

Duration or interval calculations in days (or seconds). In this case, the month, week and year boundaries don't matter. For example, the number of hours, days or weeks between two dates doesn't depend on months or year boundaries. Similarly, calculating a date 90 days in the future or past doesn't depen on month or year considerations. Even the difference between two times is properly a date-time calculation so that we can allow for rollover past midnight.

We have two ways to do this.

- We can use `float` seconds information, as produced by the `time` module. When we're using this representation, a day is $24 \times 60 \times 60 = 86,400$ seconds, and a week is $7 \times 24 \times 60 \times 60 = 604,800$ seconds. For the following examples, `t1` and `t2` and `float` seconds times.

  '`(t2-t1)/3600`' is the number of hours between two times.

  '`(t2-t1)/86400`' is the days between two dates.

  '`t1+90*86400`' is the date 90 days in the future.

- We can also use `datetime` objects for this, since `datetime` objects correctly handle arithmetic operations. When we're using this representation, we'll also work with `datetime.timedelta` objects; these have days, seconds and microseconds attributes. For the following examples, `t1` and `t2` and `datetime` objects.

  In a relatively simple case, the hours between two datetimes is '`(t2-t1).seconds/3600`'. This works when we're sure that there sill be less than 24 hours between the two `datetimes`.

  In the more general case, we have a two-part calculation: First we get the `timedelta` between two `datetimes` with '`td = t2-t1`'.

  '`td= (t2-t1); seconds= td.days*86400+td.seconds`' is seconds between two dates.

  '`td= (t2-t1); secdonds= td.days*86400+td.seconds+td.microseconds/1000000.0`' is seconds down to the `datetime.resolution`.

  '`td= (t2-t1); seconds= td.days+td.seconds/86400.0`' is days between two dates.

Calendar calculations where the month, week of month and day of week matter. For example, the number of months between two dates rarely involves the day of the month. A date that is 3 months in the future, will land on the same day of the month, except in unusual cases where it would be the 30th of February. For these situations, highly problem-specific rules have to be applied; there's no general principle.

We have two ways to do this.

- We can use `struct_time` objects as produced by the `time` module. We can replace any `struct_time` fields, and possibly create an invalid date. We may need to use `time.mktime()` to validate the resulting `struct_time` object. In the following examples, `t1` is a `struct_time` object.

  Adding some `offset` in months, correctly allowing for year-end rollover, is done as follows.

```
monthSequence= (t1.tm_year*12 + t1.tm_mon-1) + offset
futureYear, futureMonth0 = divmod( monthSequence, 12 )
t1.tm_year= futureYear
t1.tm_month= futureMonth0 + 1
```

- We can also use `datetime` objects for this. In this case, we we'll use the `replace()` method to replace a value in a `datetime` with other values. In the following examples, `t1` is a `datetime` object.

  Adding some `offset` in months, correctly allowing for year-end rollover, is done as follows.

```
monthSequence= (t1.year*12 + t1.month-1) + offset
futureYear, futureMonth0 = divmod( monthSequence, 12 )
t1= t1.replace( year=futureYear, month=futureMonth0+1 )
```

The following methods return information about a given `datetime` object. In the following definitions, `dt` is a `datetime` object.

`date()`
: Return a new `date` object from the date fields of this `datetime` object.

`time()`
: Return a new `time` object from the time fields of this `datetime` object.

`replace`(*[year, month, day, hour, minute, second, microsecond]*)
: Return a new `datetime` object from the current `datetime` object after replacing any values provided by the keyword arguments.

`toordinal()`
: Return the ordinal day number for this `datetime`. This a unique day number.

`weekday()`
: Return the day of the week. Monday = 0, Sunday = 6.

`isoweekday()`
: Return the ISO day of the week. Monday = 1, Sunday = 7.

`isocalendar()`
: Return a tuple with (ISO year, ISO week, ISO week day).

34.5 Presenting a Date-Time

To format human-readable time, we have a number of functions in the `time` module, and methods of a `datetime` object. Here are the functions in the `time` module.

`strftime`(*format, time_struct*)
: Convert a `struct_time` to a string according to a format specification. The specification rules are provided below.

  This is an example of how to produce a timestamp with the fewest implicit assumptions.

```
time.strftime( "%x %X", time.localtime( time.time() ) )
```

  This line of code shows a standardized and portable way to produce a time stamp. The `time.time()` function produces the current time in UTC (Coordinated Universal Time). Time is represented as a floating point number of seconds after an epoch.

`asctime`(*time_struct*)
: Convert a `struct_time` to a string, e.g. 'Sat Jun 06 16:26:11 1998'. This is the same as a the format string `"%a %b %d %H:%M:%S %Y"`.

`ctime`(*seconds*)
: Convert a time in seconds since the Epoch to a string in local time. This is equivalent to '`asctime(localtime(seconds))`'.

A `datetime` object has the following methods for producting formatted output. In the following definitions, `dt` is a `datetime` object.

`isoformat`(*[separator]*)
: Return string representing this date in ISO 8601 standard format. The `separator` string is used between the date and the time; the default value is "T".

```
>>> d= datetime.datetime.now()
>>> d.isoformat()
'2009-11-08T09:34:17.945641'
```

`ctime`()
: Return string representing this date and time. This is equivalent to '`time.ctime(time.mktime( dt.timetuple()))`' for some `datetime` object, `dt`.

`strftime`(*format*)
: Return string representing this date and time, formatted using the given format string. This is equivalent to '`time.strftime( format, time.mktime( dt.timetuple() )`' for some `datetime` object, `dt`.

34.6 Formatting Symbols

The `time.strftime()` and `time.strptime()` functions use the following formatting symbols to convert between `time_struct` or `datetime.datetime` and strings.

Formatting symbols like `%c`, `%x` and `%X` produce standard formats for whole date-time stamps, dates or time. Other symbols format parts of the date or time value. The following examples show a particular date (Satuday, August 4th) formatted with each of the formatting strings.

Table 34.1: Time Formatting Symbols

"%a"	Locale's 3-letter abbreviated weekday name.	'Sat'
"%A"	Locale's full weekday name.	'Saturday'
"%b"	Locale's 3-letter abbreviated month name.	'Aug'
"%B"	Locale's full month name.	'August'
"%c"	Locale's appropriate full date and time representation.	'Saturday August 04 17:11:20 2001'
"%d"	Day of the month as a 2-digit decimal number.	'04'
"%H"	Hour (24-hour clock) as a 2-digit decimal number.	'17'
"%I"	Hour (12-hour clock) as a 2-digit decimal number.	'05'
"%j"	Day of the year as a 3-digit decimal number.	'216'
"%m"	Month as a 2-digit decimal number.	'08'
"%M"	Minute as a 2-digit decimal number.	'11'
"%p"	Locale's equivalent of either AM or PM.	'pm'
"%S"	Second as a 2-digit decimal number.	'20'
"%U"	Week number of the year (Sunday as the first day of the week) as a 2-digit decimal number. All days in a new year preceding the first Sunday are considered to be in week 0.	'30'
"%w"	Weekday as a decimal number, 0 = Sunday.	'6'
"%W"	Week number of the year (Monday as the first day of the week) as a 2-digit decimal number. All days in a new year preceding the first Monday are considered to be in week 0.	'31'
"%x"	Locale's appropriate date representation.	'Saturday August 04 2001'
"%X"	Locale's appropriate time representation.	'17:11:20'
"%y"	Year without century as a 2-digit decimal number.	'01'
"%Y"	Year with century as a decimal number.	'2001'
"%Z"	Time zone name (or '' if no time zone exists).	''
"%%"	A literal '%' character.	'%'

34.7 Time Exercises

1. **Return on Investment**. Return on investment (ROI) is often stated on an annual basis. If you buy and sell stock over shorter or longer periods of time, the ROI must be adjusted to be a full year's time period. The basic calculation is as follows:

   Given the sale date, purchase date, sale price, `sp`, and purchase price, `pp`.

   Compute the period the asset was held: use `time.mktime()` to create floating point time values for sale date, `s`, and purchase date, `p`. The weighting, `w`, is computed as

   ```
   w = (86400*365.2425) / ( s - p )
   ```

   Write a program to compute ROI for some fictitious stock holdings. Be sure to include stocks held both more than one year and less than one year. See *Stock Valuation* in *Classes* for some additional information on this kind of calculation.

2. **Surface Air Consumption Rate**. When doing SACR calculations (see *Surface Air Consumption Rate*, and *Dive Logging and Surface Air Consumption Rate*) we've treated the time rather casually. In the event of a night dive that begins before midnight and ends after midnight the next day, our quick and dirty time processing doesn't work correctly.

Revise your solution to use a more complete date-time stamp for the start and end time of the dive. Use the `time` module to parse those date-time stamps and compute the actual duration of the dive.

34.8 Additional `time` Module Features

Here are some additional functions in the `time` module.

`sleep(`*seconds*`)`
: Delay execution for a given number of seconds. The argument may be a floating point number for subsecond precision.

`accept2dyear(`*arg*`)`
: If non-zero, 2-digit years are accepted. 69-99 is treated as 1969 to 1999, 0 to 68 is treated as 2000 to 2068. This is 1 by default, unless the **PYTHONY2K** environment variable is set; then this variable will be zero.

`timezone`
: Difference in seconds between UTC and local time. Often a multiple of 3600 (all US timezones are in whole hours).

  For example, if your locale is US Eastern Time, this is 18000 (5 hours).

`altzone`
: Difference in seconds between UTC and local alternate time ("Daylight Savings Time"). Often a multiple of 3600 (US time zones are in whole hours).

  For example, if your locale was set to US Eastern Time, this would be 14400 (4 hours).

`daylight`
: Non-zero if the current locale uses daylight savings time. Zero if it does not.

`tzname`
: The name of the timezone.

CHAPTER

THIRTYFIVE

FILE HANDLING MODULES

There are a number of operations closely related to file processing. Deleting and renaming files are examples of operations that change the directory information that the operating system maintains to describe a file. Python provides numerous modules for these operating system operations.

We can't begin to cover all of the various ways in which Python supports file handling. However, we can identify the essential modules that may help you avoid reinventing the wheel. Further, these modules can provide you a view of the Pythonic way of working with data from files.

The following modules have features that are essential for supporting file processing. We'll cover selected features of each module that are directly relevant to file processing. We'll present these in the order you'd find them in the Python library documentation.

Chapter 11 – File and Directory Access. Chapter 11 of the Library reference covers many modules which are essential for reliable use of files and directories. We'll look closely at the following modules.

`os.path` This module has functions for numerous common pathname manipulations. Use these functions to split and join full directory path names. This is operating-system neutral, with a correct implementation for all operating systems.

One of the most obvious differences among operating systems is the way that files are named. In particular, the *path separator* can be either the POSIX standard '`/`', or the windows '\'. Rather than make each program aware of the operating system rules for path construction, Python provides the `os.path` module to make all of the common filename manipulations completely consistent.

OS-Specific Paths

Programmers are faced with a dilemma between writing a "simple" hack to strip paths or extensions from file names and using the `os.path` module. Some programmers argue that the `os.path` module is too much overhead for such a simple problem as removing the `.html` from a file name. Other programmers recognize that most hacks are a false economy: in the long run they do not save time, but rather lead to costly maintenance when the program is expanded or modified.

`fileinput` This module has functions which will iterate over lines from multiple input streams. This allows you to write a single, simple loop that processes lines from any number of input files.

`tempfile` This module has a class and functions to generate temporary files and temporary file names. This is the most secure way to generate a temporary file.

`glob` This module provides shell style pathname pattern expansion. Unix shells translate name patterns like `*.py` into a `list` of files. This is called *globbing*. The `glob` module implements this within Python, which allows this feature to work even in Windows where it isn't supported by the OS itself.

`fnmatch` This module provides UNIX shell style filename pattern matching. This implements the glob-style rules using '`*`', '`?`' and '`[]`'. '`*`' matches any number of characters, '`?`' matches any single character, '`[chars]`'. encloses a `list` of allowed characters, '`[!chars]`' encloses a `list` of disallowed characters.

`shutil` This module has usefule, high-level file operations, including copy, rename and remove. These are the kinds of things that the shell handles with simple commands like **cp** or **rm**. This module makes these features available to a Python program or script.

Chapter 12 – Data Persistence. There are several issues related to making objects persistent. We'll look at these modules in detail in *File Formats: CSV, Tab, XML, Logs and Others*.

`pickle` `shelve` The `pickle` and `shelve` modules are used to create persistent objects; objects that persist beyond the one-time execution of a Python program. The `pickle` module produces a serial text representation of any object, however complex; this can reconstitute an object from its text representation. The `shelve` module uses a `dbm` database to store and retrieve objects. The `shelve` module is not a complete object-oriented database, as it lacks any transaction management capabilities.

`sqlite3` This module provides access to the SQLite relational database. This database provides a significant subset of SQL language features, allowing us to build a relational database that's compatible with products like MySQL or Postgres.

Chapter 13 – Data Compression and Archiving. Data Compression is covered in Chapter 12 of the Library referece. We'll look closely at the following modules.

`tarfile` `zipfile` These modules helps you read and write archive files; files which are an archive of a complex directory structure. This includes GNU/Linux tape archive (`.tar`) files, compressed GZip tar files (`.tgz` files or `.tar.gz` files) sometimes called tarballs, and ZIP files.

`zlib` `gzip` `bz2` These modules are all variations on a common theme of reading and writing files which are *compressed* to remove redundant bytes of data. The `zlib` and `bz2` modules have a more sophisticated interface, allowing you to use compression selectively within a more complex application. The `gzip` module has a different (and simpler) interface that only applies only to complete files.

Chapter 14 – File Formats. These are modules for reading and writing files in a few of the amazing variety of file formats that are in common use. We'll focus on just a few.

`csv` The `csv` module helps you parse and create Comma-Separated Value (CSV) data files. This helps you exchange data with many desktop tools that produce or consume CSV files. We'll look at this in *Comma-Separated Values: The csv Module*.

Chapter 16 - Generic Operating System Services. The following modules contain basic features that are common to all operating systems

`os` Miscellaneous OS interfaces. This includes parameters of the current process, additional file object creation, manipulations of file descriptors, managing directories and files, managing subprocesses, and additional details about the current operating system.

`time` The `time` module provides basic functions for time and date processing. Additionally `datetime` handles details of the calendar more gracefully than `time` does. We'll cover both modules in detail in *Dates and Times: the time and datetime Modules*.

`logging` Often, you want a simple, standardized log for errors as well as debugging information. We'll look at logging in detail in *Log Files: The logging Module*.

Chapter 28 - Python Runtime Services. These modules described in Chapter 26 of the Library reference include some that are used for handling various kinds of files. We'll look closely as just one.

`sys` This module has several system-specific parameters and functions, including definitions of the three standard files that are available to every program.

35.1 The os.path Module

The os.path module contains more useful functions for managing path and directory names. A serious mistake is to use ordinary string functions with literal stringsfor the path separators. A Windows program using \ as the separator won't work anywhere else. A less serious mistake is to use os.pathsep instead of the routines in the os.path module.

The os.path module contains the following functions for completely portable path and filename manipulation.

basename(*path*)
Return the base filename, the second half of the result created by 'os.path.split(path)'.

dirname(*path*)
Return the directory name, the first half of the result created by 'os.path.split(path)'.

exists(*path*)
Return True if the pathname refers to an existing file or directory.

getatime(*path*)
Return the last access time of a file, reported by os.stat(). See the time module for functions to process the time value.

getmtime(*path*)
Return the last modification time of a file, reported by os.stat(). See the time module for functions to process the time value.

getsize(*path*)
Return the size of a file, in bytes, reported by os.stat().

isdir(*path*)
Return True if the pathname refers to an existing directory.

isfile(*path*)
Return True if the pathname refers to an existing regular file.

join(*string, ...*)
Join path components using the appropriate path separator.

split(*path*)
Split a path into two parts: the directory and the basename (the filename, without path separators, in that directory). The result '(s, t)' is such that 'os.path.join(s, t)' yields the original path.

splitdrive(*path*)
Split a pathname into a drive specification and the rest of the path. Useful on DOS/Windows/NT.

splitext(*path*)
Split a path into root and extension. The extension is everything starting at the last dot in the last component of the pathname; the root is everything before that. The result '(r, e)' is such that 'r+e' yields the original path.

The following example is typical of the manipulations done with os.path.

```
import sys, os.path
def process( oldName, newName ):
    Some Processing...

for oldFile in sys.argv[1:]:
    dir, fileext= os.path.split(oldFile)
    file, ext= os.path.splitext( fileext )
    if ext.upper() == '.RST':
```

```
newFile= os.path.join( dir, file ) + '.HTML'
print oldFile, '->', newFile
process( oldFile, newFile )
```

1. This program imports the `sys` and `os.path` modules.
2. The `process()` function does something interesting and useful to the input file. It is the real heart of the program.
3. The **for** statement sets the variable `oldFile` to each `string` (after the first) in the sequence `sys.argv`.
4. Each file name is split into the path name and the base name. The base name is further split to separate the file name from the extension. The `os.path` does this correctly for all operating systems, saving us having to write platform-specific code. For example, `splitext()` correctly handles the situation where a linux file has multiple '.'s in the file name.
5. The extension is tested to be '.RST'. A new file name is created from the path, base name and a new extension ('.HTML'). The old and new file names are printed and some processing, defined in the `process()`, uses the `oldFile` and `newFile` names.

35.2 The os Module

The `os` module contains an interface to many operating system-specific functions to manipulate processes, files, file descriptors, directories and other "low level" features of the OS. Programs that import and use `os` stand a better chance of being portable between different platforms. Portable programs must depend only on functions that are supported for all platforms (e.g., `unlink()` and `opendir()`), and perform all pathname manipulation with `os.path`.

The `os` module exports the following variables that characterize your operating system.

`name`
A name for the operating system, for example `'posix'`, `'nt'`, `'dos'`, `'os2'`, `'mac'`, or `'ce'`. Note that Mac OS X has an `os.name` of `'posix'`; but `sys.platform` is `'darwin'`. Windows XP has an `os.name` of `'nt'`.

`curdir`
The string which represents the current directory (`'.'` , generally).

`pardir`
The string which represents the parent directory (`'..'` , generally).

`sep`

`altsep`
The (or a most common) pathname separator (`'/'` or `':'` or `'\'`) and the alternate pathname separator (`None` or `'/'`). Most of the Python library routines will translate `'/'` to the correct value for the operating system (typically, `'\'` on Windows.)

It is best to always use `os.path` rather than these low-level constants.

`pathsep`
The component separator used in the OS environment variable **$PATH** (`':'` is the standard, `';'` is used for Windows).

`linesep`
The line separator in text files (`'n'` is the standard; `'rn'` is used for Windowss). This is already part of the `readlines()` function.

defpath
: The default search path for executables. The standard is `':/bin:/usr/bin'` or `'.;C:\bin'` for Windows.

The `os` module has a large number of functions. Many of these are not directly related to file manipulation. However, a few are commonly used to create and remove files and directories. Beyond these basic manipulations, the `shutil` module supports a variety of file copy operations.

chdir(*path*)
: Change the current working directory to the given path. This is the directory which the OS uses to transform a relative file name into an absolute file name.

getcwd()
: Returns the path to the current working directory. This is the directory which the OS use to transform a relative file name into an absolute file name.

listdir(*path*)
: Returns a `list` of all entries in the given directory.

mkdir(*path, [mode]*)
: Create the given directory. In GU/Linux, the mode can be given to specify the permissions; usually this is an octal number. If not provided, the default of 0777 is used, after being updated by the OS umask value.

rename(*source, destination*)
: Rename the source filename to the destination filename. There are a number of errors that can occur if the source file doesn't exist or the destination file already exists or if the two paths are on different devices. Each OS handles the situations slightly differently.

remove(*file*)
: Remove (also known as delete or unlink) the file. If you attempt to remove a directory, this will raise `OSError`. If the file is in use, the standard behavior is to remove the file when it is finally closed; Windows, however, will raise an exception.

rmdir(*path*)
: Remove (also known as delete or unlink) the directory. if you attempt to remove an ordinary file, this will raise `OSError`.

Here's a short example showing some of the functions in the `os` module.

```
>>> import os
>>> os.chdir("/Users/slott")
>>> os.getcwd()
'/Users/slott'
>>> os.listdir(os.getcwd())
['.bash_history', '.bash_profile',
'.bash_profile.pysave', '.DS_Store',
'.filezilla', '.fonts.cache-1', '.fop', '.idlerc', '.isql.history',
'.lesshst', '.login_readpw',
'.monitor', '.mozilla', '.sh_history', '.sqlite_history',
'.ssh', '.subversion', '.texlive2008', '.Trash', '.viminfo', '.wxPyDemo',
'.xxe', 'Applications', 'argo.user.properties', 'Burn Folder.fpbf',
'Desktop', 'Documents', 'Downloads', 'Library', 'Movies',
'Music', 'Pictures', 'Public', 'Sites']
```

35.3 The `fileinput` Module

The `fileinput` module interacts with `sys.argv`. The `fileinput.input()` function opens files based on all the values of '`sys.argv[1:]`'. It carefully skips '`sys.argv[0]`', which is the name of the Python script file. For each file, it reads all of the lines as text, allowing a program to read and process multiple files, like many standard Unix utilities.

The typical use case is:

```
import fileinput
for line in fileinput.input():
    process(line)
```

This iterates over the lines of all files listed in '`sys.argv[1:]`', with a default of `sys.stdin` if the `list` is empty. If a filename is `-` it is also replaced by `sys.stdin` at that position in the list of files. To specify an alternative list of filenames, pass it as the argument to `input()`. A single file name is also allowed in addition to a list of file names.

While processing input, several functions are available in the `fileinput` module:

`input()`
: Iterator over all lines from the cumulative collection of files.

`filename()`
: The filename of the line that has just been read.

`lineno()`
: The cumulative line number of the line that has just been read.

`filelineno()`
: The line number in the current file.

`isfirstline()`
: True if the line just read is the first line of its file.

`isstdin()`
: True if the line was read from `sys.stdin`.

`nextfile()`
: Close the current file so that the next iteration will read the first line from the next file (if any); lines not read from the file will not count towards the cumulative line count; the filename is not changed until after the first line of the next file has been read.

`close()`
: Closes the iterator.

All files are opened in text mode. If an I/O error occurs during opening or reading a file, the `IOError` exception is raised.

Example. We can use fileinput to write a Python version of the common Unix utility, **grep**. The **grep** utility searches a `list` of files for a given pattern.

For non-Unix users, the **grep** utility looks for the given regular expression in any number of files. The name grep is an acronym of Global Regular Expression Print. This is similar to the Windows command **find**.

greppy.py

```
#!/usr/bin/env python
import sys
import re
import fileinput
pattern= re.compile( sys.argv[1] )
for line in fileinput.input(sys.argv[2:]):
    if pattern.match( line ):
        print fileinput.filename(), fileinput.filelineno(), line
```

1. The `sys` module provides access to the command-line parameters. The `re` module provides the pattern matching. The `fileinput` module makes searching an arbitrary `list` of files simple. For more information on `re`, see *Complex Strings: the re Module*.

2. The first command line argument ('`sys.argv[0]`') is the name of the script, which this program ignores.

   The second command-line argument is the pattern that defines the target of the search.

   The remaining command-line arguments are given to `fileinput.input()` so that all the named files will be examined.

3. The pattern regular expression is matched against each individual input line.

   If `match()` returns `None`, the line did not match. If `match()` returns an object, the program prints the current file name, the current line number of the file and the actual input line that matched.

After we do a '`chmod +x greppy.py`', we can use this program as follows. Note that we have to provide quotes to prevent the shell from doing globbing on our pattern `string`.

```
$ greppy.py 'import.*random' *.py
demorandom.py 2 import random
dice.py 1 import random
functions.py 2 import random
```

Windows

Windows users will be disappointed because the GNU/Linux shell languages all handle file wild-card processing ("globbing") automatically. The shell uses the file-name patterns to create a complete list of file names that match the pattern to the application.
Windows does not supply lists of file names that match patterns to application programs. Therefore, we have to use the `glob` module to transform '`sys.argv[2:]`' from a pattern to lists of files.
Also, Windows users will have to use '`"*"`' around the pattern, where Unix and Mac OS shell users will typically use '`'*'`' . This is a difference between the Unix shell quoting rules and the Windows quoting rules.

35.4 The `glob` and `fnmatch` Modules

The `glob` module adds a necessary Unix shell capability to Windows programmers. The `glob` module includes the following function

`glob`(*wildcard*)
: Return a `list` of filenames that match the given wild-card pattern. The `fnmatch` module is used for the wild-card pattern matching.

A common use for `glob` is something like the following under Windows.

```
import glob, sys
for arg in sys.argv[1:]:
    for f in glob.glob(arg):
        process( f )
```

This makes Windows programs process command line arguments somewhat like Unix programs. Each argument is passed to `glob.glob()` to expand any patterns into a `list` of matching files. If the argument is not a wild-card pattern, glob simply returns a `list` containing this one file name.

The `fnmatch` module has the algorithm for actually matching a wild-card pattern against specific file names. This module implements the Unix shell wild-card rules. These are not the same as the more sophisticated regular expression rules. The module contains the following function:

`fnmatch`(*filename, pattern*)
: Return True if the filename matches the pattern.

The patterns use `*` to match any number of characters, `?` to match any single character. `[letters]` matches any of these letters, and `[!letters]` matches any letter that is not in the given set of letters.

```
>>> import fnmatch
>>> fnmatch.fnmatch('greppy.py','*.py')
True
>>> fnmatch.fnmatch('README','*.py')
False
```

35.5 The `tempfile` Module

One common problem is to open a unique temporary file to hold intermediate results. The `tempfile` module provides us a handy way to create temporary files that we can write to and read from.

The `tempfile` module creates a temporary file in the most secure and reliable manner. The `tempfile` module includes an internal function, `mkstemp()` which dioes the hard work of creating a unique temporary file.

`TemporaryFile`(*mode='w+b', bufsize=-1, suffix='', prefix='tmp', dir=None*)
: This function creates a file which is automatically deleted when it is closed. All of the parameters are optional. By default, the mode is '`'w+b'`': write with read in binary mode.

  The `bufsize` parameter has the same meaning as it does for the built-in `open()` function.

  The keyword parameters `suffix`, `prefix` and `dir` provide some structure to the name assigned to the file. The `suffix` should include the dot, for example '`suffix='.tmp'`'.

`NamedTemporaryFile`(*mode='w+b', bufsize=-1, suffix='', prefix='tmp', dir=None, delete=True*)
: This function is similar to `TemporaryFile()` ; it creates a file which can be automatically deleted when it is closed. The temporary file, however, is guaranteed to be visible on the file system while the file is open.

  The parameters are the same as a `tempfile.TemporaryFile()`.

  If the `delete` parameter is `False`, the file is not automatically deleted.

mkstemp(*suffix='', prefix='tmp', dir=None, text=False) -> (fd, name*)
This function does the essential job of creating a temporary file. It returns the interanl file descriptor as well as the name of the file. The file is not automatically deleted. If necessary, the file created by this function can be explicitly deleted with `os.remove()`.

```
import tempfile, os
fd, tempName = tempfile.mkstemp( '.d1' )
temp= open( tempName, 'w+' )
Some Processing...
```

This fragment will create a unique temporary file name with an extension of `.d1`. Since the name is guaranteed to be unique, this can be used without fear of damaging or overwriting any other file.

35.6 The `shutil` Module

The `shutil` module helps you automate copying files and directories. This saves the steps of opening, reading, writing and closing files when there is no actual processing, simply moving files.

copy(*source, destination*)
Copy data and mode bits; basically the unix command '`cp src dst`'. If `destination` is a directory, a file with the same base name as `source` is created. If `destination` is a full file name, this is the destination file.

copyfile(*source, destination*)
Copy data from `source` to `destination`. Both names must be files.

copytree(*source, destination*)
Recursively copy the entire directory tree rooted at `source` to `destination`. `destination` must not already exist. Errors are reported to standard output.

rmtree(*path*)
Recursively delete a directory tree rooted at `path`.

Note that removing a file is done with `os.remove()` (or `os.unlink()`).

This module allows us to build Python applications that are like shell scripts. There are a lot of advantages to writing Python programs rather than shell scripts to automate mundane tasks.

First, Python programs are easier to read than shell scripts. This is because the language did not evolve in way that emphasized tersness; the shell script languages use a minimum of punctuation, which make them hard to read.

Second, Python programs have a more sophisticated programming model, with class definitions, and numerous sophisticated data structures. The shell works with simple argument lists; it has to resort to running the **test** or **expr** programs to process `string` s or numbers.

Finally, Python programs have direct access to more of the operating system's features than the shell. Generally, many of the basic GNU/Linux API calls are provided via innumerable small programs. Rather than having the shell run a small program to make an API call, Python can simply make the API call.

35.7 The File Archive Modules: `tarfile` and `zipfile`

An archive file contains a complex, hierarchical file directory in a single sequential file. The archive file includes the original directory information as well as a the contents of all of the files in those directories. There are a number of archive file formats, Python directory supports two: tar and zip archives.

The tar (Tape Archive) format is widely used in the GNU/Linux world to distribute files. It is a POSIX standard, making it usable on a wide variety of operating systems. A tar file can also be compressed, often with the GZip utility, leading to `.tgz` or `.tar.gz` files which are compressed archives.

The Zip file format was invented by Phil Katz at PKWare as a way to archive a complex, hierarchical file directory into a compact sequential file. The Zip format is widely used but is not a POSIX standard. Zip file processing includes a choice of compression algorithms; the exact algorithm used is encoded in the header of the file, not in the name of file.

Creating a `TarFile` or a `ZipFile`. Since an archive file is still – essentially – a single file, it is opened with a variation on the `open()` function. Since an archive file contains directory and file contents, it has a number of methods above and beyond what a simple file has.

`open`(*name=None, mode='r', fileobj=None, bufsize=10240*)
: This module-level function opens the given tar file for processing. The *name* is a file name `string`; it is optional because the *fileobj* can be used instead. The *fileobject* is a conventional file object, which can be used instead of the *name*; it can be a standard file like `sys.stdin`. The *buffersize* is like the built-in `open()` function.

  The *mode* is similar to the built-in `open()` function; it has numerous additional characters to specify the compression algorithms, if any.

`ZipFile`(*file, mode="r", compression=ZIP_STORED, allowZip64=False*)
: This class constructor opens the given zip file for processing. The *name* is a file name `string`. The mode is similar to the built-in `open()` function. The *compression* is the compression code. It can be `zipfile.ZIP_STORED` or `zipfile.ZIP_DEFLATED`. A *compression* of `ZIP_STORED` uses no compression; a value of `ZIP_DEFLATED` uses the Zlib compression algorithms.

  The `allowZip64` option is used when creating new, empty Zip Files. If this is set to `True`, then this will create files with the ZIP64 extensions. If this is left at `False`, any time a ZIP64 extension would be required will raise an exception.

The open function can be used to read or write the archive file. It can be used to process a simple disk file, using the filename. Or, more importantly, it can be used to process a non-disk file: this includes tape devices and network sockets. In the non-disk case, a file object is given to `tarfile.open()`.

For tar files, the mode information is rather complex because we can do more than simply read, write and append. The mode `string` adresses three issues: the kind of opening (reading, writing, appending), the kind of access (block or stream) and the kind of compression.

For zip files, however, the mode is simply the kind of opening that is done.

Opening - Both zip and tar files. A zip or tar file can be opened in any of three modes.

'r' Open the file for reading only.

'w' Open the file for writing only.

'a' Open an existing file for appending.

Access - tar files only. A tar file can have either of two fundamentally different kinds of access. If a tar file is a disk file, which supports seek and tell operations, then you we access the tar file in block mode. If the tar file is a stream, network connection or a pipeline, which does not support seek or tell operations, then we must access the archive in stream mode.

':' Block mode. The tar file is an disk file, and seek and tell operations are supported. This is the assumed default, if neither ':' or '|' are specified.

'|' Stream mode. The tar file is a stream, socket or pipeline, and cannot respond to seek or tell operations. Note that you cannot append to a stream, so the `'a|'` combination is illegal.

This access distinction isn't meaningful for zip files.

Compression - tar files only. A tar file may be compressed with GZip or BZip2 algorithms, or it may be uncompressed. Generally, you only need to select compression when writing. It doesn't make sense to attempt to select compression when appending to an existing file, or when reading a file.

(nothing) The tar file will not be compressed.

'gz' The tar file will be compressed with GZip.

'bz2' The tar file will be compressed with BZip2.

This compression distinction isn't meaningful for zip files. Zip file compression is specified in the `zipfile.ZipFile` constructor.

Tar File Examples. The most common block modes for tar files are 'r', 'a', 'w:', 'w:gz', 'w:bz2'. Note that read and append modes cannot meaningfully provide compression information, since it's obvious from the file if it was compressed, and which algorithm was used.

For stream modes, however, the compression information *must* be provided. The modes include all six combinations: 'r|', 'r|gz', 'r|bz2', 'w|', 'w|gz', 'w|bz2'.

Directory Information. Each individual file in a tar archive is described with a `TarInfo` object. This has name, size, access mode, ownership and other OS information on the file. A number of methods will retrieve member information from an archive.

`getmember(`*name*`)`
: Reads through the archive index looking for the given member *name*. Returns a `TarInfo` object for the named member, or raises a `KeyError` exception.

`getmembers()`
: Returns a `list` of `TarInfo` objects for all of the members in the archive.

`next()`
: Returns a `TarInfo` object for the next member of the archive.

`getNames()`
: Returns a `list` of member names.

Each individual file in a zip archive is described with a `ZipInfo` object. This has name, size, access mode, ownership and other OS information on the file. A number of methods will retrieve member information from an archive.

`getinfo(`*name*`)`
: Locates information about the given member *name*. Returns a `ZipInfo` object for the named member, or raises a `KeyError` exception.

`infolost()`
: Returns a `list` of `ZipInfo` objects for all of the members in the archive.

`namelist()`
: Returns a `list` of member names.

Extracting Files From an Archive. If a tar archive is opened with 'r', then you can read the archive and extract files from it. The following methods will extract member files from an archive.

`extract(`*member, [path]*`)`
: The *member* can be either a `string` member name or a `TarInfo` for a member. This will extract the file's contents and reconstruct the original file. If *path* is given, this is the new location for the file.

`extractfile(`*member*`)`
: The *member* can be either a `string` member name or a `TarInfo` for a member. This will open a simple file for access to this member's contents. The member access file has only read-oriented methods, limited to `read()`, `readline()`, `readlines()`, `seek()`, `tell()`.

If a zip archive is opened with 'r', then you can read the archive and extract the contents of a file from it.

`read`(*member*)
: The *member* is a `string` member name. This will extract the member's contents, decompress them if necessary, and return the bytes that consitute the member.

Creating or Extending an Archive. If a tar archive is opened with 'w' or 'a', then you can add files to it. The following methods will add member files to an archive.

`add`(*name, [arcname, recursive=True]*)
: Adds the file with the given *name* to the current archive file. If *arcname* is provided, this is the name the file will have in the archive; this allows you to build an archive which doesn't reflect the source structure. Generally, directories are expanded; using '`recursive=False`' prevents expanding directories.

`addfile`(*tarinfo, fileobj*)
: Creates an entry in the archive. The description comes from the *tarinfo*, an instance of `TarInfo`, created with the `gettarinfo()` function. The *fileobj* is an open file, from which the content is read. Note that the `TarInfo.size` field can override the actual size of the file. For a given filename, `fn`, this might look like the following: '`tf.addfile( tf.gettarinfo(fn), open(fn,"r") )`'.

`close`()
: Closes the archive. For archives being written or appended, this adds the block of zeroes that defines the end of the file.

`gettarinfo`(*name, [arcname, fileobj]*)
: Creates a `TarInfo` object for a file based either on *name* , or the *fileobj*. If a *name* is given, this is a local filename. The *arcname* is the name that will be used in the archive, allowing you to modify local filesystem names. If the *fileobj* is given, this file is interrogated to gather required information.

If a zip archive is opened with 'w' or 'a', then you can add files to it.

`write`(*filename, [arcname, compress]*)
: The *filename* is a `string` file name. This will read the file, compress it, and write it to the archive. If the *arcname* is given, this will be the name in the archive; otherwise it will use the original *filename*. The *compress* parameter overrides the default compression specified when the `ZipFile` was created.

`writestr`(*arcname, bytes*)
: The *arcname* is a `string` file name or a `ZipInfo` object that will be used to create a new member in the archive. This will write the given bytes to the archive. The compression used is specified when the `ZipFile` is created.

A `tarfile` Example. Here's an example of a program to examine a tarfile, looking for documentation like `.html` files or `README` files. It will provide a list of `.html` files, and actually show the contents of the `README` files.

readtar.py

```
#!/usr/bin/env python
"""Scan a tarfile looking for *.html and a README."""
import tarfile
import fnmatch
archive= tarfile.open( "SQLAlchemy-0.3.5.tar.gz", "r" )
for mem in archive.getmembers():
    if fnmatch.fnmatch( mem.name, "*.html" ):
        print mem.name
    elif fnmatch.fnmatch( mem.name.upper(), "*README*" ):
        print mem.name
```

```
        docFile= archive.extractfile( mem )
        print docFile.read()
```

A `zipfile` Example. Here's an example of a program to create a zipfile based on the `.xml` files in a particular directory.

writezip.py

```
import zipfile, os, fnmatch
bookDistro= zipfile.ZipFile( 'book.zip', 'w', zipfile.ZIP_DEFLATED )
for nm in os.listdir('..'):
    if fnmatch.fnmatch(nm,'*.xml'):
        full= os.path.join( '..', nm )
        bookDistro.write( full )
bookDistro.close()
```

35.8 The `sys` Module

The `sys` module provides access to some objects used or maintained by the interpreter and to functions that interact strongly with the interpreter.

The `sys` module also provides the three standard files used by Python.

sys.stdin Standard input file object; used by `raw_input()` and `input()`. Also available via '`sys.stdin.read()`' and related methods of the file object.

sys.stdout Standard output file object; used by the **print** statement. Also available via '`sys.stdout.write()`' and related methods of the file object.

sys.stderr Standard error object; used for error messages, typically unhandled exceptions. Available via '`sys.stderr.write()`' and related methods of the file object.

A program can assign another file object to one of these global variables. When you change the file for these globals, this will redirect all of the interpreter's I/O.

Command-Line Arguments. One important object made available by this module is the variable `sys.argv`. This variable has the command line arguments used to run this script. For example, if we had a python script called portfolio.py, and executed it with the following command:

```
python portfolio.py -xvb display.csv
```

Then the `sys.argv` `list` would be `["portfolio.py", "-xvb", "display.csv"]`. Sophisticated argument processing is done with the `optparse` module.

A few other interesting objects in the `sys` module are the following variables.

sys.version The version of this interpreter as a `string`. For example, `'2.6.3 (r263:75184, Oct 2 2009, 07:56:03) n[GCC 4.0.1 (Apple Inc. build 5493)]'`

sys.version_info Version information as a `tuple`, for example: `(2, 6, 3, 'final', 0)`.

sys.hexversion Version information encoded as a single integer. Evaluating '`hex(sys.hexversion)`' yields `'0x20603f0'`. Each byte of the value is version information.

sys.copyright Copyright notice pertaining to this interpreter.

sys.platform Platform identifier, for example, `'darwin'`, `'win32'` or `'linux2'`.

sys.prefix File Path prefix used to find the Python library, for example `'/usr'`, `'/Library/Frameworks/Python.framework/Versions/2.5'` or `'c:\Python25'`.

35.9 Additional File-Processing Modules

There are several other chapters of the Python Library Reference that cover with even more file formats. We'll identify them briefly here.

Chapter 7 – Internet Data Handling. Reading and processing files of Internet data types is very common. Internet data types have formal definitions governed by the internet standards, called Requests for Comment (RFC's). The following modules are for handling Internet data structures. These modules and the related standards are beyond the scope of this book.

`email` Helps you handle email MIME attachments.

`mailcap` Mailcap file handling.

`mailbox` Read various mailbox formats.

`mhlib` Manipulate MH mailboxes from Python.

`mimetools` Tools for parsing MIME-style message bodies.

`mimetypes` Mapping of filename extensions to MIME types.

`MimeWriter` Generic MIME file writer.

`mimify` Mimification and unmimification of mail messages.

`multifile` Support for reading files which contain distinct parts, such as some MIME data.

`rfc822` Parse RFC 822 style mail headers.

`base64` Encode and decode files using the MIME base64 data.

`binhex` Encode and decode files in binhex4 format.

`binascii` Tools for converting between binary and various ASCII-encoded binary representations.

`quopri` Encode and decode files using the MIME quoted-printable encoding.

`uu` Encode and decode files in uuencode format.

Chapter 13 - Data Persistence. Many Python programs will also deal with Python objects that are exported from memory to external files or retrieved from files to memory. Since an external file is more persistent than the volatile working memory of a computer, this process makes an object persistent or retrieves a persistent object. One mechanism for creating a persistent object is called serialization, and is supported by several modules, which are beyond the scope of this book.

`pickle` Convert Python objects to streams of bytes and back.

`cPickle` Faster version of pickle, but not subclassable.

`copy_reg` Register pickle support functions.

`shelve` Python object persistence.

`marshal` Convert Python objects to streams of bytes and back (with different constraints).

More complex file structures can be processed using the standard modules available with Python. The widely-used DBM database manager is available, plus additional modules are available on the web to provide ODBC

access or to connect to a platform-specific database access routine. The following Python modules deal with these kinds of files. These modules are beyond the scope of this book.

anydbm Generic interface to DBM-style database modules.

whichdb Guess which DBM-style module created a given database.

dbm The standard database interface, based on the ndbm library.

gdbm GNU's reinterpretation of dbm.

dbhash DBM-style interface to the BSD database library.

bsddb Interface to Berkeley DB database library

dumbdbm Portable implementation of the simple DBM interface.

Additionally, Python provides a relational database module.

sqlite3 A very pleasant, easy-to-use relational database (RDBMS). This handles a wide variety of SQL statements.

35.10 File Module Exercises

1. **Source Lines of Code**. One measure of the complexity of an application is the count of the number of lines of source code. Often, this count discards comment lines. We'll write an application to read Python source files, discarding blank lines and lines beginning with `#`, and producing a count of source lines.

   We'll develop a function to process a single file. We'll use the `glob` module to locate all of the `*.py` files in a given directory.

   Develop a `fileLineCount( name )()` which opens a file with the given *name* and examines all of the lines of the file. Each line should have `strip()` applied to remove leading and trailing spaces. If the resulting line is of length zero, it was effectively blank, and can be skipped. If the resulting line begins with `#` the line is entirely a comment, and can be skipped. All remaining lines should be counted, and `fileLineCount()` returns this count.

   Develop a `directoryLineCount( path )()` function which uses the path with the `glob.glob()` to expand all matching file names. Each file name is processed with `fileLineCount( name )()` to get the number of non-comment source lines. Write this to a tab-delimited file; each line should have the form '`filenametlines`'.

   For a sample application, look in your Python distribution for `Lib/idelib/*.py`.

2. **Summarize a Tab-Delimited File**. The previous exercise produced a file where each line has the form '`filenametlines`'. Read this tab-delimited file, producing a nicer-looking report that has column titles, file and line counts, and a total line count at the end of the report.

3. **File Processing Pipeline**. The previous two exercises produced programs which can be part of a processing pipeline. The first exercise should p should produce it's output on `sys.stdout`. The second exercise should gather it's input from `sys.stdin`. Once this capability is in place, the pipeline can be invoked using a command like the following:

   ```
   $ python lineCounter.py | python lineSummary.py
   ```

CHAPTER

THIRTYSIX

FILE FORMATS: CSV, TAB, XML, LOGS AND OTHERS

We looked at general features of the file system in *Files*. In this chapter we'll look at Python techniques for handling files in a few of the innumeraable formats that are in common use. Most file formats are relatively easy to handle with Python techniques we've already seen. Comma-Separated Values (CSV) files, XML files and packed binary files, however, are a little more sophisticated.

This only the tip of the iceberg in the far larger problem called *persistence*. In addition to simple file system persistence, we also have the possibility of object persistence using an object database. In this case, the databse processing lies between our program and the file system on which the database resides. This area also includes object-relational mapping, where our program relies on a mapper; the mapper uses to database, and the database manages the file system. We can't explore the whole persistence problem in this chapter.

In this chapter we'll present a conceptual overview of the various approaches to reading and writing files in *Overview*. We'll look at reading and writing CSV files in *Comma-Separated Values: The csv Module*, tab-delimited files in *Tab Files: Nothing Special*. We'll look reading property files in *Property Files and Configuration (or .INI) Files: The ConfigParser Module*. We'll look at the subleties of processing legacy COBOL files in *Fixed Format Files, A COBOL Legacy: The codecs Module*. We'll cover the basics of reading XML files in *XML Files: The xml.etree and xml.sax Modules*.

Most programs need a way to write sophisticated, easy-to-control log files what contain status and debugging information. For simple one-page programs, the **print** statement is fine. As soon as we have multiple modules, where we need more sophisticated debugging, we find a need for the `logging` module. Of course, any program that requires careful auditing will benefit from the `logging` module. We'll look at creating standard logs in *Log Files: The logging Module*.

36.1 Overview

When we introduced the concept of file we mentioned that we could look at a file on two levels.

- A file is a sequence of bytes. This is the OS's view of views, as it is the lowest-common denominator.
- A file is a sequence of data objects, represented as sequences of bytes.

A *file format* is the processing rules required to translate between usable Python objects and sequences of bytes. People have invented innumerable distinct file formats. We'll look at some techniques which should cover most of the bases.

We'll look at three broad families of files: text, binary and pickled objects. Each has some advantages and processing complexities.

- Text files are designed so that a person can easily read and write them. We'll look at several common text file formats, including CSV, XML, Tab-delimited, property-format, and fixed position. Since text files are intended for human consumption, they are difficult to update in place.
- Binary files are designed to optimize processing speed or the overall size of the file. Most databases use very complex binary file formats for speed. A JPEG file, on the other hand, uses a binary format to minimize the size of the file. A binary-format file will typically place data at known offsets, making it possible to do direct access to any particular byte using the `seek()` method of a Python file object.
- Pickled Objects are produced by Python's `pickle` or `shelve` modules. There are several pickle protocols available, including text and binary alternatives. More importantly, a pickled file is not designed to be seen by people, nor have we spent any design effort optimizng performace or size. In a sense, a pickled object requires the least design effort.

36.2 Comma-Separated Values: The `csv` Module

Often, we have data that is in Comma-Separated Value (CSV) format. This used by many spreadsheets and is a widely-used standard for data files.

In *Reading a CSV File the Hard Way* we parsed CSV files using simple `string` manipulations. The `csv` module does a far better job at parsing and creating CSV files than the programming we showed in those examples.

About CSV Files. CSV files are text files organized around data that has rows and columns. This format is used to exchange data between spread-sheet programs or databases. A CSV file uses a number of punctuation rules to encode the data.

- Each row is delimited by a line-ending sequence of characters. This is usually the ASCII sequence '`rn`'. Since this may not be the default way to process text files on your platform, you have to open files using the "rb" and "wb" modes.
- Within a row, columns are delimited by a '`,`'. To handle the situation where a column's data contains a '`,`', the column data may be quoted; surrounded by '`"`' characters. If the column contains a '`"`', there are two common rules used. One CSV dialect uses an escape character, usually '`\"`'. The other dialect uses double '`""`'.

In the ideal case, a CSV file will have the same number of columns in each row, and the first row will be column titles. Almost as pleasant is a file without column titles, but with a known sequence of columns. In the more complex cases, the number of columns per row varies.

The `csv` Module. The CSV module provides you with readers or writers; these are objects which use an existing `file` object, created with the `file()` or `open()` function. A CSV reader will read a file, parsing the commas and quotes, delivering you the data elements of each row in a sequence or mapping. A CSV writer will create a file, adding the necessary commas and quotes to create a valid CSV file.

The following constructors within the `csv` module are used to create a `reader`, `DictReader`, `writer` or `DictWriter`.

`reader`(*csvfile*)
: Creates a `reader` object which can parse the given file, returning a sequence of values for each line of the file. The `csvfile` can be any iterable object.

  This can be used as follows.

```
rdr= csv.reader( open( "file.csv", "rb" ) )
for row in rdr:
    print row
```

`writer`(*csvfile*)
: Creates a `writer` object which can format a sequence of values and write them to a line of the file. The `csvfile` can be any object which supports a `write()` method.

  This can be used as follows.

```
target= open( "file.csv", "wb" )
wtr= csv.writer( target )
wtr.writerow( ["some","list","of","values"] )
target.close()
```

  It's very handy to use the **with** statement to assure that the file is properly closed.

```
with open( "file.csv", "wb" ) as target:
    wtr= csv.writer( target )
    wtr.writerow( ["some","list","of","values"] )
```

`DictReader`(*csvfile, [fieldnames]*)
: Creates a `DictReader` object which can parse the given file, returning a dictionary of values for each line of the file. The dictionary keys are typically the first line of the file. You can, optionally, provide the field names if they are not the first line of the file. The `csvfile` can be any iterable object.

`DictWriter`(*csvfile, [fieldnames]*)
: Creates a `DictWriter` object which can format a dictionary of values and write them to a line of the file. You must provide a sequence of field names which is used to format each individual dictionary entry. The `csvfile` can be any object which supports a `write()` method.

Reader Functions. The following functions within a `reader` (or `DictReader`) object will read and parse the CSV file.

Writer Functions. The following functions with a `writer` (or `DictWriter`) object will format and write a CSV file.

Basic CSV Reading Example.

The basic CSV reader processing treats each line of the file as data. This is typical for files which lack column titles, or files which have such a complex format that special parsing and analysis is required. In some cases, a file has a simple, regular format with a single row of column titles, which can be processed by a special reader we'll look at below.

We'll revise the `readquotes.py` program from *Reading a CSV File the Hard Way*. This will properly handle all of the quoting rules, eliminating a number of irritating problems with the example in the previous chapter.

readquotes2.py

```
import csv
qFile= file( "quotes.csv", "rb" )
csvReader= csv.reader( qFile )
for q in csvReader:
    try:
        stock, price, date, time, change, opPrc, dHi, dLo, vol = q
        print stock, float(price), date, time, change, vol
    except ValueError:
        pass
qFile.close()
```

1. We open our quotes file, `quotes.csv`, for reading, creating an object named `qFile`.

2. We create a `csv.reader` object which will parse this file for us, transforming each line into a sequence of individual column values.
3. We use a **for** statement to iterate through the sequence of lines in the file.
4. In the unlikely event of an invalid number for the price, we surround this with a **try** statement. The invalid number line will raise a `ValueError` exception, which is caught in the **except** clause and quietly ignored.
5. Each stock quote, `q`, is a sequence of column values. We use multiple assignment to assign each field to a relevant variable. We don't need to strip whitespace, split the string, or handle quotes; the reader already did this.
6. Since the price is a string, we use the `float()` function to convert this string to a proper numeric value for further processing.

Column Headers as Dictionary Keys In some cases, you have a simple, regular file with a single line of column titles. In this case, you can transform each line of the file into a dictionary. The key for each field is the column title. This can lead to programs which are more clear, and more flexible. The flexibility comes from not assuming a specific order to the columns.

We'll revise the `readportfolio.py` program from *Reading "Records"*. This will properly handle all of the quoting rules, eliminating a number of irritating problems with the example in the previous chapter. It will make use of the column titles in the file.

readportfolio2.py

```
import csv
quotes=open( "display.csv", "rb" )
csvReader= csv.DictReader( quotes )
invest= 0
current= 0
for data in csvReader:
    print data
    invest += float(data["Purchase Price"])*float(data["# Shares"])
    current += float(data["Price"])*float(data["# Shares"])
print invest, current, (current-invest)/invest
```

1. We open our portfolio file, `display.csv`, for reading, creating a file object named `quotes`.
2. We create a `csv.DictReader` object from our `quotes` file. This will read the first line of the file to get the column titles; each subsequent line will be parsed and transformed into a dictionary.
3. We initialize two counters, `invest` and `current` to zero. These will accumulate our initial investment and the current value of this portfolio.
4. We use a **for** statement to iterate through the lines in `quotes` file. Each line is parsed, and the column titles are used to create a dictionary, which is assigned to `data`.
5. Each stock quote, `q`, is a `string`. We use the `strip()` operation to remove excess whitespace characters; the `string` which is created then performs the `split()` method to separate the fields into a `list`. We assign this `list` to the variable `values`.
6. We perform some simple calculations on each `dict`. In this case, we convert the purchase price to a number, convert the number of shares to a number and multiply to determine how much we spent on this stock. We accumulate the sum of these products into `invest`.

   We also convert the current price to a number and multiply this by the number of shares to get the current value of this stock. We accumulate the sum of these products into `current`.

7. When the loop has terminated, we can write out the two numbers, and compute the percent change.

Writing CSV Files The most general case for writing CSV is shown in the following example. Assume we've got a list of objects, named `someList`. Further, let's assume that each object has three attributes: `this`, `that` and `aKey`.

```
import csv
myFile= open( " :replaceable:`result` ", "wb" )
wtr= csv.writer( myFile )
for someData in :replaceable:`someList` :
    aRow= [ someData.this, someData.that, someData.aKey, ]
    wtr.writerow( aRow )
myFile.close()
```

In this case, we assemble the list of values that becomes a row in the CSV file.

In some cases we can provide two methods to allow our classes to participate in CSV writing. We can define a `csvRow()` method as well as a `csvHeading()` method. These methods will provide the necessary tuples of heading or data to be written to the CSV file.

For example, let's look at the following class definition for a small database of sailboats. This class shows how the `csvRow()` and `csvHeading()` methods might look.

```
class Boat( object ):
    csvHeading= [ "name", "rig", "sails" ]
    def __init__( aBoat, name, rig, sails ):
        self.name= name
        self.rig= rig
        self.sails= sails
    def __str__( self ):
        return "%s (%s, %r)" % ( self.name, self.rig, self.sails )
    def csvRow( self ):
        return [ self.name, self.rig, self.sails ]
```

Including these methods in our class definitions simplifies the loop that writes the objects to a CSV file. Instead of building each row as a list, we can do the following: '`wtr.writerow( someData.csvRow() )`' .

Here's an example that leverages each object's internal dictionary (`__dict__`) to dump objects to a CSV file.

```
db= [
    Boat( "KaDiMa", "sloop", ( "main", "jib" ) ),
    Boat( "Glinda", "sloop", ( "main", "jib", "spinnaker" ) ),
    Boat( "Eillean Glas", "sloop", ( "main", "genoa" ) ),
    ]
test= file( "boats.csv", "wb" )
wtr= csv.DictWriter( test, Boat.csvHeading )
wtr.writerow( dict( zip( Boat.csvHeading, Boat.csvHeading ) ) )
for d in db:
    wtr.writerow( d.__dict__ )
test.close()
```

36.3 Tab Files: Nothing Special

Tab-delimited files are text files organized around data that has rows and columns. This format is used to exchange data between spread-sheet programs or databases. A tab-delimited file uses just rwo punctuation

rules to encode the data.

- Each row is delimited by an ordinary newline character. This is usually the standard '`n`'. If you are exchanging files across platforms, you may need to open files for reading using the "rU" mode to get universal newline handling.
- Within a row, columns are delimited by a single character, often '`t`'. The column punctuation character that is chosen is one that will never occur in the data. It is usually (but not always) an unprintable character like '`t`'.

In the ideal cases, a CSV file will have the same number of columns in each row, and the first row will be column titles. Almost as pleasant is a file without column titles, but with a known sequence of columns. In the more complex cases, the number of columns per row varies.

When we have a single, standard punctuation mark, we can simply use two operations in the `string` and `list` classes to process files. We use the `split()` method of a `string` to parse the rows. We use the `join()` method of a `list` to assemble the rows.

We don't actually need a separate module to handle tab-delimited files.

Reading. The most general case for reading Tab-delimited data is shown in the following example.

```
myFile= open( " :replaceable:`somefile` ", "rU" )
for aRow in myFile:
    print aRow.split('\t')
myFile.close()
```

Each row will be a `list` of column values.

Writing. The writing case is the inverse of the reading case. Essentially, we use a '`"t".join( someList )`' to create the tab-delimeted row. Here's our sailboat example, done as tab-delimited data.

```
test= file( "boats.tab", "w" )
test.write( "\t".join( Boat.csvHeading ) )
test.write( "\n" )
for d in db:
    test.write( "\t".join( map( str, d.csvRow() ) ) )
    test.write( "\n" )
test.close()
```

Note that some elements of our data objects aren't string values. In this case, the value for sails is a tuple, which needs to be converted to a proper string. The expression '`map(str, someList )`' applies the `str()` function to each element of the original list, creating a new list which will have all string values. See *Sequence Processing Functions: map(), filter() and reduce()*.

36.4 Property Files and Configuration (or `.INI`) Files: The `ConfigParser` Module

A property file, also known as a configuration (or `.INI`) file defines property or configuration values. It is usually just a collection of settings. The essential property-file format has a simple row-oriented format with only two values in each row. A configuration (or `.INI`) file organizes a simple list of properties into one or more named sections.

A property file uses a few punctuation rules to encode the data.

- Lines begining with '`#`' or '`;`' are ignored. In some dialects the comments are '`#`' and '`!`'.

- Each property setting is delimited by an ordinary newline character. This is usually the standard '`n`'. If you are exchanging files across platforms, you may need to open files for reading using the "rU" mode to get universal newline handling.
- Each property is a simple name and a value. The name is a string characters that does not use a separator character of '`:`' or '`=`'. The value is everything after the punctuation mark, with leading and trailing spaces removed. In some dialects space is also a separator character.

Some property file dialects allow a value to continue on to the next line. In this case, a line that ends with '\' (the cwo-character sequence '\' '`\n`') escapes the usual meaning of '`\n`'. Rather being the end of a line, '`\n`' is demoted to just another whitespace character.

A property file is an extension to the basic tab-delimited file. It has just two columns per line, and some space-stripping is done. However, it doesn't have a consistent separator, so it is slightly more complex to parse.

The extra feature introduced in a configuration file is named sections.

- A line beginning with '`[`', ending with '`]`', is the beginning of a section. The '`[]`'s surround the section name. All of the lines from here to the next section header are collected together.

Reading a Simple Property File. Here's an example of reading the simplest kind of property file. In this case, we'll turn the entire file into a dictionary. Python doesn't provide a module for doing this. The processing is a sequence string manipulations to parse the file.

```
propFile= file( r"C:\Java\jdk1.5.0_06\jre\lib\logging.properties", "rU" )
propDict= dict()
for propLine in propFile:
    propDef= propLine.strip()
    if len(propDef) == 0:
        continue
    if propDef[0] in ( '!', '#' ):
        continue
    punctuation= [ propDef.find(c) for c in ':= ' ] + [ len(propDef) ]
    found= min( [ pos for pos in punctuation if pos != -1 ] )
    name= propDef[:found].rstrip()
    value= propDef[found:].lstrip(":= ").rstrip()
    propDict[name]= value
propFile.close()
print propDict
print propDict['handlers']
```

The input line is subject to a number of processing steps.

1. First the leading and trailing whitespace is removed. If the line is empty, nothing more needs to be done.
2. If the line begins with '`!`' or '`#`' ('`;`' in some dialects) it is ignored.
3. We find the location of all relevant puncuation marks. In some dialects, space is not permitted. Note that we through the length of the line on the end to permit a single word to be a valid property name, with an implicit value of a zero-length string.
4. By discarding punction positions of -1, we are only processing the positions of punctuation marks which actually occur in the string. The smallest of these positions is the left-most punctuation mark.
5. The name is everything before the punctuation mark with whitespace remove.
6. The value is everything after the punctuaion mark. Any additional separators are removed, and any trailing whitespace is also removed.

Reading a Config File. The `ConfigParser` module has a number of classes for processing configuration files. You initialize a ConfigParse object with default values. The object can the read one or more a configuration files. You can then use methods to determine what sections were present and what options were defined in a given section.

```
import ConfigParser
cp= ConfigParser.RawConfigParser( )
cp.read( r"C:\Program Files\Mozilla Firefox\updater.ini" )
print cp.sections()
print cp.options('Strings')
print cp.get('Strings','info')
```

Eschewing Obfuscation. While a property file is rather simple, it is possible to simplify property files further. The essential property definition syntax is so close to Python's own syntax that some applications use a simple file of Python variable settings. In this case, the settings file would look like this.

settings.py

```
# Some Properties
TITLE = "The Title String"
INFO = """The information string.
Which uses Python's ordinary techniques
for long lines."""
```

This file can be introduced in your program with one statement: '`import settings`' . This statement will create module-level variables, `settings.TITLE` and `settings.INFO`.

36.5 Fixed Format Files, A COBOL Legacy: The `codecs` Module

Files that come from COBOL programs have three characteristic features:

- The file layout is defined positionally. There are no delimiters or separators on which to base file parsing. The file may not even have '`n`' characters at the end of each record.
- They're usually encoded in EBCDIC, not ASCII or Unicode.
- They may include packed decimal fields; these are numeric values represented with two decimal digits (or a decimal digit and a sign) in each byte of the field.

The first problem requires figuring the starting position and size of each field. In some cases, there are no gaps (or filler) between fields; in this case the sizes of each field are all that are required. Once we have the position and size, however, we can use a string slice operation to pick those characters out of a record. The code is simply '`aLine[start:start+size]`'.

We can tackle the second problem using the `codecs` module to decode the EBCDIC characters. The result of '`codecs.getdecoder('cp037')`' is a function that you can use as an EBCDIC decoder.

The third problem requires that our program know the data type as well as the position and offset of each field. If we know the data type, then we can do EBCDIC conversion or packed decimal conversion as appropriate. This is a much more subtle algorithm, since we have two strategies for converting the data fields. See *Strategy* for some reasons why we'd do it this way.

In order to mirror COBOL's largely decimal world-view, we will need to use the `decimal` module for all numbers and airthmetic.

We note that the presence of packed decimal data changes the file from text to binary. We'll begin with techniques for handling a text file with a fixed layout. However, since this often slides over to binary file processing, we'll move on to that topic, also.

Reading an All-Text File. If we ignore the EBCDIC and packed decimal problems, we can easily process a fixed-layout file. The way to do this is to define a handy structure that defines our record layout. We can use this structure to parse each record, transforming the record from a string into a dictionary that we can use for further processing.

In this example, we also use a generator function, `yieldRecords()`, to break the file into individual records. We separate this functionality out so that our processing loop is a simple **for** statement, as it is with other kinds of files. In principle, this generator function can also check the length of `recBytes` before it yields it. If the block of data isn't the expected size, the file was damaged and an exception should be raised.

```
layout = [
    ( 'field1', 0, 12 ),
    ( 'field2', 12, 4 ),
    ( 'anotherField', 16, 20 ),
    ( 'lastField', 36, 8 ),
]
reclen= 44
def yieldRecords( aFile, recSize ):
    recBytes= aFile.read(recSize)
    while recBytes:
        yield recBytes
        recBytes= aFile.read(recSize)
cobolFile= file( 'my.cobol.file', 'rb' )
for recBytes in yieldRecords(cobolFile, reclen):
    record = dict()
    for name, start, size in layout:
        record[name]= recBytes[start:start+len]
```

Reading Mixed Data Types. If we have to tackle the complete EBCDIC and packed decimal problem, we have to use a slightly more sophisticated structure for our file layout definition. First, we need some data conversion functions, then we can use those functions as part of picking apart a record.

We may need several conversion functions, depending on the kind of data that's present in our file. Minimally, we'll need the following two functions.

`display`(*bytes*)
: This function is used to get character data. In COBOL, this is called display data. It will be in EBCDIC if our files originated on a mainframe.

```
def display( bytes ):
    return bytes
```

`packed`(*bytes*)
: This function is used to get packed decimal data. In COBOL, this is called '`COMP-3`' data. In our example, we have not dealt with the insert of the decimal point prior to the creation of a `decimal.Decimal` object.

```
import codecs
display = codecs.getdecoder('cp037')
def packed( bytes ):
    n= [ '' ]
    for b in bytes[:-1]:
        hi, lo = divmod( ord(b), 16 )
```

```
            n.append( str(hi) )
            n.append( str(lo) )
        digit, sign = divmod( ord(bytes[-1]), 16 )
        n.append( str(digit) )
        if sign in (0x0b, 0x0d ):
            n[0]= '-'
        else:
            n[0]= '+'
        return n
```

Given these two functions, we can expand our handy record layout structure.

```
layout = [
    ( 'field1', 0, 12, display ),
    ( 'field2', 12, 4, packed ),
    ( 'anotherField', 16, 20, display ),
    ( 'lastField', 36, 8, packed ),
]
reclen= 44
```

This changes our record decoding to the following.

```
cobolFile= file( 'my.cobol.file', 'rb' )
for recBytes in yieldRecords(cobolFile, reclen):
    record = dict()
    for name, start, size, convert in layout:
        record[name]= convert( recBytes[start:start+len] )
```

This example underscores some of the key values of Python. Simple things can be kept simple. The layout structure, which describes the data, is both easy to read, and written in Python itself. The evolution of this example shows how adding a sophisticated feature can be done simply and cleanly.

At some point, our record layout will have to evolve from a simple tuple to a proper class definition. We'll need to take this evolutionary step when we want to convert packed decimal numbers into values that we can use for further processing.

36.6 XML Files: The `xml.etree` and `xml.sax` Modules

XML files are text files, intended for human consumption, that mix markup with content. The markup uses a number of relatively simple rules. Additionally, there are structural requirements that assure that an XML file has a minimal level of validity. There are additional rules (either a Document Type Defintion, DTD, or an XML Schema Definition, XSD) that provide additional structural rules.

There are several XML parsers available with Python.

`xml.expat` We'll ignore this parser, not for any particularly good reason.

`xml.sax` We'll look at the SAX parser because it provides us a way to break gigantic XML files into more manageable chunks.

`xml.dom` This is a document object model (DOM) for XML.

`xml.minidom` This is a stripped-down implementation of the XML document object model, along with a parser to build the document objects from XML.

`xml.pulldom` This module uses SAX to create a document objects from a portion of a larger XML document.

xml.etree This is a more useful DOM-oriented parser that allows sophisticated XPATH-like searching through the resulting document objects.

xml.sax Parsing. The Standard API for XML (SAX) parser is described as an event parser. The parser recognizes different elements of an XML document and invokes methods in a handler which you provide. Your handler will be given pieces of the document, and can do appropriate processing with those pieces.

For most XML processing, your program will have the following outline: This parser will then use your `ContentHandler` as it parses.

1. Define a subclass of `xml.sax.ContentHandler`. The methods of this class will do your unique processing will happen.
2. Request the module to create an instance of an `xml.sax.Parser`.
3. Create an instance of your handler class. Provide this to the parser you created.
4. Set any features or options in the parser.
5. Invoke the parser on your document (or incoming stream of data from a network socket).

Here's a short example that shows the essentials of building a simple XML parser with the `xml.sax` module. This example defines a simple `ContentHandler` that prints the tags as well as counting the occurances of the '`<informaltable>`' tag.

```
import xml.sax
class DumpDetails( xml.sax.ContentHandler ):
    def __init__( self ):
        self.depth= 0
        self.tableCount= 0
    def startElement( self, aName, someAttrs ):
        print self.depth*' ' + aName
        self.depth += 1
        if aName == 'informaltable':
            self.tableCount += 1
    def endElement( self, aName ):
        self.depth -= 1
    def characters( self, content ):
        pass # ignore the actual data

p= xml.sax.make_parser()
myHandler= DumpDetails()
p.setContentHandler( myHandler )
p.parse( "../p5-projects.xml" )
print myHandler.tableCount, "tables"
```

Since the parsing is event-driven, your handler must accumulate any context required to determine where the individual tags occur. In some content models (like XHTML and DocBook) there are two levels of markup: structural and semantic. The structural markup includes books, parts, chapters, sections, lists and the like. The semantic markup is sometimes called "inline" markup, and it includes tags to identify function names, class names, exception names, variable names, and the like. When processing this kind of document, you're application must determine the which tag is which.

A `ContentHandler` Subclass. The heart of a SAX parser is the subclass of `ContentHandler` that you define in your application. There are a number of methods which you may want to override. Minimally, you'll override the `startElement()` and `characters()` methods. There are other methods of this class described in section 20.10.1 of the *Python Library Reference*.

`setDocumentLocator(`*locator*`)`
The parser will call this method to provide an `xml.sax.Locator` object. This object has the XML

document ID information, plus line and column information. The locator will be updated within the parser, so it should only be used within these handler methods.

`startDocument()`
: The parser will call this method at the start of the document. It can be used for initialization and resetting any context information.

`endDocument()`
: This method is paired with the `startDocument()` method; it is called once by the parser at the end of the document.

`startElement`(*name, attrs*)
: The parser calls this method with each tag that is found, in non-namespace mode. The `name` is the string with the tag name.

  The `attrs` parameter is an `xml.sax.Attributes` object. This object is reused by the parser; your handler cannot save this object.

  The `xml.sax.Attributes` object behaves somewhat like a mapping. It doesn't support the '`[]`' operator for getting values, but does support `get()`, `has_key()`, `items()`, `keys()`, and `values()` methods.

`endElement`(*name*)
: The parser calls this method with each tag that is found, in non-namespace mode. The `name` is the string with the tag name.

`startElementNS`(*name, qname, attrs*)
: The parser calls this method with each tag that is found, in namespace mode. You set namesace mode by using the parser's '`p.setFeature( xml.sax.handler.feature_namespaces, True )`'. The `name` is a tuple with the URI for the namespace and the tag name. The `qname` is the fully qualified text name.

  The `attrs` is described above under `ContentHandler.startElementNS()`.

`endElementNS`(*name, qname*)
: The parser calls this method with each tag that is found, in namespace mode. The `name` is a tuple with the URI for the namespace and the tag name. The `qname` is the fully qualified text name.

`characters`(*content*)
: The parser uses this method to provide character data to the `ContentHandler`. The parser may provide character data in a single chunk, or it may provide the characters in several chunks.

`ignorableWhitespace`(*whitespace*)
: The parser will use this method to provide ignorable whitespace to the `ContentHandler`. This is whitespace between tags, usually line breaks and indentation. The parser may provide whitespace in a single chunk, or it may provide the characters in several chunks.

`processingInstructions`(*target, data*)
: The parser will provide all '`<? target data ?>`' processing instructions to this method. Note that the initial '`<?xml version="1.0" encoding="UTF-8"?>`' is not reported.

`xml.etree` **Parsing**. The Document Object Model (DOM) parser creates a document object model from your XML document. The parser transforms the text of an XML document into a DOM object. Once your program has the DOM object, you can examine that object.

Here's a short example that shows the essentials of building a simple XML parser with the `xml.etree` module. This example locates all instances of the '`<informaltable>`' tag in the XML document and prints parts of this tag's content.

```
#!/usr/bin/env python
from xml.etree import ElementTree
```

```
dom1 = ElementTree.parse("../PythonBook-2.5/p5-projects.xml")
for t in dom1.getiterator("informaltable"):
    print t.attrib
    for row in t.find('thead').getiterator('tr'):
        print "head row"
        for header_col in row.getiterator('th'):
            print header_col.text
    for row in t.find('tbody').getiterator('tr'):
        for body_col in row.getiterator('td'):
            print body_col.text
```

The DOM Object Model. The heart of a DOM parser is the DOM class hierarchy.

There is a widely-used XML Document Object Model definition. This standard applies to both Java programs as well as Python. The `xml.dom` package provides definitions which meet this standard.

The standard doesn't address how XML is parsed to create this structure. Consequently, the `xml.dom` package has no official parser. You could, for example, use a SAX parser to produce a DOM structure. Your handler would create objects from the classes defined in `xml.dom`.

The `xml.dom.minidom` package is an implementation of the DOM standard, which is slightly simplified. This implementation of the standard is extended to include a parser. The essential class definitions, however, come from `xml.dom`.

The standard element hierarchy is rather complex. There's an overview of the DOM model in *The DOM Class Hierarchy*.

The ElementTree Document Object Model. When using `xml.etree` your program will work with a number of `xml.etree.ElementTree` objects. We'll look at a few essential classes of the DOM. There are other classes in this model, described in section 20.13 of the *Python Library Reference*. We'll focus on the most commonly-used features of this class.

class `ElementTree()`

`parse`(*source*)
: Generally, ElementTree processing starts with parsing an XML document. The source can either be a filename or an object that contains XML text.

  The result of parsing is an object that fits the ElementTree interface, and has a number of methods for examining the structure of the document.

`getroot()`
: Return the root Element of the document.

`find`(*match*)
: Return the first child element matching `match`. This is a handy shortcut for '`self.getroot().find(match)`'. See `Element.find()`.

`findall`(*match*)
: Locate all child elements matching `match`. This is a handy shortcut for '`self.getroot().findall(match)`'. See `Element.findall()`.

  Returns an iterable yielding all matching elements in document order.

`findtext`(*condition, [default=None]*)
: Locate the first child element matching `match`. This is a handy shortcut for '`self.getroot().findtext(match)`'. See `Element.findtext()`.

`getiterator`(*[tag=None]*)
: Creates a tree iterator with the current element as the root. The iterator iterates over this element

and all elements below it, in document (depth first) order. If tag is not None or '*', only elements whose tag equals tag are returned from the iterator.

See `Element.getiterator()`.

class `Element()`

The ElementTree is a collection of individual Elements. Each Element is either an Element, a Comment, or a Processing Instruction. Generall, Comments and Processing Instructions behave like Elements.

`tag`
The tag for this element in the XML stucture.

`text`
Generally, this is the text found between the element tags.

`tail`
This holds the text found after an element's end tag and before the next tag. Often this is simply the whitespace between tags.

`attrib`
A mutable mapping containing the element's attributes.

`get`(*name, [default=None]*)
Fetch the value of an attribute.

`items()`
Return all attributes in a list as (name, value) tuples.

`keys()`
Return a list of all attribute names.

`find`(*match*)
Return the first child element matching `match`. The `match` may be a simple tag name or and XPath expression. Returns an `Element` instance or `None`.

`findall`(*match*)
Locate all child elements matching `match`. The `match` may be a simple tag name or and XPath expression.

Returns an iterable yielding all matching elements in document order.

`findtext`(*condition, [default=None]*)
Locate the first child element matching `match`. The `match` may be a simple tag name or and XPath expression. Returns the text value of the first matching element. If the element is empty, the text will be a zero-length string. Return `default` if no element was found.

`getiterator`(*[tag=None]*)
Creates a tree iterator with the current element as the root. The iterator iterates over this element and all elements below it, in document (depth first) order. If tag is not None or '*', only elements whose tag equals tag are returned from the iterator.

`getchildren()`
Iterate through all children. The elements are returned in document order.

When using `Element.find()`, `Element.findall()` and `Element.findtext()`, a simple XPATH-like syntax can be used.

Match queries can have the form '`"tag/tag/tag"`' to specify a specific grant-parent-parent-child nesting of tags. Additionally, "*" can be used as a wildcard.

For example, here's a query that looks for a specific nesting of tags.

```
from xml.etree import ElementTree
dom1 = ElementTree.parse("../PythonBook-2.5/p5-projects.xml")
for t in dom1.findall("chapter/section/informaltable"):
    print t
```

Note that full XPATH syntax is accepted, but most of it is ignored.

36.7 Log Files: The `logging` Module

Most programs need a way to write sophisticated, easy-to-control log files what contain status and debugging information. Any program that requires careful auditing will benefit from using the `logging` module to create an easy-to-read permanent log. Also, when we have programs with multiple modules, and need more sophisticated debugging, we'll find a need for the `logging` module.

There are several closely related concepts that define a log.

1. Your program will have a hierarchical tree of `Logger`s. Each `Logger` is used to do two things. It creates `LogRecord` object with your messages about errors, or debugging information. It provides these `LogRecord`s to `Handler`s.

   Generally, each major component will have it's own logger. The various loggers can have separate filter levels so that debugging or warning messages can be selectively enabled or disabled.

2. Your program will have a small number of `Handler`s, which are given `LogRecord`s. A `Handler` can ignore the records, write them to a file or insert them into a database.

   It's common to have a handler which creates a very detailed log in a persistent file, and a second handler that simply reports errors and exceptions to the system's stderr file.

3. Each `Handler` can make use of a `Formatter` to provide a nice, readable version of each `LogRecord` message.

4. Also, you can build sophisticated `Filter`s if you need to handle complex situations.

The default configuration gives you a single `Logger` , named '`""`', which uses a `StreamHandler` configured to write to standard error file, stderr.

Advantages. While the logging module can appear complex, it gives us a number of distinct advatages.

- **Multiple Loggers**. We can easily create a large number of separate loggers. This helps us to manage large, complex programs. Each component of the program can have it's own, indepenent logger.

  We can configure the collection of loggers centrally, however, supporting sophisticated auditing and debugging which is independent of each individual component.

  Also, all the loggers can feed a single, common log file.

  Each logger can also have a severity level filter. This allows us to selectively enable debugging or disable warnings on a logger-by-logger basis.

- **Hierarchy of Loggers**. Each `Logger` instance has a name, which is a '`.`'-separated string of names. For example, '`'myapp.stock'`', '`'myapp.portfolio'`'.

  This forms a natural hierarchy of `Logger`s. Each child inherits the configuration from its parent, which simplifies configuration.

  If, for example, we have a program which does stock portfolio analysis, we might have a component which does stock prices and another component which does overall portfolio calculations. Each component, then, could have a separate `Logger` which uses component name. Both of these `Logger`s are children of the '`""`' `Logger` ; the configuration for the top-most `Logger` would apply to both children.

Some components define their own Loggers. For example SQLAlchemy, has a set of Loggers with ''sqlalchemy'' as the first part of their name. You can configure all of them by using that top-level name. For specific debugging, you might alter the configuration of just one Logger, for example, ''sqlalchemy.orm.sync''.

- **Multiple Handlers**. Each Logger can feed a number of Handlers. This allows you to assure that a single important log messages can go to multiple destinations. A common setup is to have two Handlers for log messages: a FileHandler which records everything, and a StreamHandler which writes only severe error messages to stderr.

  For some kinds of applications, you may also want to add the SysLogHandler (in conjunction with a Filter) to send some messages to the operating system-maintained system log as well as the application's internal log.

  Another example is using the SMTPHandler to send selected log messages via email as well as to the application's log and stderr.

- **Level Numbers and Filters**. Each LogRecord includes a message level number, and a destination Logger name (as well as the text of the message and arguments with values to insert into the message). There are a number of predefined level numbers which are used for filtering. Additionally, a Filter object can be created to filter by destination Logger name, or any other criteria.

  The predefined levels are CRITICAL, ERROR, WARNING, INFO, and DEBUG. These are coded with numeric values from 50 to 10.

  Critical messages usually indicate a complete failure of the application, they are often the last message sent before it stops running; error messages indicate problems which are not fatal, but preclude the creation of usable results; warnings are questions or notes about the results being produced. The information messages are the standard messages to describe successful processing, and debug messages provide additional details.

  By default, all Loggers will show only messages which have a level number greater than or equal to WARNING, which is generally 30. When enabling debugging, we rarely want to debug an entire application. Instead, we usually enable debugging on specific modules. We do this by changing the level of a specific Logger.

  You can create additional level numbers or change the level numbers. Programmers familiar with Java, for example, might want to change the levels to SEVERE, WARNING, INFO, CONFIG, FINE, FINER, FINEST, using level numbers from 70 through 10.

Module-Level Functions. The following module-level functions will get a Logger that can be used for logging. Additionally, there are functions can also be used to create Handlers, Filters and Formatters that can be used to configure a Logger.

getLogger(*name*)
: Returns a Logger with the given name. The name is a '.'-separated string of names (e.g., '"x.y.z"') If the Logger already exists, it is returned. If the Logger did not exist, it is created and returned.

addLevelName(*level, name*)
: Defines (or redefines) a level number, proving a name that will be displayed for the given level number Generally, you will parallel these definitions with your own constants. For example, 'CONFIG=20; logging.addLevelName(CONFIG,"CONFIG")'

basicConfig(...)
: Configures the logging system. By default this creates a StreamHandler directed to stderr, and a default Formatter. Also, by default, all Loggers show only WARNING or higher messages. There are a number of keyword parameters that can be given to basicConfig().

  Parameters

- *filename* – This keyword provides the filename used to create a `FileHandler` instead of a `StreamHandler`. The log will be written to the given file.
- *filemode* – If a filename is given, this is the mode to open the file. By default, a file is opened with '`'a'`', appending the log file.
- *format* – This is the format string for the `Handler` that is created. A `Formatter` object has a `format()` method which expects a dictionary of values; the format string uses '`"%(key)s"`' conversion specifications. See *String Formatting with Dictionaries* for more information. The dictionary provided to a `Formatter` is the `LogRecord` , which has a number of fields that can be interpolated into a log string.
- *datefmt* – The date/time format to use for the asctime attribute of a `LogRecord`. This is a format string based on the time package `time.strftime()` function. See *Dates and Times: the time and datetime Modules* for more information on this format string.
- *level* – This is the default message level for all loggers. The default is `WARNING`, 30. Messages with a lower level (i.e., INFO and DEBUG) are not show.
- *stream* – This is a stream that will be used to initialize a `StreamHandler` instead of a `FileHandler`. This is incompatible with `filename`. If both `filename` and `stream` are provided, stream is ignored.

Typically, you'll use this in the following form: '`logging.basicConfig( level=logging.INFO )`'.

`fileConfig`(*file*)
Configures the logging system. This will read a configuration file, which defines the loggers, handlers and formatters that will be built initially. Once the loggers are built by the configuration, then the `logging.getLogger()` function will return one of these pre-built loggers.

`shutdown()`
Finishes logging by flushing all buffers and closing all handlers, which generally closes any internally created files and streams. An application must do this last to assure that all log messages are properly recorded in the log.

Logger Method Functions. The following functions are used to create a `LogRecord` in a `Logger`; a `LogRecord` is then processed by the `Handler`s associated with the `Logger`.

Many of these functions have essentially the same signature. They accept the text for a message as the first argument. This message can have string conversion specifications, which are filled in from the various arguments. In effect, the logger does '`message % ( args )`' for you.

You can provide a number of argument values, or you can provide a single argument which is a dictionary. This gives us two principle methods for producing log messages.

- '`log.info( "message %s, %d", "some string", 2 )`'
- '`log.info( "message %(part1)s, %(anotherpart)d", "part1" : "some string", "anotherpart": 2 )`'

These functions also have an optional argument, `exc_info` , which can have either of two values. You can provide the keyword argument '`exc_info= sys.exc_info()`'. As an alternative, you can provide '`exc_info=True`', in which case the logging module will call `sys.exc_info()` for you.

`debug`(*message, args, ...*)
Creates a `LogRecord` with level `DEBUG`, then processes this `LogRecord` on this `Logger`. The `message` is the message text; the `args` are the arguments which are provided to the formatting operator, '`%`'.

`info`(*message, args, ...*)
Creates a `LogRecord` with level `INFO` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary.

`warning`(*message, args, ...*)
Creates a `LogRecord` with level `WARNING` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary.

`error`(*message, args, ...*)
Creates a `LogRecord` with level `ERROR` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary.

`critical`(*message, args, ...*)
Creates a `LogRecord` with level `CRITICAL` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary.

`log`(*level, message, args, ...*)
Creates a `LogRecord` with the given `lvl` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary. The exc_info keyword argument can provide exception information.

`exception`(*message, args, ...*)
Creates a `LogRecord` with level `ERROR` on this logger. The positional arguments fill in the message; a single positional argument can be a dictionary.

Exception info is added to the logging message, as if the keyword parameter '`exc_info=True`'. This method should only be called from an exception handler.

`isEnabledFor`(*level*)
Returns `True` if this `Logger` will handle messages of this level or higher. This can be handy to prevent creating really complex debugging output that would only get ignored by the logger. This is rarely needed, and is used in the following structure:

```
if log.isEnabledFor(logging.DEBUG):
    log.debug( "some complex message" )
```

The following method functions are used to configure a `Logger`. Generally, you'll configure Loggers using the module level `basicConfig()` and `fileConfig()` functions. However, in some specialized circumstances (like unit testing), you may want finer control without the overhead of a configuration file.

`propagte`
When set to `True`, all the parents of a given `Logger` must also handle the message. This assures consistency for audit purposes.

When `False`, the parents will not handle the message. A `False` value might be used for keeping debugging messages separate from other messages. By default this is a `True` value.

`setLevel`(*level*)
Sets the level for this `Logger` ; messages less severe are ignored. Messages of this severity or higher are handled. The special value of `logging.NOTSET` indicates that this `Logger` inherits the setting from the parent. The root logger has a default value of `logging.WARNING`.

`getEffectiveLevel()`
ets the level for this `Logger`. If this `Logger` has a setting of `logging.NOTSET` (the default for all `Loggers`) then it inherits the level from its parent.

`addFilter`(*filter*)
Adds the given `Filter` object to this `Logger`.

`removeFilter`(*filter*)
Removes the given `Filter` object from this `Logger`.

`addHandler`(*handler*)
Adds the given `Handler` object to this `Logger`.

`removeHandler`(*handler*)
Removes the given `Handler` object from this `Logger`.

There are also some functions which would be used if you were creating your own subclass of `Logger` for more specialized logging purposes. These methods include `log.filter()`, `log.handle()` and `log.findCaller()`.

Using a Logger. Generally, there are a number of ways of using a `Logger`. In a module that is part of a larger application, we will get an instance of a `Logger`, and trust that it was configured correctly by the overall application. In the top-level application we may both configure and use a `Logger`.

This example shows a simple module file which uses a Logger.

logmodule.py

```
import logging, sys

logger= logging.getLogger(__name__)

def someFunc( a, b ):
    logger.debug( "someFunc( %d, %d )", a, b )
    try:
        return 2*int(a) + int(b)
    except ValueError, e:
        logger.warning( "ValueError in someFunc( %r, %r )", a, b, exc_info=True )

def mainFunc( *args ):
    logger.info( "Starting mainFunc" )
    z= someFunc( args[0], args[1] )
    print z
    logger.info( "Ending mainFunc" )

if __name__ == "__main__":
    logging.fileConfig( "logmodule_log.ini" )
    mainFunc( sys.argv[1:] )
    logging.shutdown()
```

1. We import the `logging` module and the `sys` module.
2. We ask the logging module to create a `Logger` with the given name. We use the Python assigned '`__name__`' name. This work well for all imported library modules and packages.

   We do this through a factory function to assure that the logger is configured correctly. The logging module actually keeps a pool of `Logger`s, and will assure that there is only one instance of each named `Logger`.
3. This function has a debugging message and a warning message. This is typical of most function definitions. Ordinarily, the debug message will not show up in the log; we can only see it if we provide a configuration which sets the log level to `DEBUG` for the root logger or the `logmodule` `Logger`.
4. This function has a pair of informational messages. This is typical of "main" functions which drive an overall application program. Applications which have several logical steps might have informational messages for each step. Since informational messages are lower level than warnings, these don't show up by default; however, the main program that uses this module will often set the overall level to '`logging.INFO`' to enable informational messages.

36.8 File Format Exercises

1. **Create An Office Suite Result**. Back in *Iteration Exercises* we used the **for** statement to produce tabular displays of data in a number of exercises. This included "How Much Effort to Produce Software?", "Wind Chill Table", "Celsius to Fahrenheit Conversion Tables" and "Dive Planning Table". Update one of these programs to produce a CSV file. If you have a desktop office suite, be sure to load the CSV file into a spreadsheet program to be sure it looks correct.

2. **Proper File Parsing**. Back in *File Module Exercises* we built a quick and dirty CSV parser. Fix these programs to use the CSV module properly.

3. **Configuration Processing**. In *Stock Valuation*, we looked at a program which processed blocks of stock. One of the specific programs was an analysis report which showed the value of the portfolio on a given date at a given price. We make this program more flexible by having it read a configuration file with the current date and stock prices.

4. **Office Suite Extraction**. Most office suite software can save files in XML format as well as their own proprietary format. The XML is complex, but you can examine it in pieces using Python programs. It helps to work with highly structured data, like an XML version of a spreadsheet. For example, your spreadsheet may use tags like '`<Table>`', '`<Row>`' and '`<Cell>`' to organize the content of the spreadsheet.

   First, write a simple program to show the top-level elements of the document. It often helps to show the text within those elements so that you can correlate the XML structure with the original document contents.

   Once you can display the top-level elements, you can focus on the elements that have meaningful data. For example, if you are parsing spreadsheet XML, you can assembled the values of all of the '`<Cell>`'s in a '`<Row>`' into a proper row of data, perhaps using a simple Python `list`.

36.9 The DOM Class Hierarchy

This is some supplemental information on the `xml.dom` and `xml.minidom` object models for XML documents.

class `Node()`

The `Node` class is the superclass for all of the various DOM classes. It defines a number of attributes and methods which are common to all of the various subclasses. This class should be thought of as abstract: it is not used directly; it exists to provide common features to all of the subclasses.

Here are the attributes which are common to all of the various kinds of `Node` objects.

`nodeType`

This is an integer code that discriminates among the subclasses of `Node`. There are a number of helpful symbolic constants which are class variables in xml.dom.Node. These constants define the various types of Nodes.

`ELEMENT_NODE`, `ATTRIBUTE_NODE`, `TEXT_NODE`, `CDATA_SECTION_NODE`, `ENTITY_NODE`, `PROCESSING_INSTRUCTION_NODE`, `COMMENT_NODE`, `DOCUMENT_NODE`, `DOCUMENT_TYPE_NODE`, `NOTATION_NODE`.

`attributes`

This is a map-like collection of attributes. It is an instance of `xml.dom.NamedNodeMap` . It has method functions including `get()` , `getNamedItem()` , `getNamedItemNS()` , `has_key()` , `item()` , `items()` , `itemsNS()` , `keys()` , `keysNS()` , `length()` , `removeNamedItem()` , `removeNamedItemNS()` , `setNamedItem()` , `setNamedItemNS()` , `values()` . The `item()` and `length()` methods are defined by the standard and provided for Java compatibility.

localName
If there is a namespace, then this is the portion of the name after the colon. If there is no namespace, this is the entire tag name.

prefix
If there is a namespace, then this is the portion of the name before the colon. If there is no namespace, this is an empty string.

namespaceURI
If there is a namespace, this is the URI for that namespace. If there is no namespace, this is None .

parentNode
This is the parent of this Node. The Document Node will have None for this attribute, since it is the parent of all Nodes in the document. For all other Node s, this is the context in which the Node appears.

previousSibling
Sibling Nodes share a common parent. This attribute of a Node is the Node which precedes it within a parent. If this is the first Node under a parent, the previousSibling will be None . Often, the preceeding Node will be a Text containing whitespace.

nextSibling
Sibling Nodes share a common parent. This attribute of a Node is the Node which follows it within a parent. If this is the last Node under a parent, the nextSibling will be None . Often, the following Node will be Text containing whitespace.

childNodes
The list of child Nodes under this Node. Generally, this will be a xml.dom.NodeList instance, not a simple Python list . A NodeList behaves like a list , but has two extra methods: item() and length() , which are defined by the standard and provided for Java compatibility.

firstChild
The first Node in the childNodes list, similar to childNodes[:1]. It will be None if the childNodes list is also empty.

lastChild
The last Node in the childNodes list, similar to childNodes[-1:]. It will be None if the childNodes list is also empty.

Here are some attributes which are overridden in each subclass of Node. They have slightly different meanings for each node type.

nodeName
A string with the "name" for this Node. For an Element, this will be the same as the tagName attribute. In some cases, it will be None.

nodeValue
A string with the "value" for this Node. For an Text , this will be the same as the data attribute. In some cases, it will be None.

Here are some methods of a Node.

hasAttributes()
This function returns True if there are attributes associated with this Node.

hasChildNodes()
This function returns True if there child Node s associated with this Node.

class Document(*Node***)**
This is the top-level document, the object returned by the parser. It is a subclass of Node, so it inherits

all of those attributes and methods. The Document class adds some attributes and method functions to the Node definition.

documentElement
: This attribute refers to the top-most Element in the XML document. A Document may contain DocumentType, ProcessingInstruction and Comment Nodes, also. This attribute saves you having to dig through the childNodes list for the top Element.

getElementsByTagName(*tagName*)
: This function returns a NodeList with each Element in this Document that has the given tag name.

getElementsByTagNameNS(*namespaceURI, tagName*)
: This function returns a NodeList with each Element in this Document that has the given namespace URI and local tag name.

class Element(*Node*)
: This is a specific element within an XML document. An element is surrounded by XML tags. In '<para id="sample">Text</para>', the tag is '<para>', which provides the name for the Element. Most Elements will have Attributes as well as children. The Element class adds some attributes and method functions to the Node definition.

tagName
: The full name for the tag. If there is a namesace, this will be the complete name, including colons. This will also be in nodeValue .

getElementsByTagName(*tagName*)
: This function returns a NodeList with each Element in this Element that has the given tag name.

getElementsByTagNameNS(*namespaceURI, tagName*)
: This function returns a NodeList with each Element in this Element that has the given namespace URI and local tag name.

hasAttribute(*name*)
: Returns True if this Element has an Attr with the given name.

hasAttribute(*namespaceURI, localName*)
: Returns True if this Element has an Attr with the given name based on the namespace and localName.

getAttribute(*name*)
: Returns the string value of the Attr with the given name. If the attribute doesn't exist, this will return a zero-length string.

getAttributeNS(*namespaceURI, localName*)
: Returns the string value of the Attr with the given name. If the attribute doesn't exist, this will return a zero-length string.

getAttributeNode(*name*)
: Returns the Attr with the given name. If the named attribute doesn't exist, this method returns None.

getAttributeNodeNS(*namespaceURI, localName*)
: Returns the Attr with the given name. If the named attribute doesn't exist, this method returns None.

class Attr(*Node*)
: This is an attribute, within an Element. In '<para id="sample">Text</para>', the tag is '<para>'; this tag has an attribute of 'id' with a value of 'sample' . Generally, the nodeType, nodeName and nodeValue attributes are all that are used. The Attr class adds some attributes to the Node definition.

name
The full name of the attribute, which may include colons. The `Node` class defines `localName`, `prefix` and `namespaceURI` which may be necessary for correctly processing this attribute.

value
The string value of the attribute. Also note that `nodeValue` will have a copy of the attribute's value.

class `Text`(*Node*)

class `CDATASection`(*Node*)
This is the text within an element. In '`<para id="sample">Text</para>`' , the text is '`Text`' . Note that end of line characters and indentation also count as `Text` nodes. Further, the parser may break up a large piece of text into a number of smaller `Text` nodes. The `Text` class adds an attribute to the `Node` definition.

data
The text. Also note that `nodeValue` will have a copy of the text.

class `Comment`(*Node*)
This is the text within a comment. The '`<!--`' and '`-->`' characters are not included. The `Comment` class adds an attribute to the `Node` definition.

data
The comment. Also note that `nodeValue` will have a copy of the comment.

CHAPTER

THIRTYSEVEN

PROGRAMS: STANDING ALONE

This chapter will cover additional aspects of creating some common kinds of programs in Python. We'll survey the landscape in *Kinds of Programs*. Then, in *Command-Line Programs: Servers and Batch Processing* will the essence of program startup using command-line options and operands.

We'll look at parsing command line options in *The optparse Module*

Interactive graphical user interfaces are beyond the scope of this book. There are several handy graphic frameworks, including Tkinter and GTK that help you write graphical user interfaces. However, GUI programs are still started from the command line, so this section is relevant for those kinds of programs.

37.1 Kinds of Programs

There are many design patterns for our application programs. We can identify a number of features that distinguish different kinds of programs. We can create a taxonomy of program designs based on how we interact with them. We could also create a taxonomy based on the program's internal structure or its interfaces.

We can look at programs from a number of perspectives.

- The type of interaction (command-line vs. user interaction).
- The type of architecture (stand-alone vs. client-server).

Interaction. We can look at a program based on the type of interaction that it has with a person. There's a spectrum of interaction.

- A program can be started from the command line and have no further interaction with the human user. We can call these batch programs because they usually process a batch of individual transactions. We can also call them command-line programs because our only interaction is at the command prompt.

  A large number of data analysis and business-oriented programs work with batches of data. Additionally, we can describe servers as being similar to batch programs. This is a focus for this chapter.

- A program can have very sophisticated interaction with the human user. The interaction may be character-oriented, or it can have a graphic user interface (GUI) and be started by double-clicking an icon. What's important is that the user drives the processing, not the batch of data. T

  ypically, a program with rich user interaction will be a client of one or more services. These programs are beyond the scope of this book.

Architecture. We can also look at programs based on their architecture and how they interact with other programs.

- Some programs stand alone. They have an executable file which starts things off, and perhaps includes some libraries. Often a client program is a stand-alone program that runs on someone's desktop. This is a focus for this chapter.
- Some programs plug into a larger and more sophisticated frameworks. The framework is, essentially, a closely related collection of libraries and interfaces. Most web applications are built as programs which plug into a web server framework. There is a tremendous amount of very common processing in handling a web transaction. There's little value in repeating this programming, so we inherit it from the framework.

We can distinguish programs in how they interact with other programs to create a larger system. We'll turn to this topic in the next chapter, *Architecture: Clients, Servers, the Internet and the World Wide Web*.

- Some programs are clients. They rely on services provided by other programs. The service it relies on might be a web server or a database server. In some cases, the client program has rich user interaction and stands alone.
- Some programs are servers. They provide services to other programs. The service might be domain names, time, or any of a myriad of services that are an essential part of Linux and other operating systems.
- Some programs are both servers and clients of other services. Most servers have no interaction; they are command-line programs which are clients of other command-line programs. A web server typically has plug in web applications which use database servers. A database server may make use of other services within an operating system.

Combinations. Many programs combine interaction with being a client of one or more services. Most browsers, like Firefox, are clients for servers which use a number of protocols, including HTTP, POP3, IMAP4, FTP, NNTP, and GOPHER. Besides being a client, a browser also provides graphics, handling numerous MIME data types for different kinds of images and sounds.

These interactive, client-side applications are the most complex, and we can't begin to cover them in this book.

In order to cover the basics, we have to focus on command-line programs which stand-alone. From there we can branch out to command-line clients and servers.

Command-Line Subspecies. Stand-alone, command-line programs have a number of design patterns.

- Some programs are *filters* that read an input file, perform an extract or a calculation and produce a result file that is derived from the input.
- Programs can be *compilers*, performing extremely complex transformations from one or more input files to create an output file.
- Programs can be *interpreters*, where statements in a language are read and processed. Some programs, like the Unix **awk** utility, combine filtering and interpreting.

Some command-line programs are *clients* of services. An FTP client program may display contents of an FTP server, accepting user commands through a graphical user interface (GUI) and transferring files. An IMAP client program may extract data from mailboxes on a mail server, accepting commands and transferring or displaying mail messages.

Yet another common type of command-line program is a *server*. These programs are also interactive, but they interact with client programs, not a person through a GUI. An HTTP server like Apache, for instance, responds to browser requests for web pages. An FTP server responds to FTP client requests for file transfers. A server is often a kind of batch program, since it is left running for indefinite periods of time, and has no user interaction.

37.2 Command-Line Programs: Servers and Batch Processing

Many programs have minimal or no user interaction at all. They are run from a command-line prompt, perform their function, and exit gracefully. They may produce a log; they may return a status code to the operating system to indicate success for failure.

Almost all of the core Linux utilities (**cp**, **rm**, **mv**, **ln**, **ls**, **df**, **du**, etc.) are programs that decode command-line parameters, perform their processing function and return a status code. Except for a few explicitly interactive programs like editors (**ex**, **vi**, **emacs**, etc.), almost all of the core elements of Linux are filter-like programs.

There are two critical features that make a command-line program well-behaved. First, the program should accept the arguments in a standard manner. Second the program should generally limit output to the standard output and standard error files created by the environment. When any other files are written it must be by user request and possibly require interactive confirmation.

Command Line Options and Operands. The standard handling of command-line arguments is given as 13 rules for UNIX commands, as shown in the *intro* section of UNIX man pages. These rules describe the program names (rules 1-2), simple options (rules 3-5), options that take argument values (rules 6-8) and operands (rules 9 and 10) for the program.

1. The program name should be between two and nine characters. This is consistent with most file systems where the program name is a file name. In the Python environment, the program file must have extension of `.py`.
2. The program name should include only lower-case letters and digits. The objective is to keep names relatively simple and easy to type correctly. Mixed-case names and names with punctuation marks can introduce difficulties in typing the program name correctly. To be used as a module or package in Python, the program file name *must* be just letters, digits and '`_`'s.
3. Option names should be one character long. This is difficult to achieve in complex programs. Often, options have two forms: a single-character short form and a multi-character long form.
4. Single-character options are preceded by '`-`'. Multiple-character options are preceeded by '`--`'. All options have a flag that indicates that this is an option, not an operand. Single character options, again, are easier to type, but may be hard to remember for new users of a program.
5. Options with no arguments may be grouped after a single '`-`'. This allows a series of one-character options to be given in a simple cluster, for example '`ls -ldai bin`' clusters the '`-l`', '`-d`', '`-a`' and '`-i`' options.
6. Options that accept an argument value use a space separator. The option arguments are not run together with the option. Without this rule, it might be difficult to tell a option cluster from an option with arguments. Without this rule '`cut -ds`' could be an argument value of `s` for the '`-d`' option, or it could be clustered single-character options '`-d`' and '`-s`'.
7. Option-arguments cannot be optional. If an option requires an argument value, presence of the option means that an argument value will follow. If the presence of an option is somehow different from supplying a value for the option, two separate options must be used to specify these various conditions.
8. Groups of option-arguments following an option must be a single word; either separated by commas or quoted. For example: '`-d "9,10,56"`'. A space would mean another option or the beginning of the operands.
9. All options must precede any operands on the command line. This basic principle assures a simple, easy to understand uniformity to command processing.
10. The string '`--`' may be used to indicate the end of the options. This is particularly important when any of the operands begin with '`-`' and might be mistaken for an option.

11. The order of the options relative to one another should not matter. Generally, a program should absorb all of the options to set up the processing.
12. The relative order of the operands (or arguments) may be significant. This depends on what the operands mean and what the program does.
13. The operand '`-`' preceded and followed by a space character should only be used to mean standard input. This may be passed as an operand, to indicate that the standard input file is processed at this time. For example, '`cat file1 - file2`' will process file1, standard input and file2.

These rules are handled by the `optparse` module.

Output Control. A well-behaved program does not overwrite data without an explicit demand from a user. Programs with a assumed, default or implicit output file are a pronblem waiting to happen. A well-behaved program should work as follows.

1. A well-designed program has an obvious responsibility that is usually tied to creating one specific output. This can be a report, or a file of some kind. In a few cases we may find it necessary to optimize processing so that a number of unrelated outputs are produced by a single program.
2. The best policy for this output is to write the resulting file to standard output (`sys.stdout`, which is the destination for the **print** statement.) Any logging, status or error reporting is sent to `sys.stderr`. If this is done, then simple shell redirection operators can be used to collect this output in an obvious way.

   ```
   python someProgram.py >this_file_gets_written
   ```

3. In some cases, there are actually two outputs: details and a useful summary. In this case, the summary should go to standard output, and an option specifies the destination of the details.

   ```
   python aProgram.py -o details.dat >summary.txt
   ```

Program Startup and the Operating System Interface. The essential operating system interface to our programs is relatively simple. The operating system will start the Python program, providing it with the three standard files (stdin, stdout, stderr; see *File Semantics* for more information), and the command line arguments. In response, Python provides a status code back to the operating system. Generally a status code of 0 means things worked perfectly. Status codes which are non-zero indicate some kind of problem or failure.

When we run something like

```
python casinosim.py -g craps
```

The operating system command processor (the Linux **shell** or Windows **cmd.exe**) breaks this line into a command (**python**) and a sequence of argument values. The shell finds the relevant executable file by searching it's **PATH**, and then starts the program, providing the rest of the command line as argument values to that program.

A Python program will see the command line arguments assigned to `sys.argv` as `["casinosim.py", "-g", "craps"]`. `argv[0]` is the name of the main module, the script Python is currently running.

When the script in `casinosym.py` finishes running, the Python interpreter also finishes, and returns a status code of 0 to the operating system.

To return a non-zero status code, use the `sys.exit()` function.

Reuse and The Main-Import Switch. In *Module Use: The import Statement* we talked about the Main-Import switch. The global `__name__` variable is essential for determing the context in which a module is used.

A well-written application module often includes numerous useful class and function definitions. When combining modules to create application programs, it may be desirable to take a module that had been originally designed as a stand-alone program and combine it with others to make a larger and more sophisticated program. In some cases, a module may be both a main program for some use cases and a library module for other use cases.

The `__name__` variable defines the context in which a module is being used. During evaluation of a file, when '`__name__ == "__main__"`', this module is the *main* module, started by the Python interpreter. Otherwise, `__name__` will be the name of the file being imported. If `__name__` is not the string `"__main__"`, this module is being imported, and should take no action of any kind.

This test is done with the as follows:

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

This kind of reuse assures that programming is not duplicated. It is notoriously difficult to maintain two separate files that are supposed to contain the same program text. This kind of "cut and paste reuse" is a terrible burden on programmers. Python encourages reuse through both classes and modules. All modules can be cofigured as importable and reusable programming.

37.3 The optparse Module

The command line arguments from the operating system are put into the `sys.argv` variable as a sequence of strings. Looking at the syntax rules for command line options and operands in the previous section we can see that it can be challenging to parse this sequence of strings.

The `optparse` module helps us parse the options and operands that are provided to our program on the command line. This module has two very important class definitions: `OptionParser()` and `Values`.

An `OptionParser` object does two things:

- It contais a complete map of your options, operands and any help strings or documentation. This module can, therefore, produce a complete, standard-looking command synopsis. The *`-h`* and *`--help`* options will do this by default.
- It parses the '`sys.argv[1:]`' list of strings and creates a `Values` object with the resulting option values.

The `OptionParser` has the following methods and attributes. There are a number of features which are used by applications which need to create a specialized subclass. We'll focus on the basic use case and ignore some of the features focused on extensibility.

class `OptionParser`(*keywords...*)

The constructor for an `optparse.OptionParser` has a number of keyword arguments that can be used to define the program's options.

Parameters

- *usage* – This keyword parameter sets the usage summary that will print when the options cannot be parsed, or help is requested. If you don't provide this, then your program's name will be taken from '`sys.argv[0]`' . You can suppress the usage information by setting this to the special constant `optparse.SUPPRESS_USAGE` .
- *version* – This keyword parameter provides a version string. It also adds the option of '`-version`' which displays this string. This string can contain the formatting characters '`%prog`' which will be replaced with the program's name.

- *description* – A paragraph of text with an overview of your program. This is displayed in respose to a help request.
- *add_help_option* – This is `True` by default; it adds the '`-h`' and '`-help`' options. You can set this to `False` to prevent adding the help options.
- *prog* – The name of your program. Use this if you don't want '`sys.argv[0]`' to be used.

`add_option`(*string, keywords...*)

This method of an `OptionParser` defines an option. The positional argument values are the various option strings for this option. There can be any mixture of short ('`-X`') and long ('`--long`') option strings. This is followed by any number of keyword arguments to provide additional details about this option. It is rare, but possible to have multiple short option strings for the same option.

Here's an example:

```
import optparse
parser= optparse.OptionParser()
parser.add_option( "-o", "--output", "-w", dest="output_file", metavar="output" )
```

Thisdefines three different variations that set a single destination value, `output_file`. In the help text, the string "'`output`"' will be used to identify the three alternative option strings.

Parameters

- *action* – This keyword parameter takes a string. It defines what to do when this option appears on the command line. The default action is `"store"`. Choices include `"store"`, `"store_const"`, `"store_true"`, `"store_false"`, `"append"`, `"count"`, `"callback"` and `"help"`.

  The store actions store the option's value.

  The append action accumulates a list of values.

  The count action counts occurances of the option. Count is often used so that `-v` is verbose and `-vv` is even more verbose.

- *type* – This keyword parameter takes a string. It defines what type of value this option uses. The default type is "string". Choices include `"string"`, `"int"`, `"long"`, `"choice"`, `"float"` and `"complex"`.

  For an action of `"count"`, the type is defined as `"int"`; you don't need to specify a type.

- *dest* – This keyword parameter takes a string. It defines the attribute name in the `OptionParse` object that will have the final value. If you don't provide a value, then the first long option name will be used to create the attribute. If you didn't provide any long option names, then the first short option name will be used.

- *nargs* – This keyword parameter takes an integer. It defines how many values are permitted for this option. The default value is 1. If this value is more than 1, then a tuple is created to contain the sequence of values.

- *const* – If the `action` parameter was `"store_const"`, this keyword parameter provides the constant value which is stored.

- *choice* – If the `type` parameter was `"choice"`, this is a list of strings that contain the valid choices. If the option's value is not in this list, then this is a run-time error. This set of choices is displayed as the help for this option.

- *help* – This keyword parameter provides the help text for this option.

- *metavar* – This keyword parameter provides the option's name as shown to the user in the help documentation. This may be different than the abbreviations chosen for the option.
- *callback* – If the `action` parameter was `"callback"`, this is a callable (either a function or a class with a `__call__()` method) that is called. This is called with four positional values: the `Option` object which requested the callback, the command line option string, the option's value string, and the overall `OptionParser` object.
- *callback_args* –
- *callback_kwargs* – If the action was `"callback"`, these keyword parameters provide the additional arguments and keywords used when calling the given function or object.

`set_defaults`(*keywords...*)

This method of an `OptionParser` provides all of the option's default values. Each keyword parameter is a destination name. These must match the `dest` names (or the the option string) for each option that you are providing a default value.

`parse_args`(*[args], [values=None],) -> (options, operands*)

This method will parse the provided command-line argument strings and update a given `optparse.Values` object. By default, this will parse '`sys.argv[1:]`' so you don't need to provide a value for the `args` parameter. Also, this will create and populate a fresh `optparse.Values` object, so you don't need to provide a value for the `values` parameter.

The usual approach is '`options, operands = myParser.parse_args()`'.

A `Values` object is created by an `OptionParser`. It has the attribute values built from defaults and actual parsed arguments. The attributes are defined by the options seen during parsing and any default settings that were provided to the `OptionParser`.

A Complete Example. Here's a more complete example of using `optparse`.

Assume we have a program with the following synopsis. `-v-h-d mm/dd/yy-s symbolfile`

`portfolio.py`

This program has two single-letter options: '`-v`' and '`-h`'. It has two options which take argument values, '`-d`' and '`-s`'. Finally, it accepts an operand of a file name.

These options can be processed as follows:

```
"""portfolio.py -- examines a portfolio file
"""
import optparse
class Portfolio( object ):
    def __init__( self, date, symbol ):
        ...
    def process( self, aFile ):
        ...

def main():
    oparser= optparse.OptionParser( usage=__doc__ )
    oparser.add_option( "-v", action="count", dest="verbose" )
    oparser.add_option( "-d", dest="date" )
    oparser.add_option( "-s", dest="symbol" )
    oparser.set_defaults( verbose=0, date=None, symbol="GE" )
    options, operands = oparser.parse_args()
```

```
    portfolio= Portfolio( options.date, options.symbol )
    for f in operands:
        portfolio.process( f )

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

The program's options are added to the parser. The default values, similarly are set in the parser. The `parse_args()` function separates the the options from the arguments, and builds the options object with the defaults and the parsed options. The `process()` function performs the real work of the program, using the options and operands extracted from the command line.

37.4 Command-Line Examples

Let's look at a simple, but complete program file. The program simulates several dice throws. We've decided that the command-line synopsis should be: `-v-s samples`

`dicesim.py`

The '`-v`' option leads to *verbose* output, where every individual toss of the dice is shown. Without the '`-v`' option, only the summary statistics are shown. The '`-s`' option tells how many samples to create. If this is omitted, 100 samples are used.

Here is the entire file. This program has a five-part design pattern that we've grouped into three sections.

dicesim.py

```
#!/usr/bin/env python
"""dicesim.py

..  program:: dicesym.py

    Simulate rolls of dice.

..  cmdoption:: -v

    Produce verbose output, show each sample

..  cmdoption:: -s samples

    The number of samples (default 100)
"""

import dice
import optparse
import sys

def dicesim( samples=100, verbosity=0 ):
    """Simulate the roll of two dice by producing the requested samples.

    :param samples: the number of samples, default is 100
    :param verbose: the level of detail to show
    """
```

```
    d= dice.Dice()
    t= 0
    for s in range(samples):
        n= d.roll()
        if verbosity != 0: print n
        t += n
    print "%s samples, average is %s" % ( samples, t/float(samples) )

def main():
    parser= optparse.OptionParser()
    parser.add_option( '-v', dest='verbosity', action='count' )
    parser.add_option( '-s', dest='samples', type='int' )
    parser.set_defaults( verbosity=0, samples=100 )
    opts, args = parser.parse_args()

    dicesim( samples=opts.samples, verbosity=opts.verbosity )

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

1. The docstring provides the synopsis of the program, plus any other relevant documentation. This should be reasonably complete. Each element of the documentation is separated by blank lines. Several standard document extract utilities expect this kind of formatting.

   Note that the docstring uses Restuctured Text markup with the Sphinx extensions. This will allow Sphinx to produce good-looking documentation for our program.

2. The imports line lists the other modules on which this program depends. Each of these modules might have the main-import switch and a separate main program. Our objective is to reuse the imported classes and functions, not the main function.

3. The `dicesym()` function is is the actual heart of the program. It is a function that does the essential work. It's designed so that it can be imported by some other program and reused.

4. The `main()` function is the interface between the operating system that initiates this program and the actual work in `dicesym()`. This does not have much reuse potential.

5. The top-level **if** statement makes the determination if this is a main program or an import. If it is an import, then `__name__` is not `"__main__"`, and no additional processing happens beyond the definitions. If it is the main program, the `__name__` is `"__main__"`; the arguments are parsed by `main()`, which calls `dicesym()` to do the real work.

This is a typical layout for a complete Python main progam. There are two clear objecives. First, keep the `main()` program focused; second, provide as many opportunities for reuse as possible.

37.5 Other Command-Line Features

Python, primarily, is a programming language. However, Python is also a family of related programs which interpret the Python language. While we can generally assume that the Python language is the same as the Python interpreter, there are some subtleties that are features of the interpreter, separate from the language.

Generally, the CPython interpreter is the baseline against which others are compared, and from which others are derived. Other interpreters include Jython and Iron Python.

The Python interpreter has a fairly simple command-line interface. We looked at it briefly in *Script Mode*. In non-Windows environments, you can use the man command to see the full set of command-line options. In all cases, you can run **python -h** or **python –help** to get a summary of the options.

Generally there are several kinds of command-line options.

- **Identify The Program**. This is done with *-c*, *-m*, **-** and the *file* argument. The *-c* option provides the Python program on the command line as a quoted string. This isn't terribly useful. However, we can use it for things like the following.

  ```
  python -c 'import sys; print sys.version'
  ```

  Note the rarely-used '`;`' to terminate a statement.

  The *-m* option will locate a module on the **PYTHONPATH** and execute that module. This allows you to install a complete application in the Python library and execute the top-level "main program" script.

  As we noted in *Script Mode*, the command-line argument to the Python interpreter is expected to be a Python program file. Additionally, we can provide a Python program on standard input and use **python -** to read and process that program.

- **Select the Division Operator Semantics**. This is done with *-Q*. As we noted in *Division Operators*, there are two senses for division. You can control the meaning of '`/`' using *-Qnew* and *-Qold*. You can also debug problems with *-Qwarn* or *-Qwarnall*. Rather than rely on *-Qnew*, you should include '`from __future__ import division`' in every program that uses the new '`//`' operator and the new sense of the '`/`' operator.

- **Optimization**. This is done with *-O* and *-OO* to permit some optimization of the Python bytecode. This may lead to small performance improvements.

  Generally, there are two sources for performance improvements that are far more important than optimization. First, and most fundamentally, correct choices of data structures and algorithms have the most profound influence on performance. Second, modules can be written in C and use the Python API's. These C-language modules can dramatically improve performance, also.

- **Startup and Loading**. The *-S* and *-E* options control the way Python starts and which modules it loads.

  The *-E* option ignores all environment variables (**PYTHONPATH** is the most commonly used environment variable.)

  Ordinarily Python executes an implicit '`import site`' when it starts executing. The `site` module populates `sys.path` with standard locations for packages and modules. The *-S* option will suppress this behavior.

- **Debugging**. The *-d*, *-i*, *-v* and *-u* options provide some debugging help.

  Python has some additional debugging information that you can access with the *-d* option. The *-i* option will allow you to execute a script and then interact with the Python intrpreter. The *-v* option will display verbose information on the **import** processing.

  Sometimes it will help to remove the automatic buffering of standard output. If you use the *-u* option, mixed stderr and stdout streams may be easier to read.

- **Indentation Problem-Solving**. The *-t* option gives warning on inconsistent use of tabs and spaces. The *-tt* option makes these warnings into errors, stopping your program from running.

  The *-x* option skips the first line of a file. This can be used for situations where the first line of a Python file can't be a simple '`#!`' line. If the first line can't be a comment to Python, this will skip that line.

  Additionally, Python comes with a **Tabnanny** script that can help resolve tab and space indentation issues.

  These problems can be prevented by using spaces instead of tabs.

There are a number of environment variables that Python uses. We'll look at just a few.

`PYTHONPATH`
: This defines the set of directories searched for modules. This is in addition to the directories placed on to `sys.path` by the `site` module.

`PYTHONSTARTUP`
: This file is executed when you start Python for interactive use. You can use the script executed at startup time to import useful modules, define handy functions or alter your working environment in other ways.

37.6 Command-Line Exercises

1. **Create Programs**. Refer back to exercises in *Language Basics*. See sections *Numeric Types and Expressions*, *Condition Exercises*, *Iteration Exercises*, *Function Exercises*. Modify these scripts to be stand-alone programs. In particular, they should get their input via `optparse` from the command line instead of `input()` or other mechanism.
2. **Larger Programs**. Refer back to exercises in *Data Structures*. See sections *String Exercises*, *Tuple Exercises*, *List Exercises*, *Dictionary Exercises*, *Exception Exercises*. Modify these scripts to be stand-alone programs. In many cases, these programs will need input from files. The file names should be taken from the command line using `optparse`.
3. **Object-Oriented Programs**. Refer back to exercises in *Class Definition Exercises*, *Advanced Class Definition Exercises*. Modify these scripts to be stand-alone programs.

37.7 The `getopt` Module

This is additional reference material on the `getopt` module for parsing command-line options and arguments.

The command line arguments from the operating system are put into the `sys.argv` variable as a sequence of strings. Looking at the syntax rules for command line options and operands in the previous section we can see that it can be challenging to parse this sequence of strings.

The `getopt` module helps us parse the options and operands that are provided to our program on the command line. This module has one very important function, also named `getopt()`.

`getopt`(*args, options, [long_options]*)
: Decode the given sequence of arguments, `args`, using the given set of `options` and `long_options`. Returns a tuple. The first value is a sequence of normalized (option, value) pairs. The scond value is a sequence of the program's operand values.

  The `args` value should not include `sys.argv[0]`, the program name. Therefore, the argument value for `args` is almost always '`sys.argv[1:]`'.

  The `options` value is a string of the one-letter options. Any options which require argument values are followed by a '`:`'. For example, '`"ab:c"`' means that the program will accept *`-a`*, *`-c`* , *`-ac`* , *`-b value`* as options.

  The `long_options` value is optional, if present it is a list of the long options. If a long option requires a parameter value, it's name must end in '`=`'. For example, '`("silent","debug","log=")`' means that options like *`--silent`*, *`--debug`*, and *`--log=myfile.log`* are accepted as options.

There are two results of `getopt()`: the options and the operands. The options is a list of '`( :replaceable:`name`` , *value*)' pairs. The operands is the list of names which follow the last option. In most cases, this list is a list of file names to be used as input.

There are several ways to handle the options list.

- We can iterate through this list, setting global variables, or configuring some processing object. This works well when we have both short and long option names for the same configuration setting.

```
options, operands = getopt.getopt( sys.argv[1:], ... )
for name, value in options:
    if name == "-X" or name == "--long":
         set some global variable
```

- We can define our configuration as a dictionary. We can then update this dictionary with the options. This forces the rest of our program to handle the '`-X`' or '`--long`' names for cofiguration parameters.

```
config = { "-X" : default, "--long": default }
options, operands = getopt.getopt( sys.argv[1:], ... )
config.update( dict(options) )
```

- We can define our configuration as a dictionary. We can initialize that configuration dictionary with the given options then fold in default values. While pleasantly obvious, it still makes the '`-X`' and '`--long`' options visible throughout our program.

```
options, operands = getopt.getopt( sys.argv[1:], ... )
config= dict(options)
config.setdefault( "-X", value )
config.setdefault( "--long", value )
```

One very adaptable and reusable structure is the following.

```
class MyApplication( object ):
    def __init__( self ):
        self.someProperty= some_default

    def process( self, aFileName ):
    """ The Real Work. """
        This is the real work of this applications

def main():
    theApp= MyApplication()
    options, operands = getopt.getopt( sys.argv[1:], "..." )
    for name, value in options:
        if name == "-X" or name == "--long":
            set properties in theApp
    for fileName in operaands:
        theApp.process( aFileName )
```

A Complete Example. Here's a more complete example of using `getopt`. Assume we have a program with the following synopsis. `-v-h-d mm/dd/yy-s symbolfile`

`portfolio.py`

This program has two single-letter options: '`-v`' and '`-h`'. It has two options which take argument values, '`-d`' and '`-s`'. Finally, it accepts an operand of a file name.

These options can be processed as follows:

```
"""portfolio.py -- examines a portfolio file
"""
import getopt
class Portfolio( object ):
    ...

def main():
    portfolio= Portfolio()
    opts, operands = getopt( sys.argv[1:], "vhd:s:" )
    for o,v in opts:
        if o == "-v": portfolio.verbose= True
        elif o == "-h":
            print __doc__
            return
        elif o == "-d": portfolio.date= v
        elif o == "-s": portfolio.symbol= v
    for f in operands:
        portfolio.process( f )

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

The program's options are coded as `"vhd:s:"`: the single-letter options ('`-v`' and '`-h`') and the value options ('`-d`' and '`-s`'). The `getopt()` function separates the the options from the arguments, and returns the options as a sequence of option flags and values.

The `process()` function performs the real work of the program, using the options and operands extracted from the command line.

CHAPTER

THIRTYEIGHT

ARCHITECTURE: CLIENTS, SERVERS, THE INTERNET AND THE WORLD WIDE WEB

The *World-Wide Web* is a metaphorical description for the sophisticated interactions among computers. The core technology that creates this phenomenon is the Internetworking Protocol suite, sometimes called *The Internet*. Fundamentally, the internetworking protocols define a relationship between pieces of software called the *client-server model*. In this case some programs (like browsers) are clients. Other programs (like web servers, databases, etc.) are servers.

This client-server model of programming is very powerful and adaptable. It is powerful because it makes giant, centralized servers available to large numbers of remote, widely distributed users. It is adaptable because we don't need to send software to everyone's computer to make a change to the centralized service.

Essentially, every client-server application involves a client application program, a server application, and a protocol for communication betweem the two processes. In most cases, these protocols are part of the popular and enduring suite of internetworking protocols based on TCP/IP. For more information in TCP/IP, see *Internetworking with TCP/IP* [Comer95].

We'll digress into the fundamentals of TCP/IP in *About TCP/IP*. We'll look at what's involved in a web server in *The World Wide Web and the HTTP protocol*. We'll look briefly at web services in *Web Services* . We'll look at slightly lower-level protocols in *Writing Web Clients: The urllib2 Module*. Finally, we'll show how you can use low-level sockets in *Socket Programming*. Generally, you can almost always leverage an existing protocol; but it's still relatively simple to invent your own.

38.1 About TCP/IP

The essence of TCP/IP is a multi-layered view of the world. This view separates the mechanics of operating a simple Local Area Network (LAN) from the interconnection between networks, called *internetworking*.

Hardware. The lowest level of network services are provided by mechanisms like Ethernet (see the IEEE 802.3 standards), which covers wiring between computers. The Ethernet standards include alternatives like 10BaseT (for twisted pairs of thin wires), 10Base2 (for thicker coaxial cabling). Network services may also be wireless, using the IEEE 802.11 standards. In all cases, though, these network services provide for simple naming of devices and moving bits from device to device.

What makes these "low level" is that these services are limited by having to know the hardware name of the receiving device; usually called the MAC address. When you buy a new network card for your computer, you – effectively – change your computer's hardware name.

The TCP/IP standards put several layers of control on top of these data passing mechanisms. While these additional layers allow interconnection between networks, they also provide a standard library for using all of the various kinds of network hardware that is available.

Internetworking Protocol. First, the Internet Protocol (IP) standard specifies addresses that are independent of the underlying hardware. The IP also breaks messages into packets and reassembles the packets in order to be independent of any network limitations on transmission lengths.

Additionally, the IP standard specifies how to route packets among networks, allowing packets to pass over bridges and routers between networks. This is the fundamental reason why internetworking was created in the first place.

Finally, IP provides a formal Network Interface Layer to divorce IP and all higher level protocols from the mechanics of the actual network. This allows for independent evolution of the application software (like the World Wide Web) and the various network alternatives (wired, wirelss, broadband, dial-up, etc.)

Transport Control Protocol. The Transport Control Protocol (TCP) protocol relies on IP. It provides a reliable stream of bytes from one application process to another. It does this by breaking the data into packets and using IP to route those packets from source to receiver. It also uses IP to send status information and retry lost or corrupted packets. TCP keeps complete control so that the bytes that are sent are recieved exactly once and in the correct order.

Many applications, in turn, depend on the TCP/IP protocol capabilities. The Hypertext Transport Protocol (HTTP), used to view a web page, works by creating a TCP/IP connection (called a *socket*) between browser and web server. A request is sent from browser to web server. The web server responds to the browser request. When the web page content is complete, the socket is closed and the socket connection can be discarded.

Python Modules. Python provides a number of complete client protocols that are built on TCP/IP in the following modules: `urllib`, `httplib`, `ftplib`, `gopherlib`, `poplib`, `imaplib`, `nntplib`, `smtplib`, `telnetlib`. Each of these exploits one or more protocols in the TCP/IP family, including HTTP, FTP, GOPHER, POP, IMAP, NNTP, SMTP and Telnet. The `urllib` and `urllib2` modules make use of multiple protocols, including HTTP and FTP, which are commonly provided by web servers.

We'll look into the details of just one of these higher-level procotols built on TCP/IP. We'll look at HTTP and how this serves web pages for people. We'll look at using this to create a web service, also.

Protocols, like SMTP, POP and IMAP are used to route and read email. One can argue that SMTP is perhaps the most used protocol ever invented, since every email on the internet is pushed around by SMTP.

38.2 The World Wide Web and the HTTP protocol

One of the most widely-used protocol built on top of TCP/IP is probably HTTP. It is the backbone of the World Wide Web. The HTTP protocol defines two parties: the client (or browser) and the server. The browser is generally some piece of software like FireFox, Opera or Safari. The web server is usually based on the Apache web server, but there are several others in common use.

The HyperText Transfer Protocol (HTTP) specifies a request and a reply. Our client (usually a browser) sends a request. The web server sends us a reply. [And yes, the World Wide Web is that simple. the sophistication comes from all the clever things that browsers and servers do with this simple protocol.]

Requests. An HTTP request includes a number of pieces of information. A few of these pieces of information are of particular interest to a web application.

operation The operation (or method) is generally '`GET`' or '`POST`'. There are other commands specified in the protocol (like '`PUT`' or '`DELETE`'), but they aren't provided by browsers.

This isn't visible. Generally, any URL you enter into a browser is accessed with a '`GET`' method. When you fill in a form and click a button, then the form is often sent as a POST request.

url The URL locates tthe resource. It includes a scheme, a path, a query, and other optional information like a query.

When we browse `http://homepage.mac.com/s_lott`, the `//homepage.mac.com/s_lott` is the path.

The `http:` is the *scheme* (or protocol) being used.

headers There are a number of headers which are included in the query; these describe the browser, and what the browser is capable of. The headers summarize some of the browser's preferences, like the language and locale. They also describe any additional data that is attached to the request. The "content-length" header, in particular, tells you that form input or a file upload is attached.

Reply. An HTTP reply includes a number of pieces of information. It always begins with a MIME-type string that tells the browser what kind of document will follow. This string us often '`text/html`' or '`text/plain`'.

The reply also includes the status code and a number of headers. Often the headers are version infromation that the browser can reveal via the **Page Info** menu item in the browser. Finally, the reply includes the actual document, either plain text, HTML or an image.

There are a number of HTTP status codes. Generally, a successful request has a status code of 200, indicating that request is complete, and the page is being sent.

The 30x status codes indicate that the page was moved, the `"Location"` header provides the URL to which the browser will redirect.

The 40x status codes indicate problems with the request. Generally, the resource was not found.

The 50x status codes indicate problems with the server or the fundamental syntax of the request.

38.3 Writing Web Clients: The `urllib2` Module

Since the World Wide Web is a client-server protocol, we can create clients or servers (or both). Generally, the clients are web browsers.

There are, however, numerous applications where we want to get software from a server on the web, but we don't want to use a browser. We might have a daily extract of data, or an hourly summary of Twitter postings.

These can be done by writing a web client. Fundamentally, a web client engages in an HTTP request and processes the reply that comes from the web server.

When the response is in a structured markup language (like HTML or XML), then we'll need to parse this resulting file format. We looked at XML parsing in *XML Files: The xml.etree and xml.sax Modules*. HTML parsing is similar.

Resources. A central piece of the design for the World-Wide Web is the concept of a Uniform Resource Locator (URL) and Uniform Resource Identifier (URI). A URL provides several pieces of information for getting at a piece of data located somewhere on the internet. A URL has several data elements. Here's an example URL: http://www.python.org/download/

- A scheme or protocol ('`http`')

- A location which provides the service. This includes the location ('`www.python.org`') and an optional port number. The default port number depends on the scheme. Port 80 is for '`http`'.
- A path ('`download`')
- An operation ('`GET`' is generally used)

It turns out that we have a choice of several schemes for accessing data, making it very pleasant to use URL's. The protocols include

- **ftp**. The File Transfer Protocol, FTP. This will send a single file from an FTP server to our client. For example, `ftp://aeneas.mit.edu/pub/gnu/dictionary/cide.a` is the identifier for a specific file.
- **http**. The Hypertext Transfer Protocol, HTTP. Amongst other things that HTTP can do, it can send a single file from a web server to our client. For example, `http://www.crummy.com/software/BeautifulSoup/download/BeautifulSoup.py` retrieves the current release of the Beautiful Soup module.
- **file**. The local file protocol. We can use a URL beginning with `file:///` to access files on our local computer.

HTTP Interaction. A great deal of information on the World Wide Web is available using simple URI's. In any well-design web site, we can simply '`GET`' the resource that the URL identifies.

A large number of transactions are available through HTTP requests. Many web pages provide HTML that will be presented to a person using a browser.

In some cases, a web page provides an HTML form to a person. The person may fill in a form and click a button. This executes an HTTP `POST` transaction. The `urllib2` module allows us to write Python programs which, in effect, fill in the blanks on a form and submit that request to a web server.

Also note that some web sites manage interaction with people via cookies. This, too, can be handled with `urllib2`.

Example. By using URL's in our programs, we can write software that reads local files as well as it reads remote files. We'll show just a simple situation where a file of content can be read by our application. In this case, we located a file provided by an HTTP server and an FTP server. We can download this file and read it from our own local computer, also.

As an example, we'll look at the *Collaborative International Dictionary of English*, CIDE. Here are three places that these files can be found, each using different protocols. However, using the `urrllb2` module, we can read and process this file using any protocol and any server.

FTP `ftp://aeneas.mit.edu/pub/gnu/dictionary/cide.a` This URL describes the `aeneas.mit.edu` server that has the CIDE files, and will respond to the FTP protocol.

HTTP `http://ftp.gnu.org/gnu/gcide/gcide-0.46/cide.a` This URL names the `ftp.gnu.org` server that has the CIDE files, and responds to the HTTP protocol.

FILE `file:///Users/slott/Documents/dictionary/cide.a` This URL names a file on my local computer. Your computer may not have this path or this file.

urlreader.py

```
#!/usr/bin/env python
"""Get the "A" section of the GNU CIDE Collaborative International Dictionary of English
"""
import urllib2
```

```
#baseURL= "ftp://aeneas.mit.edu/pub/gnu/dictionary/cide.a"
baseURL= "http://ftp.gnu.org/gnu/gcide/gcide-0.46/cide.a"
#baseURL= "file:///Users/slott/Documents/dictionary/cide.a"

dictXML= urllib2.urlopen( baseURL, "r" )
print len(dictXML.read())
dictXML.close()
```

1. We import the `urllib2` module.
2. We name the URL's we'll be reading. In this case, any of these URL's will provide the file.
3. When we open the URL, we can read the file.

38.4 Writing Web Applications

A web application is usually embedded in a web server. The point of a web application is to respond to HTTP requests with appropriate replies. The HTTP protocol is fairly simple, making it possible – in principle – to write a complete web server in Python.

In the long run, however, a web server written entirely in Python doesn't scale well. To provide reasonable levels of service to large numbers of users, there are a great many optimizations that are essential.

One of the most important optimizations relates to the nature of the various downloads from a web server. When we request a page, the initial download in response to the '`GET`' request is usually an HTML document. Embedded in the HTML are references to numerous other files, including style sheets, Javascript libraries, images and other media.

The HTML is often built dynamically and requires a sophisticated Python-based application. The rest of the content, however, is more-or-less static, and does not require deep sophistication. The static media needs to be sent as simply as possible.

This dichotomy between small, complex dynamic HTML content and large, simple static content leads us to a two-part design. We want to use Python only for the HTML, and use some other, faster, application for the static content. It works out best if we embed our Python application in a web server like Apache. We can delegate the static content to Apache. We reserve the dynamic HTML creation for our Python web application programs.

We usually use a component called `mod_wsgi` to extend Apache with Python. The idea is to configure Apache to separate requests for static media content from the requests for the dynamic HTML pages. Apache serves the static content from local files. Apache delegates (via `mod_wsgi`) some web requests to our Python application.

Priviledge. Note that web servers usually listen on port 80. Writing applications that use this port (or any other port numbered below 1024) requires special operating system privileges.

Writing priviledged applications is beyond the scope of this book. For that reason, we'll focus on writing applications which do one of two things.

- Use a higher-numbered port. 8000, 8008 or some other non-priviledged port is typical.
- Plug into the Apache server. Apache is a priviledged process, and can open port 80, handing requests to our applications through some kind of gateway.

38.4.1 About Web Servers

A web server handles half of the HTTP conversation. We have a number of choices of ways to implement this half of the protocol.

- We can write our own from scratch. Python provides us some seed modules from which we can build a working server. In some applications, where the volume is low, this is entirely appropriate.

  See the `BaseHTTPServer`, `SimpleHTTPServer` and `CGIHTTPServer` modules for simple web servers. Also see the `wsgiref` package for a more sophisticated web server.

  As noted above, this is relatively inefficient because we'll be using the vast power of Python to serve a lot of static content files.

  Also, it's difficult to listen for web requests on port 80 using a Python application.

- We can plug into the Apache server.
  - Apache supports a wide variety of Gateway Interface technologies, including CGI and SCGI. Using the Python `cgi` module, we can create a CGI or SCGI script. This is an inefficient use of system resources because each request starts a complete, fresh Python interpreter.
  - We can plug into the Apache server with `mod_python`. This Apache module embeds a Python interpreter directly in Apache. This embedded interpreter then runs your Python programs as part of Apache's response to HTTP requests. This is very secure and very fast. This is a relatively direct connection with Apache.
  - One of the most popular (and flexible) connections to Apache is `mod_wsgi`. We can use the `mod_wsgi` Apache extension in one of two ways. We can embed Python into Apache, or we can have Python running as a separate daemon process.

    Using Python as a separate deamon means that the Apache process is free to serve other web requests while our Python process is doing the complex work of creating the HTML.

Generally, using `cgi` or `mod_wsgi` is still rather complex. There are numerous details of parsing requests, handing sessions, identifying users, managing logs, etc., which are common problems with common solutions.

Web Frameworks. Rather than invent all of the supporting technology for a web site, it's easiest to use a *web application framework*. If we use a framework, we can focus on the content and presentation of our web site and leave the housekeeping to the folks who write the framework.

A web framework will connect to Apache; it will handle the details of parsing a web request and providing a suitable response. Using a web framework means that we do much, much less programming. Python has dozens of popular, successful web frameworks. You can look at **Zope**, **Pylons**, **Django** and **TurboGears** for some examples of dozens of ways that the Python community has simplified the construction of web applications.

We can't easily cover any of the web frameworks in this book. But we can take a quick look at `BaseHTTPServer`, just to show what's involved in HTTP.

38.4.2 Using `BaseHTTPServer`

Fundamentally, a web server is an application that listens for and handles requests sent using the HTTP protocol. The handler is required to formulate a suitable response.

This "listen and handle" loop is implemented by an instance of the `BaseHTTPServer.HTTPServer` class. We construct the server by providing a handler class. Each HTTP request will lead to creation of an instance of the handler class.

The `BaseHTTPServer.HTTPServer` class has two methods to provide the overall "main loop" of a web server.

class `HTTPServer()`

`__init__`(*address, handlerClass*)

Parameters

- *address* – A two-tuple, with server name and port number, usually something like `('',8008)`.
- *handlerClass* – A subclass of `BaseHTTPServer.BaseHTTPRequestHandler`. This is the class itself, not an instance of the class. The server will create objects of this class and invoke that object's methods.

`handle_request()`

This method of a server will handle just one request. It's handy for debugging. Or, you could create your own "serve forever" loop.

`serve_forever()`

This method of a server will handle requests until the server is stopped forcibly. A forcible stop is usually an external kill signal (or the equivalent in Windows).

An `HTTPServer` object requires a subclass of `BaseHTTPServer.BaseHTTPRequestHandler`. The base class does a number of standard operations related to handling web service requests.

Generally, you'll need to override just a few methods. Since most browsers will only send '`GET`' or '`POST`' requests, you only need to provide `do_GET()` and `do_POST()` methods.

class `YourRequestHandler`(*BaseHTTPRequestHandler*)

`do_GET`(*self*)
Handle a '`GET`' request from a browser. The request is available in a number of attribute values.

`do_POST`(*self*)
Handle a '`POST`' request from a browser. The request is available in a number of attribute values.

This class has a number of instance variables which characterize the specific request that is currently being handled.

`client_address`
An internet address as used by Python. This is a 2-tuple: (host address, port number).

`command`
The command in the request. This will usually be '`GET`' or '`POST`'.

`path`
The requested path.

`request_version`
The protocol version string sent by the browser. Generally it will be `'HTTP/1.0'` or `'HTTP/1.1'`.

`headers`
This is a collection of headers, usually an instance of `mimetools.Message`. This is a mapping-like class that gives you access to the individual headers in the request. The header `"cookie"`, for instance, will have the cookies being sent back by the browser. You will need to decode the value of the cookie, usually using the `Cookie` module.

`rfile`
: If there is an input stream, this is a file-like object that can read that stream. Do not read this without providing a specific size to read. Generally, you want to get '`headers['Content-Length']`' and read this number of bytes. If you do not specify the number of bytes to read, and there is no supplemental data, your program will wait for data on the underlying socket. Data which will never appear.

`wfile`
: This is the response socket, which the browser is reading. The response protocol requires that it be used as follows:

  1. Use '`self.send_response( number )`' or '`self.send_response( number, text )`'. Usually you simply send 200.
  2. Use '`self.send_header( header, value )`' to send specific headers, like `"Content-type"` or `"Content-length"`. The `"Set-cookie"` header provides cookie values to the browser. The `"Location"` header is used for a 30x redirect response.
  3. Use '`self.end_headers()`' to finish sending headers and start sending the resulting page.
  4. Then (and only then) you can use `self.wfile.write()` to send the page content.
  5. Use '`self.wfile.close()`' if this is a HTTP/1.0 connection.

Your class should provide some class level values which are provided to the browser.

`server_version`
: A string to identify your server and version. This string can have multiple clauses, each separated by whitespace. Each clause is of the form product/version. The default is `'BaseHTTP/0.3'`.

`error_message_format`
: This is the web page to send back by the send_error method. The send_error method uses the error code to create a dictionary with three keys: `"code"`, `"message"` and `"explain"`. The `"code"` item in the dictionary has the numeric error code. The `"message"` item is the short message from the `self.responses` dictionary. The "explain" method is the long message from the `self.responses` dictionary. Since a dictionary is provided, the formatting string for his error message must include dictionary-oriented conversion strings: `%(code)d`, `%(message)s` and `%(explain)s`.

`protocol_version`
: This is the HTTP version being used. This defaults to `'HTTP/1.0'`. If you set this to `'HTTP/1.1'`, then you should also use the `"Content-Length"` header to provide the browser with the precise size of the page being sent.

`responses`
: A dictionary, keyed by status code. Each entry is a two-tuple with a short message and a long explanation. These two values become the message and the explain in an error message.

  The message for status code 200, for example, is `'OK'`. The explanation is somewhat longer.

This class has a number of methods which you'll want to use from within your `do_GET()` and `do_POST()` methods.

`send_error`(*code, [message]*)
: Send an error response. By default, this is a complete, small page that shows the code, message and explanation. If you do not provide a `message`, the short message from the '`self.responses[code]`' mapping will be used.

`send_response`(*code, [message]*)
: Sends a response in pieces. If you do not provide a `message`, the short message from the '`self.responses[code]`' mapping will be used.

  This method is the first step in sending a response. This must be followed by `self.send_header()` if any headers are present. It must be followed by `self.end_headers()`. Then the page content can be sent.

`send_header`(*name, value*)
: Send one HTTP header and its value. Use this to send specific headers, like `"Content-type"` or `"Content-length"`. If you are doing a redirect, you'll need to include the `"Location"` header.

`end_headers()`
: Finish sending the headers; get ready to send the page content. Generally, this is followed by writing to `self.wfile`.

`log_request`(*code, [size]*)
: Uses `self.log_message()` to write an entry into the log file for a normal response. This is done automatically by `send_headers()`.

`log_error`(*format, args...*)
: Uses `self.log_message()` to write an entry into the log file for an error response. This is done automatically by `send_error()`.

`log_message`(*format, args...*)
: Writes an entry into the log file. You might want to override this if you want a different format for the error log, or you want it to go to a different destination than `sys.stderr`.

Example. The following example shows the skeleton for a simple HTTP server. This sever merely displays the '`GET`' or '`POST`' request that it receives. A Python-based web server can't ever be fast enough to replace Apache. However, for some applications, you might find it convenient to develop a small, simple application which handles HTTP.

webserver.py

```
import BaseHTTPServer

class MyHandler( BaseHTTPServer.BaseHTTPRequestHandler ):
    server_version= "MyHandler/1.1"
    def do_GET( self ):
        self.log_message( "Command: %s Path: %s Headers: %r"
                          % ( self.command, self.path, self.headers.items() ) )
        self.dumpReq( None )
    def do_POST( self ):
        self.log_message( "Command: %s Path: %s Headers: %r"
                          % ( self.command, self.path, self.headers.items() ) )
        if self.headers.has_key('content-length'):
            length= int( self.headers['content-length'] )
            self.dumpReq( self.rfile.read( length ) )
        else:
            self.dumpReq( None )
    def dumpReq( self, formInput=None ):
        response= "<html><head></head><body>"
        response+= "<p>HTTP Request</p>"
        response+= "<p>self.command= <tt>%s</tt></p>" % ( self.command )
        response+= "<p>self.path= <tt>%s</tt></p>" % ( self.path )
```

```
        response+= "</body></html>"
        self.sendPage( "text/html", response )
    def sendPage( self, type, body ):
        self.send_response( 200 )
        self.send_header( "Content-type", type )
        self.send_header( "Content-length", str(len(body)) )
        self.end_headers()
        self.wfile.write( body )

def httpd(handler_class=MyHandler, server_address = ('', 8008), ):
    srvr = BaseHTTPServer.HTTPServer(server_address, handler_class)
    srvr.serve_forever()

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

1. You must create a subclass of `BaseHTTPServer.BaseHTTPRequestHandler`. Since most browsers will only send 'GET' or 'POST' requests, we only provide `do_GET()` and `do_POST()` methods. Additionally, we provide a value of `server_version` which will be sent back to the browser.
2. The HTTP protocol allows our application to put the input to a form either in the URL or in a separate data stream. Generally, a forms will use a POST request; the data is available.
3. This is the start of a debugging routine that dumps the complete request. This is handy for learning how HTTP works.
4. This shows the proper sequence for sending a simple page back to a browser. Thi s technique will work for files of all types, including images. This method doesn't handle complex headers, particularly cookies, very well.
5. This creates the server, `srvr`, as an instance of `BaseHTTPServer.HTTPServer` which uses `MyHandler` to process each request.

38.4.3 Using WSGI-based Web Servers

Fundamentally, an web server is an application that listens for and handles requests sent using the HTTP protocol. The handler is required to formulate a suitable response.

Python Enhance Proposal **PEP 333** defines a standard approach to handling web requests, called the Web Services Gateway Interface, WSGI. This standard allows us to build large, sophisticated web sites as a composition of many smaller components.

It's best to think of WSGI as a system of pipes for routing requests and responses.

To make this composition work, each WSGI application must adhere to a standardized definition.

- A WSGI application is a function or a callable object.
- The request is given to the application in the form of a dictionary.
- The response from the application is broken into two parts: the status plus headers are separated from the response body. A WSGI application is given a function that is must use to send the status and headers. The return value of the WSGI application is the body of the response.

A WSGI application must have the following signature.

`wsgi_app`(*environ, start_response*)

Parameters

- *environ* – A dictionary with the entire HTTP request environment. This includes the OS environment, the HTTP headers, a number of items that define the request, plus some additioanl WSGI-specific items.
- *start_response* – A function that is used to start sending the status and headers.

`start_response`(*status, header_list*)

The `start_response()` function is what your application uses to start sending an HTTP response. This includes the status and the various headers.

Parameters

- *status* – The status number
- *header_list* – A list of 2-tuples. Each item has a header name and value.

All WSGI-compatible applications must do two things. They must see to it that the `start_response()` function is called. They must return a list of strings.

When we think of a WSGI application as a pipe, we see that an application will accomplish the above requirements one of two ways.

- Some WSGI applications will call another WSGI application, and return that application's list of strings.
- Other WSGI applications will call the `start_response()` function and return a list of strings that form the body of the response.

The WSGI environment includes the following items that define the request.

REQUEST_METHOD The HTTP request method, generally `"GET"` or `"POST"`.

SCRIPT_NAME The initial portion of the request URL path. This may be empty, depending on the structure of your applications.

PATH_INFO The remainder of the request URL path, designating the resource within your application.

QUERY_STRING The portion of the request URL that follows the "?".

CONTENT_TYPE The value of any `Content-Type` header in the HTTP request. If an upload is being done, this may have a value.

CONTENT_LENGTH The value of any `Content-Length` header in the HTTP request. If an upload is being done, this may have a value.

SERVER_NAME

SERVER_PORT The host name and port number

SERVER_PROTOCOL The protocol the client used; either `"HTTP/1.0"` or `"HTTP/1.1"`.

The WSGI environment includes the following WSGI-specific items.

wsgi.version The tuple (1,0), representing WSGI version 1.0.

wsgi.url_scheme The "scheme" portion of the URL; either `"http"` or `"https"`.

wsgi.input An input file from which the HTTP request body can be read. Generally, the body of a POST request will contain the input fields from the associated HTML form.

wsgi.errors An output file to which error output can be written. This generally the main log file for the server.

wsgi.multithread `True` if the application object may be simultaneously invoked by another thread in the same process.

An application might use this information to determine how to manage database connections or other resources.

wsgi.multiprocess `True` if an equivalent application object may be simultaneously invoked by another process.

wsgi.run_once `True` if the server or gateway expects that the application will only be invoked once by the containing process; i.e., is this a one-shot CGI-style script.

There are numerous WSGI-based applications and frameworks. We'll look at some components based on the `wsgiref` implementation. A good alternative is the werkzeug implementation. For more information, see http://werkzeug.pocoo.org/.

Here's an example of a WSGI application that dumps it's environment as the response page.

```
import cgi
def dump_all_app(environ, start_response):
    status = '200 OK'
    headers = [('Content-type', 'text/html')]
    start_response(status, headers)

    env_dump= [
        "<tt>%s=%r</tt><br/>" % (k,cgi.escape(str(environ[k]))) for k in environ
    ]
    return [
        "<html>",
        "<head><title>dump_all</title></head>",
        "<body><p>"] + env_dump + ["</p></body>",
        "</html>"
        ]
```

1. We import the `cgi` library to make use of the `cgi.escape()` function. This function replaces `"<"` with '`"<"`', `">"` with '`">"`', and `"&"` with '`"&"`' to allow the value of an environment value to contain HTML.
2. We define our application according to the WSGI standard. We accept an environment and a function that will start our response.
3. We define a simple status and the single mandatory header, which we send via the supplied `start_response` function.
4. We then return a sequence of strings that is the body of page.

WSGI Server. Separate from the WSGI applications is the WSGI server. This is built around a single application that will respond to requests on a specific port. This example uses the `wsgiref` implementation.

```
from wsgiref.simple_server import make_server
httpd = make_server('', 8008, dump_all_app)
print "Serving HTTP on port 8008..."

# Respond to requests until process is killed
httpd.serve_forever()
```

Composite Applications. The beauty of WSGI is that it allows the construction of Composite Applications.

There are two general design patterns.

- **Dispatching or Routing**. In this case, a WSGI application selects among other applications and forwards the request to one or more other applications.

A URL parsing application, for example, can use `wsgiref.util.shift_path_info()` as part of transforming a URL into an application.

- **Middleware or Pipe**. In this case, a WSGI application enriches the environment and passes the request to another application.

  For example, authorization and authentication is a kind of pipe. The authorization application forwards valid requests with user information or reponds with an error.

Each individual aspect of a complex web application can be separated into a distinct WSGI application. This individual aspects include things like the following.

- Authentication. An fork-style application can handle the HTTP_Authentication header. If the request lacks a proper header, this application can respond with an status 401. It can delegate basic authentication to one application and digest authentication to another application.

  One authenticated, an application can enrich the environment with the authenticated user information. Perhaps fetching any saved session information.

- Authorization. A pipeline application can determine if the user is actually allowed to perform the requested function. If the user is not authorized, it can produce a redirection to a login page. If the user is authorized, it can redirect to another application that does "real" work.

- Caching. A pipeline application can check for a given URL and return a previous result for known URL's that haven't expired. For new, unknown URL's (or expired URL's) the request can be passed on to application that does the "real" work.

- Form Data Parsing. A pipeline application can parse the form data and enrich the environment with data from the various form fields. After parsing, another application can be called to process the form input.

- Upload Storing. A pipeline application can capture the uploaded file and save it in an upload directory for further processing. It can enrich the environment with information about the uploaded file. After saving, another application can be called to process the uploaded file.

38.5 Sessions and State

The HTTP protocol is defined as being stateless. Each request-reply transaction is independent, with no memory of any prior transaction. If a web server is only providing access to static pages of content, this stateless transaction is precisely what we expect.

However, if we want a richer, more sophisticated, data processing application, we expect the application to be stateful. Indeed, one of the primary reasons for using computers is to store and retrieve information. Stored information represents the state of a database or file.

Also, an individual transaction often involves the server retaining state as we enter data, correct that data, and finally commit the change to the database.

The core issue is this. Given the stateless HTTP transactions and numerous concurrent clients, how do we distinguish the sequence of requests for a single uiser?

Cookies. The HTTP/1.1 standard introduced the concept of a *cookie*. A cookie is a small packet of data that is sent to a browser as part of a response header. The browser must then include the cookie as part of each subsequent request. This permits a web server to recognize a specific browser session, and assure that the user's interactions are stateful.

By making the HTTP session stateful, a web application can respond in more meaningful ways.

Sessions. To create stateful web applications, we need to introduce the concept of a *session*. The web application must do the following kinds of things.

1. **New Session?** If the request has no cookie, it represents a new session. Create a distinct session object, put that object's unique key into a cookie and put the cookie into the response header.
2. **Existing Session?** If the request has a cookie, it represents an existing session. Locate the distinct session object that matches the cookie.

All data that must be reflected back to the user must be kept in an object that is unique to each session. Clearly, these session objects will accumulate as a web server runs.

For speed of access, the sessions are kept in a simple dictionary. Periodically, the web server must examine the sessions and discard any that are older than some reasonable threshold. For private information (like financial or medical records) 20 minutes is deemed old enough. For other things, session objects may last for several hours.

38.6 Handling Form Inputs

While the full extent of web applications is beyond the scope of this book, we can look at the essential ingredients in processing form input in a web server.

Here's an example of a simple form. This form will send a POST request to the path `.` when the user clicks the **Convert** button.

The input will include three name-value pairs with keys of `fahrenheit` (from the `<input type="text">`), `celsius` (from the other `<input>` tag) and `action` (from the `<button type="submit">`).

```
<html><head><title>Conversion</title><head>
<body><form action="." method="POST">
<label>Fahrenheit</label> <input type="text" name="fahrenheit"/>
<br/>
<label>Celsius</label> <input type="text" name="celsius"/>
<br/>
<button type="submit" name="action" value="submit">Convert</button>
</form>
</body>
</html>
```

Browser Processing. Given a form, a browser displays the elements. It then allows the user to interact with the form.

When the user clicks submit, the contents for the form are transformed into a HTTP request.

The '`method`' attribute of the form determines what request method is used and how the form's data is packaged for transmission to the web server.

- For `method="GET"`, the request is a '`GET`', and the contents of the form are URL-encoded and put into the URL after a '`?`'.

  The request might look like this.

  ```
  http://localhost:8008/?fahrenheit=&celsius=12.0&action=submit
  ```

  A WSGI application will find this data in '`environ["QUERY_STRING"]`'.

  The easiest way to handle this data is to use `cgi.parse()` in the `cgi` module.

  ```
  data = cgi.parse( environ["QUERY_STRING"], environ )
  ```

- For `method="POST"`, the request is a '`POST`', and then contents of the form are URL-encoded and put into the request as a stream of data.

  A WSGI application will find this data in the file-like object '`environ["wsgi.input"]`'. This object has the data associated with the request. The number of bytes is given by '`environ["CONTENT_LENGTH"]`'.

  The easiest way to handle this data is to use `cgi.parse()` in the `cgi` module.

  ```
  data = cgi.parse( environ["wsgi.input"], environ )
  ```

Application Processing. Generally, the best design pattern is to build applications that have the following outline. This isn't complete, but it is a useful starting point. We'll add to this below.

1. When the user clicks a URL, the browser sends a '`GET`' request. The application responds with an empty form.
2. The user fills in the form, clicks the submit button. The browser sends a '`POST`' request, often to the same URL. The application validates the form input. If the input is valid, the application responds with the resulting page. If the input is not valid, the application responds with the form and any error messages.

   The form's data is parsed with `cgi.parse()`.

Here's an example WSGI application that shows the POST and GET processing.

```
form ="""\
    <html><head><title>title</title><head>
    <body>
    <p>%(messages)s</p>
    <form action="." method="GET">
    <label>label1</label> <input type="text" name="field1" value="%(field1)s"/>
    <br/>
    <label>label2</label> <input type="text" name="field2" value="%(field2)s"/>
    <br/>
    <button type="submit" name="action" value="submit">Convert</button>
    </form>
    </body>
    </html>
"""

def conversion( environ, start_response ):
    # For a GET, display the empty form.
    if environ['REQUEST_METHOD'] == "GET":
        status = '200 OK' # HTTP Status
        headers = [('Content-type', 'text/html')] # HTTP Headers
        start_response(status, headers)
        return [ form % { 'field1' : '', 'field2' : '', 'messages':'' } ]
    # For a POST, parse the input, validate it, and try to process it.
    else:
        data= cgi.parse( environ['wsgi.input'], environ )
        try:
            if 'field1' in data:
                field1= data.get('field1',[""])[0]
            if 'field2' in data:
                field2= data.get('celsius',[""])[0]
            # Validate...
            # Do processing...
            status = '200 OK' # HTTP Status
            headers = [('Content-type', 'text/html')] # HTTP Headers
```

```
        start_response(status, headers)
        return [ form % { 'field1' : field1, 'field2' : field2, 'messages':'' } ]
    except Exception, e:
        status = '400 ERROR' # HTTP Status
        headers = [('Content-type', 'text/html')] # HTTP Headers
        start_response(status, headers, exc_info=e)
        return [ form % { 'field1' : '', 'field2' : '', 'messages':repr(data) } ]
```

The Post and Back Problem. Note that if you submit the form as a 'POST' and click your browser's 'back' button, after looking at the next page, the form gets submitted again. Your browser will confirm that you want to submit form data again.

This behavior is usually prevented by using the "Redirect-after-Post" (also called the "Post-Redirect-Get") design pattern. The response to a page processed with 'POST', is a status 301 (Redirect) response. This response must include a header with a label of 'Location' and a value that is a URL to which the browser will address a 'GET' request. This makes the back button behave nicely.

The complete overview, then, is the following.

1. When the user clicks a URL, the browser sends a 'GET' request.

   - If there's no cookie, the application creates a new, unique sesions and builds the appropriate cookie.
   - If there's a cookie, the application retrieves the session and any saved state in that session. The saved state may include error messages, status messages, and previously entered values on the form.

   The application responds with the form, including any messages.

2. The user fills in the form, clicks the submit button. The browser sends a 'POST' request, often to the same URL.

   - If there's no cookie, something has gone awry. This is handled like the 'GET' request – the cookie must be added and the form sent.
   - There should be a cookie with session information that provides any needed context.

   The application validates the form input.

   If the input is valid, the application does the expected processing. The session is updated with completion messages. The application sends a '"301 REDIRECT"' response. This causes the browser to do a 'GET' to the given location.

   If the input is not valid, the application responds with the form and any error messages.

In more complex applications, there may be multiple pages, or multiple-step transactions. There may also be a "confirm" page at the end which summarizes the transaction before the real work is done. This requires accumulating considerable information in the session.

38.7 Web Services

When we looked at HTTP in *The World Wide Web and the HTTP protocol*, we were interested in its original use case of serving web pages for people. We can build on HTTP, creating an interface between software components, something called a *web service*. A web service leverages the essential request-reply nature of HTTP, but takes the elaborate human-centric HTML web page out of the response. Instead of sending back something for people to read, web services send just the facts without a sophisticated presentation.

Web services allow us to have a multi-server architecture. A central web server provides interaction with people. When a person's browser makes a request, this central web server can make web service requests of other servers to gather the information. After gathering the information, the central server aggregates it and builds the final HTML-based presentation, which is the reply sent to the human user.

Web services are an adaptation of HTTP; see *The World Wide Web and the HTTP protocol* for a summary. Web services rely on a number of other technologies. There are several competing alternatives, and we'll look at web services in general before looking at a specific technique.

38.7.1 Web Services Overview

There are a number of ways of approaching the problem of coordinating work between clients and servers. All of these alternatives have their advantages and disadvantages.

- **XML-RPC**. The XML-RPC protcol uses XML notation to make a remote procedure call (RPC). It works by sending an HTTP request that contains the name of the procedure to call and the arguments to that procedure. This protocol uses HTTP "POST" requests to provide the XML document.
- **SOAP**. There are two variations on the Simple Object Access Protocol (SOAP): remote procedure call variation and document. The RPC variant is basically the next generation of XML-RPC, where an XML document encodes the name of the procedure and the arguments. The document variant merely sends an XML document; the document provides all the information required by the server. This protocol is supported by additional standards like Web Services Definition Language (WSDL).
- **REST**. The Representational State Transfer (REST) protcol uses the HTTP operations ('`POST`', '`GET`', '`PUT`', '`DELETE`') and Uniform Resource Identifiers (URI) to manipulate remote objects. This protocol is perhaps the simplest of the web services protocols; for this reason it is very popular.

We'll focus on REST because it can be done largely using `urllib2` features (see *Writing Web Clients: The urllib2 Module*) and the JSON library.

RESTful Web Services. The essence of REST is that we are accessing a resource that resides on another, remote computer. In order to do this, we must transfer a representation of that object's state.

We have, therefore, three separate issues that we have to address.

1. Representing an object's state. We can use XML for this. There are other notations including JSON and YAML which are also used to represent an object's state. We'll focus on JSON because it's widely used and very simple.

   This representation issue happens on both client and server side of the transaction. When the client wants to create or update a resource, it must represent the object. When the server wants to provide a resource, it must represent the object, also.

2. Making the client request. This means marshalling the arguments, making the request, and unmarshalling the response. Since REST is based on HTTP, this is a kind of HTTP client access using one of the four methods: '`GET`', '`POST`', '`PUT`', '`DELETE`'.

3. Serving requests. This means unmarshalling arguments, doing something useful, and marshalling a response. Since this is based on HTTP, this is a kind of HTTP server.

   A '`GET`' request, generally, doesn't have any arguments; it identifies a resource, which is marshalled and returned.

   A '`POST`' request creates a new resource. The associated data is an URL-encoded version of the resources to create. Often the created resource is marshalled and returned as a kind confirmation.

   A '`PUT`' request will replace a resource. The associated data is an URL-encoded version of the resources to replace or update the existing resource.

A 'DELETE' request will remove a resource. Generally, this doesn't have any arguments; it identifies a resource, which is removed.

38.7.2 Web Services Server

Let's imagine that we've built a an extremely good simulation of a roulette wheel. We'd like to package this as a web service so that many people can share this in their simulations of Roulette.

In some cases, a web service is built into a more complete web application framework. Often the server will have a human interface as well as a web service interface. The human interface will use HTML. The web service interface will use JSON.

We'll simplify things slightly, and create a family of WSGI applications to route requests, handle the JSON replies and handle HTML replies.

The Resource. The resource we're serving is a roulette wheel. We created this Python module that defines the wheel. Each spin creates a dictionary that shows a number of bets which are won by this spin.

This is a separate module that includes just the class definition that we'll be serving.

wheel.py

```
import random

class Wheel( object ):
    redNumbers= set( [1,3,5,7,9,12,14,16,18,19,21,23,25,27,30,32,34,36] )
    domain = range(1,37) + [ "0", "00" ]
    def __init__( self ):
        self.rng= random.Random()
        self.last_spin= None
        self.count= 0
    def spin( self ):
        n = random.choice( Wheel.domain )
        if n in ( "0", "00" ):
            self.last_spin= {
                "number": n,
                "color": "green",
                "even": False,
                "high": None,
                "twelve": None,
                "column": None,
            }
        else:
            color = "red" if n in Wheel.redNumbers else "black"
            self.last_spin= {
                "number": n,
                "color": color,
                "even": n%2==0,
                "high": n>=18,
                "twelve": n//12,
                "column": n%3,
            }
        self.count += 1
        return self.last_spin
```

The WSGI Applications. We'll define several WSGI Applications that will create a comprehensive wheel web service.

This first example is the top-level "routing" application that parses the URL and delegates the work to another application. This is not a very flexible design. There are numerous better examples of very flexible routing using regular expression matching and other techniques.

wheelservice.py, part 1

```
import wsgiref.util
import cgi
import sys
import traceback
import json
import wheel

# A global object so we can maintain state.
theWheel= wheel.Wheel()

def routing( environ, start_response ):
    """Route based on top-level name of URL."""
    try:
        top_name = wsgiref.util.shift_path_info( environ )
        if top_name == "html":
            return person( environ, start_response )
        elif top_name == "json":
            return service( environ, start_response )
        else:
            start_response( '404 NOT FOUND',  [("content-type","text/plain")] )
            return [ "Resource not found." ]
    except Exception, e:
        environ['wsgi.errors'].write( "Exception %r" % e )
        traceback.print_exc( file=environ['wsgi.errors'] )
        status = "500 ERROR"
        response_headers = [("content-type","text/plain")]
        start_response(status, response_headers, sys.exc_info())
        return ["Application Problems.  ", repr(e) ]
```

1. We define some global state information for these applications to share. In this case, all the application share `theWheel`.
2. The `routing()` function is a WSGI application, and has the proper arguments.
3. We use `wsgiref.util.shift_path_info()` to parse out the first level of the URL path, and use this to distiguish between the HTML-oriented human interface and the JSON-oriented web interface.
4. In case of an exception, we print the traceback to the log, and return an error page.

A common extension to this routing is to respond to the '`/favicon.ico`' request by providing a graphic image file that can be displayed in the URL box of the browser.

This second example is the next-level "person" and "service" applications. These do the real work of the overall service. They either respond to a person (using HTML) or to a web services client (using JSON).

wheelservice.py, part 2

```
def person( environ, start_response, exc_info=None ):
    """Print some information about the stateful wheel."""
    global theWheel
    status = '200 OK'
    headers = [('Content-type', 'text/html')]
    start_response(status, headers, exc_info)
    return [
        "<html>",
        "<head><title>Wheel Service</title></head>",
        "<body>",
        "<p>Wheel service is spinning.</p>"
        "<p>Served %d spins.</p>" % (theWheel.count,),
        "</body>",
        "</html>"
    ]

def service( environ, start_response ):
    """Update the stateful wheel."""
    global theWheel
    spin= theWheel.spin()
    status= '200 OK'
    headers =  [("content-type","text/plain")]
    start_response( status, headers )
    return [ json.dumps(spin) ]
```

1. The `person()` function is a WSGI application, and has the proper arguments.
2. The `person()` function refers to the global state information, `theWheel`. It creates an HTML page with some status information.
3. The `service()` function is a WSGI application, and has the proper arguments.
4. The `service()` function refers to the global state information, `theWheel`. It uses `json` to formulate a reply in JSON notation.

The WSGI Service. The WSGI service simply wraps our composite application `routing()` and serves it.

wheelservice.py, part 3

```
from wsgiref.simple_server import make_server

httpd = make_server('', 8008, routing)
print "Serving HTTP on port 8008..."

# Respond to requests until process is killed
httpd.serve_forever()
```

38.7.3 Web Services Client

Let's imagine that a colleague has built a web service which provides us with an extremely good simulation of a roulette wheel. Our colleague has provided us with the following summary of this web service.

host '10.0.1.5'. While IP address numbers are the lowest-common denominator in naming, some people will create Domain Name Servers (DNS) which provide interesting names instead of numeric addresses.

If you are testing on a single computer, you will use 'localhost'.

port number '8008'. While the basic HTTP service is defined to run on port 80, you may have other web services which, for security reasons, aren't available on port 80. Port numbers from 1024 and up may be allocated for other purposes, so port numbers are often changed as part of the configuration of a program.

path '/json/' for the basic web services request. This isn't the best definition for this resource, since it can't easily be expanded.

method 'GET'.

response JSON-encoded dictionary with attributes of the spin.

This gives us a final URL of 'http://localhost:8008/json/' for access to this service.

To create a web services client, we can use the urllib2 module to access this service.

wheelclient.py

```
import urllib2
import json

def get_a_spin( ):
    result= urllib2.urlopen( "http://localhost:8008/json/" )
    assert result.code == 200
    assert result.msg == "OK"
    # print result.headers # to see information about the service
    data= result.read()
    return json.loads( data )

spin= get_a_spin()
print spin
```

1. We import the urllib2 library, which allows us to do HTTP 'GET' and 'POST' as part of a RESTful web service.
2. We import the json library, which we'll use to decode the response from the web service.
3. We define a function which will use the web service to get a spin of a roulette wheel. This function uses urllib2.urlopen() to make a 'GET' request to the given URL. The server will respond with a JSON-encoded response.
4. We load use json.loads() to parse the response and build a dictionary.

38.8 Client-Server Exercises

38.8.1 Create a Customized FTP Client

Write a simple, special-purpose FTP client that establishes a connection with an FTP server, gets a directory and ends the connection. The FTP directory commands are "DIR" and "LS". The responses may be long and complex, so this program must be prepared to read many lines of a response.

For more information, RFC 959 has complete information on all of the commands an FTP server should handle. Generally, the DIR or LS command, the '`GET`' and '`PUT`' commands are sufficient to do simple FTP transfers.

Your client will need to open a socket on port 21. It will send the command line, and then read and print all of the reply information. In many cases, you will need to provide additional header fields in order to get a satisfactory response from a web server.

To test this, you'll need to either activate an FTP server on your computer, or locate another computer that offers FTP services.

38.8.2 Desktop Web Application

You can easily write a desktop application that uses web technology, but doesn't use the Internet. Here's how it would work.

- Your application is built as a very small web server, based on `BaseHTTPServer.HTTPServer` or `wsgiref.simple_server`. This application prepares HTML pages and forms for the user.
- The user will interact with the application through a standard browser like Firefox, Opera or Safari. Rather than connect to a remote web server somewhere in the Internet, this browser will connect to a small web server running on your desktop.

  The URL will be '`http://localhost:8008/`'.
- You can package your application with a simple shell script (or `.BAT` file) which does two things. (This can also be done as a simple Python program using the `subprocess` module.)

  1. It starts a subprocess to run the HTTP server side of your application.
  2. It starts another subprocess to run the browser, providing an initial link of `'http://localhost:8008'` to point the browser at your application server.

Since this is a single-user application, there won't be multiple, concurrent sessions, which greatly simplifies web application implementation.

Example Application. We could, for example, write a small application that did Fahrenheit to Celsius conversion. We would create a Python web server and a "wrapper" script that launched the server and launched a browser.

The Input Form. While the full power of HTML is beyond the scope of this book, we'll provide a simple form using the `<form>`, `<label>`, `<button>` and `<input>` tags.

Here's an example of a simple form. This form will send a POST request to the path `.` when the user clicks the **Convert** button.

The input will include name-value pairs with keys of `fahrenheit`, `celsius` and `action`. The value will be a list of strings. Since the form only has a simple text field with a given name, there will be a single string in each list.

The `cgi.parse()` function can parse the encoded form input.

```
<html><head><title>Conversion</title><head>
<body><form action="." method="POST">
<label>Fahrenheit</label> <input type="text" name="fahrenheit"/>
<br/>
<label>Celsius</label> <input type="text" name="celsius"/>
<br/>
<button type="submit" name="action" value="submit">Convert</button>
</form>
```

```
</body>
</html>
```

The WSGI Applications. You'll need to write at least one WSGI application to handle the form input.

- If the '`environ['REQUEST_METHOD']`' is `"GET"`, this is an initial request, the form should be returned.
- If the '`environ['REQUEST_METHOD']`' is `"POST"`, this is is the form, as filled in by the user.
  - Extract the fields provided by the user. Attempt to convert the input to a floating-point number. If this fails, or if both fields are empty, present the form with error messages.
  - Calculate the value of the empty field from the completed field. Present the form with values filled in.

An Overview of the WSGI Server. You'll use `wsgiref.make_server()` to create a server from your form-handling application. You'll need to provide an address like `('', 8008)` , and the name of your application. This object's `serve_forever()` method will then handle HTTP requests on port 8008.

38.8.3 Complete Roulette Server

We'll create an alternative implementation of the simple Roulette server shown in *Web Services*.

We'll define a simple REST-based protocol for placing bets, spinning the wheel and retrieving the results of the placed bets.

Each BET will be considered a "resource". We'll use '`POST`' to create the resource, and '`GET`' to check on the resource after the spin.

The spin is a subtle issue. In a sense, we're merely getting a value. However, executing the spin, changes the state of the various bets. Therefore, the spin should be a kind of '`POST`' transaction.

Session and State. A web site that interacts with a browser generally uses cookies to maintain state so that the person doesn't have to be aware of how state is maintained.

For web services applications, it's cosiderably simpler to maintain state explicitly. A WS client program can use explicit session identification.

We'll handle this thorough a simple '`GET`' request which provides a unique session identifier.

A more secure method would include HTTP Digest Authentication. However, that's beyond the scope of this book.

Resource Details. Our top-level application will examine the request URL. We'll consider the top-level URL as the "resource" type. Our top-level application can then route the request based on this resource name.

session A '`POST`' request to `/session/` will allocate a new session. The response is a JSON document with the session identifier.

The data sent is a JSON document with information like the bettor's name.

The session identifier must be used in all further transactions to identify the specific bettor.

bet A '`POST`' request to '`/bet/session/`' will create a new bet. The processing could look like the following.

The data sent is a JSON document with a list of bets with a specific proposition ("red", "black", "even", "odd", etc.) and an amount.

Roulette tables often have a minimum and a maximum bet amount. These might be $10 and $500. In addition to valid names and amounts, the total of the bets must also conform to these limits to be considered valid.

If a bet (or the total) is invalid, the server should respond with a "501 INVALID" status. This message body should include details on which bet was rejected and why.

If the entire sequence of bets and amounts are valid, the server should respond with a "200 OK" status. The response body is a JSON document that includes a confirmation. This can be a simple sequential number or a UUID or some similar secure hand-shake.

A '`GET`' request to '`/bet/session/confirmation/`' will return the status of the requested bet. The response is a JSON document with the bet and the outcome. If the wheel has not been spun, the outcome is `None`. Otherwise, the outcome is the bet's payout multiplied by the amount of the bet.

spin A '`POST`' request to '`/spin/session/`' indicates that the bets and placed and the wheel can be spun.

This will respond with a JSON document that has the wheel spin confirmation number. Currently, there's not much use for this information except to acknowledge that the wheel was spun.

After a '`POST`' request to '`/spin/session/`', a client will have to do a '`GET`' request to retrieve bet results.

38.8.4 Roulette Client

Write a simple client which places a number of bets on the Roulette server, using the Martingale betting strategy.

The Martingale strategy is relatively simple. A bet is placed on just one 2:1 proposition (Red, Black, Even, Odd, High or Low). A base betting amount (the table minimum) is used. If the outcome of the spin is a winner, the betting amount is reset to the base. If the outcome of the spin is a loser, the betting amount is doubled.

Note that this "double up on a loss" betting will lead to situations where the ideal bet is beyond the table maximum. In that case, your simulation must adjust the bets to be the table maximum.

Also note that a proper simulation has a budget for betting. When the budget is exhausted, the simulation has to stop playing.

38.8.5 Roulette Client

We can write a web application which uses our Roulette Server. This will lead to a fairly complex (but typical) architecture, with two servers and a client.

- We'll have the Roulette Server from the Complete Roulette Server exercise, running on some non-priviledged port (like 36000). This server accepts bets and spins the wheel on behalf of a client process. It has no user interaction, it simply maintains state, in the form of bets placed.
- We'll have a web server, similar to the Desktop Web Application exercise, running on port 8008. This application can present a simple form for placing a bet or spinning the wheel.

The user can fill in the fields to define a bet. When the user clicks the **Bet** button, the web application will make a request to the Roulette Server and present the results in the HTML page that is returned to the user.

If the bet is valid, the web application will make a request to the Roulette Server to spin the wheel. It will present the results in the HTML page that is returned to the user.

This interaction between web application and Roulette server can all be done with `urllib2`.

- We'll can then use a browser to contact our web server. This client will browse "http://localhost:8008" to get a web page with a simple form for placing a bets and spinning the wheel.

A simple HTML form might look like the following.

```
<html><head><title>Roulette</title></head>
<body>
<p>Results from previous request go here</p>
<form action="." method="POST">
<label>Amount</label> <input type="text" name="amount"/>
<br/>
<label>Proposition</label> <select name="proposition">
<option>Red</option>
<option>Black</option>
<option>Even</option>
<option>Odd</option>
<option>High</option>
<option>Low</option>
</select>
<br/>
<button type="submit" name="action" value="bet">Bet</button>
</form>
</body>
</html>
```

A '`GET`' request can present the form.

A '`POST`' request must parse the input to find the values of the two fields (`"proposition"` and `"amount"`). It must validate input on the form, make requests to the server, and present the results.

38.8.6 Chess Server

In *Chessboard Locations* we described some of the basic mechanics of chess play. A chess server would allow exactly two clients to establish a connection. It would then a chess moves from each client and respond to both clients with the new board position.

We can create a simple web service that has a number of methods for handling chess moves. To do this, we'll need to create a basic `ChessBoard` class which has a number of methods that establish players, move pieces, and report on the board's status.

It's essential that the `ChessBoard` be a single object that maintains the state of the game. When two players are connected, each will need to see a common version of the chessboard.

Here are some of the methods that are essential to making this work.

class `ChessBoard()`

`__init__`(*self*)
Initialize the chessboard with all pieces in the starting position. It will also create two variables

to store the player names. These two player names will initially be None, since no player has connected.

`connect`(*self*)
: Allow a player to connect to the chess server. If two players are already connected, this will return an Error message. Otherwise, this will return an acceptance message that includes the player's assigned color (White or Black.)

`move`(*self, player, from, to*)
: Handle a request by a player to move a piece from one location to another location. Both locations are simply file (a-h) and rank (1-8). If the move is allowed, the response is an acknowledgement. Otherwise, an error response is sent. The chess server will need to track the moves to be sure they players are alternating moves properly.

`board`(*self*)
: The response is a 128-character string that reports the state of the board. It has each rank in order from 8 to 1; within each rank is each file from a to h. Each position is two characters with a piece code or spaces if the position is empty.

A web service will offer a simple RESTful resource for interacting.

game

- A '`POST`' request to '`/game`' should include a JSON document that identifies the player.

  The successful response is a JSON document which provides a game identification for the player along with the player's color.

- A '`POST`' request to '`/game/game/`' includes a JSON document with the player identification and their move.

  If this is valid, the reponse is a JSON document with the move number and board position.

  If this is invalid, the response is a JSON document with the move number, board position and the error message.

- A '`GET`' request to '`/game/game/`' will respond with the history of moves and the board position.

A client application for this web service can use `urllib2` to make the various '`POST`' and '`GET`' requests of the server.

Generally the ue case for the client would have the following outline.

1. The client process will attempt a connection. If that fails, the server is somehow unable to start a new game.
2. The client will display the board state and wait for the user to make a move. Once the move is entered, the client will make web services requests to provide moves from the given player and display the resulting board status.
3. Also, the client must "poll" the server to see if the other player has entered their move.

   If a web page includes the following HTML, it will periodically refresh itself, polling the server. '`<meta http-equiv="refresh" content="60">`'. This is included within the '`<head>`' tags. This will poll once every 60 seconds.

   For a desktop applicaiton, the polling is usually done by waiting a few seconds via `time.sleep()`.

38.9 Socket Programming

Socket-level programming isn't our first choice for solving client-server problems. Sockets are nicely supported by Python, however, giving us a way to create a new protocol when the vast collection of existing internetworking protocols are inadequate.

Client-server applications include a client-side program, a server, a connection and a protocol for communication betweem the two processes. One of the most popular and enduring suite of client-server protocols is based on the Internetworking protocol: TCP/IP. For more information in TCP/IP, see *Internetworking with TCP/IP* [Comer95] .

All of the TCP/IP protocols are based on the basic *socket* . A socket is a handy metaphor for the way that the Transport Control Protocol (TCP) reliably moves a stream of bytes between two processes.

The `socket` module includes a number of functions to create and connect sockets. Once connected, a socket behaves essentially like a file: it can be read from and written to. When we are finished with a socket, we can close it, releasing the network resources that were tied up by our processing.

38.9.1 Client Programs

When a client application communicates with a server, the client does three things: it establishes the connection, it sends the request and it reads the reply from the server. For some client-server relationships, like a databsae server, there may be multiple requests and replies. For other client-server requests, for example, the HTTP protocol, a single request may involve a number of replies.

To establish a connection, the client needs two basic facts about the server: the IP address and a port number. The IP address identifies the specific computer (or host) that will handle the request. The port number identifies the application program that will process the request on that host. A typical host will respond to requests on numerous ports. The port numbers prevent requests from being sent to the wrong application program. Port numbers are defined by several standards. Examples include FTP (port 21) and HTTP (port 80).

A client program makes requests to a server by using the following outline of processing.

1. **Develop the server's address**. Fundamentally, an IP address is a 32-bit host number and a 16-bit port number. Since these are difficult to manage, a variety of coding schemes are used. In Python, an address is a 2-tuple with a string and a number. The string representes the IP address in dotted notation (`"194.109.137.226"`) or as a domain name (`"www.python.org"`); the number is the port number from 0 to 65535.
2. **Create a socket and connect it to this address**. This is a series of function calls to the `socket` module. When this is complete, the socket is connected to the remote IP address and port and the server has accepted the connection.
3. **Send the request**. Many of the standard TCP/IP protocols expect the commands to be sent as strings of text, terminated with the `n` character. Often a Python file object is created from the socket so that the complete set of file method functions for reading and writing are available.
4. **Read the reply**. Many of the standard protocols will respond with a 3-digit numeric code indicating the status of the request. We'll review some common variations on these codes, below.

Developing an Address. An IP address is numeric. However, the Internet provides *domain names*, via Domain Name Services (DNS). This permits useful text names to be associated with numeric IP addresses. We're more used to `"www.python.org"`. DNS resolves this to an IP address. The `socket` module provides functions for DNS name resolution.

The most common operation in developing an address is decoding a host name to create the numeric IP address. The `socket` module provides several functions for working with host names and IP addresses.

`gethostname()`
: Returns the current host name.

`gethostbyname(`*host*`)`
: Returns the IP address (a string of the form '255.255.255.255') for a host.

`socket::gethostbyaddr( address ) -> ( name, aliasList, addressList )()`
: Return the true host name, a list of aliases, and a list of IP addresses, for a host. The host argument is a string giving a host name or IP number.

`socket::getservbyname( servicename, protocolname ) -> integer()`
: Return a port number from a service name and protocol name. The protocol name should be 'tcp' or 'udp'.

Typically, the `socket.gethostbyname()` function is used to develop the IP address of a specific server name. It does this by makig a DNS inquiry to transform the host name into an IP address.

Port Numbers. The port number is usually defined by your application. For instance, the FTP application uses port number 21. Port numbers from 0 to 1023 are assigned by RFC 1700 standard and are called the *well known ports*. Port numbers from 1024 to 49151 are available to be registered for use by specific applications. The Internet Assigned Numbers Authority (IANA) tracks these assigned port numbers. See http://www.iana.org/assignments/port-numbers. You can use the private port numbers, from 49152 to 65535, without fear of running into any conflicts. Port numbers above 1024 may conflict with installed software on your host, but are generally safe.

Port numbers below 1024 are restricted so that only priviledged programs can use them. This means that you must have root or administrator access to run a program which provides services on one of these ports. Consequently, many application programs which are not run by root, but run by ordinary users, will use port numbers starting with 1024.

It is very common to use ports from 8000 and above for services that don't require root or administrator privileges to run. Technically, port 8000 has a defined use, and that use has nothing to do with HTTP. Port 8008 and 8080 are the official alternatives to port 80, used for developing web applications. However, in spite of an official use, port 8000 is often used for web applications.

The usual approach is to have a standard port number for your application, but allow users to override this in the event of conflicts. This can be a command-line parameter or it can be in a configuration file.

Generally, a client program must accept an IP address as a command-line parameter. A network is a dynamic thing: computers are brought online and offline constantly. A "hard-wired" IP address is an inexcusable mistake.

Create and Connect a Socket. A socket is one end of a network connection. Data passes bidirectionally through a socket between client and server. The `socket` module defines the `SocketType`, which is the class for all sockets. The `socket()` function creates a socket object.

`socket(`*family, [type, protocol]*`)`
: Open a socket of the given type. The `family` argument specifies the address family; it is normally `socket.AF_INET`. The `type` argument specifies whether this is a TCP/IP stream (`socket.SOCK_STREAM`) or UDP/IP datagram (`socket.SOCK_DGRAM`) socket. The protocol argument is not used for standard TCP/IP or UDP/IP.

A `SocketType` object has a number of method functions. Some of these are relevant for server-side processing and some for client-side processing. The client side method functions for establishing a connection include the following.

`connect(`*address*`)`
: Connect the socket to a remote address; the address is usually a (host address, port #) tuple. In the event of a problem, this will raise an exception.

`connect_ex`(*address*)
Connect the socket to a remote address; the address is usually a (host address, port #) tuple. This will return an error code instead of raising an exception. A value of 0 means success.

`fileno`()
Return underlying file descriptor, usable by the `select` module or the `os.read()` and `os.write()` functions.

`getpeername`()
Return the remote address bound to this socket; not supported on all platforms.

`getsockname`()
Return the local address bound to this socket.

`getsockopt`(*level, opt, [buflen]*)
Get socket options. See the UNIX man pages for more information. The level is usually `SOL_SOCKET`. The option names all begin with `SO_` and are defined in the module. You will have to use the `struct` module to decode results.

`setblocking`(*flag*)
Set or clear the blocking I/O flag.

`setsockopt`(*level, opt, value*)
Set socket options. See the UNIX man pages for more information. The `level` is usual `SOL_SOCKET`. The option names all begin with `SO_` and are defined in the module. You will have to use the `struct` module to encode parameters.

`shutdown`(*how*)
Shutdown traffic on this socket. If how is 0, receives are disallowed; if how is 1, sends are disallowed. Usually this is 2 to disallow both reads and writes. Generally, this should be done before the `close()` .

`close`()
Close the socket. It's usually best to use the `shutdown()` method before closing the socket.

Sending the Request and Receiving the Reply. Sending requests and processing replies is done by writing to the socket and reading data from the socket. Often, the response processing is done by reading the `file` object that is created by a socket's `makefile()` method. Since the value returned by `makefile()` is a conventional file, then `readlines()` and `writelines()` methods can be used on this file object.

A `SocketType` object has a number of method functions. Some of these are relevant for server-side processing and some for client-side processing. The client side method functions for sending (and receiving) data include the following.

`recv`(*bufsize, [flags]*)
Receive data, limited by `bufsize`. `flags` are `MSG_OOB` (read out-of-band data) or `MSG_PEEK` (examine the data without consuming it; a subsequent `recv()` will read the data again).

`recvfrom`(*bufsize, [flags],) -> (string, address*)
Receive data and sender's address, arguments are the same as `recv()`.

`send`(*string, [flags]*)
Send data to a connected socket. The `MSG_OOB` flag is supported for sending out-of-band data.

`sendto`(*string, [flags]*)
Send data to a given address, using an unconnected socket. The flags option is the same as `send()`. Return value is the number of bytes actually sent.

`makefile`(*mode, bufsize*)
Return a file object corresponding to this socket. The `mode` and `bufsize` options are the same as used in the built in `file()` function.

Example. The following examples show a simple client application using the `socket` module.

This is the `Client` class definition.

```
#!/usr/bin/env python
import socket
class Client( object ):
    rbufsize= -1
    wbufsize= 0
    def __init__( self, address=('localhost',7000) ):
        self.server=socket.socket( socket.AF_INET, socket.SOCK_STREAM )
        self.server.connect( address )
        self.rfile = self.server.makefile('rb', self.rbufsize)
        self.wfile = self.server.makefile('wb', self.wbufsize)
    def makeRequest( self, text ):
        """send a message and get a 1-line reply"""
        self.wfile.write( text + '\n' )
        data= self.rfile.read()
        self.server.close()
        return data
print "Connecting to Echo Server"
c= Client()
response= c.makeRequest( "Greetings" )
print repr(response)
print "Finished"
```

A `Client` object is initialized with a specific server name. The host (`"localhost"`) and port number (`8000`) are default values in the class `__init__()` function. The address of `"localhost"` is handy for testing a client and a server on your PC. First the socket is created, then it is bound to an address. If no exceptions are raised, then an input and output file are created to use this socket.

The `makeRequet()` function sends a message and then reads the reply.

38.9.2 Server Programs

When a server program starts, it creates a socket on which it listens for requests. The server has a three-step response to a client. First, it accepts the connection, then it reads and processes the client's request. Finally, it sends a reply to the client. For some client-server relationships, like a database server, there may be multiple requests and replies. Since database requests may take a long time to process, the server must be multi-threaded in order to handle concurrent requests. In the case of HTTP, a single request will lead to multiple replies.

A server program handles requests from a client by using the following outline of processing.

1. **Create a Listener Socket**. A listener socket is waiting for client connection requests.
2. **Accept a Client Connection**. When a client attempts a connection, the socket's `accept()` method will return a "daughter" socket connected to the client. This daughter socket is used for all subsequent processing.
3. **Read the request**. Many of the standard TCP/IP protocols expect the commands to be sent as strings of text, terminated with the `n` character. Often a Python file object is created from the socket so that the complete set of file method functions for reading and writing are available.
4. **Send the reply**. Many of the standard protocols will respond with a 3-digit numeric code indicating the status of the request. We'll review some common variations on these codes, below.

Create and Listen on a Socket. The following methods are relevant when creating server-side sockets. These server side method functions are used for establishing the public socket that is waiting for client connections. In each definition, the variable `s` is a socket object.

`bind`(*address*)
: Bind the socket to a local address tuple of (IP Address and port number). This tuple is the address and port that will be used by clients to connect with this server. Generally, the first part of the tuple is simply "" to indicate that this server uses the address of the computer on which it is running.

`listen`(*queueSize*)
: Start listening for incoming connections, queueSize specifies the number of queued connections.

`accept`() -> (*socket, address*)
: Accept a client connection, returning a socket connected to the client and client address.

  The original bound socket, which was set in listen mode is left alone, and is still listening for the next connection.

Once the socket connection has been accepted, processing is a simple matter of reading and writing on the daughter socket.

We won't show an example of writing a server program using simple sockets. The best way to make use of server-side sockets is to use the `SocketServer` module.

38.9.3 Practical Server Programs with SocketServer

Generally, we use the `SocketServer` module for simple socket processing. Usually, we create a `TCPSocket` using this module. This can simplify the processing of requests and replies. The `SocketServer` module is the basis for the `SimpleHTTPServer` (see *The World Wide Web and the HTTP protocol*).

Much of server-side processing is encapsulated in two classes of the `SocketServer` module. You will subclass the `StreamRequestHandler` class to process TCP/IP requests. This subclass will include the methods that do the essential work of the program.

You will then create an instance of the `TCPServer` class and give it your `RequestHandler` subclass. The instance of `TCPServer` will to manage the public socket, and all of the basic processing. For each connection, it will create an instance of your subclass of `StreamRequestHandler` to handle the connection.

Define a `RequestHandler`. Defining a handler is done by creating a subclass of `StreamRequestHandler` or `BaseRequestHandler` and adding a `handle()` method function. The `BaseRequestHandler` defines a simple framework that `TCPServer` can use when data is received on a socket.

Generally, we use a subclass of `StreamRequestHandler`. This class has methods that create files from the socket. This alliows the `handle()` method function to simply read and write files. Specifically, the superclass will assure that the variables `self.rfile` and `self.wfile` are available.

For example, the echo service runs in port 7. The echo service simply reads the data provided in the socket, and echoes it back to the sender. Many Linux boxes have this service enabled by default. We can build the basic echo handler by creating a subclass of `StreamRequestHandler`.

```
#!/usr/bin/env python
"""My Echo"""
import SocketServer
class EchoHandler( SocketServer.StreamRequestHandler ):
    def handle(self):
        input= self.request.recv(1024)
        print "Input: %r" % ( input, )
        self.request.send("Heard: %r\n" % ( input, ) )
server= SocketServer.TCPServer( ("",7000), EchoHandler )
```

```
print "Starting Server"
server.serve_forever()
```

This class can be used by a `TCPServer` instance to handle requests. In this, the `TCPServer` instance named `server` creates an instance of `EchoHandler` each time a connection is made on port 7. The derived socket is given to the handler instance, as the instance variable `self.request`.

A more sophisticated handler might decode input commands and perform unique processing for each command. For example, if we were building an on-line Roulette server, there might be three basic commands: a place bet command, a show status command and a spin the wheel command. There might be additional commands to join a table, chat with other players, perform credit checks, etc.

Methods of `TCPServer`. In order to process requests, there are two methods of a `TCPServer` that are of interest.

`handle_request()`
: Handle a single request: wait for input, create the handler object to process the request.

`serve_forever()`
: Handle requests in an infinite loop. Runs until the loop is broken with an exception.

38.9.4 Protocol Design Notes

Generally, HTTP-based web services do almost everything we need; and they do this kind of thing in a simple and standard way. Using sockets is done either to invent something new or to cope with something very old. Using web services is often a better choice than inventing your own protocol.

If you can't, for some reason, make suitable use of web services, here are some lessons gleaned from the reading the Internetworking Requests for Comments (RFCs).

Many protocols involve a request-reply conversational style. The client connects to the server and makes requests. The server replies to each request. Some protocols (for example, FTP) may involve a long conversation. Other protocols (for example, HTTP) involve a single request and (sometimes) a single reply. Many web sites leverate HTTP's ability to send multiple replies, but some web sites send a single, tidy response.

Many of the Internet standard requests are short 1- to 4-character commands. The syntax is kept intentionally very simple, using spaces for delimeters. Complex syntax with optional clauses and sophisticated punctuation is often an aid for people. In most web protocols, a sequence of simple commands are used instead of a single, complex statement.

The responses are often 3-digit numbers plus explanatory comments. The application depends on the 3-digit number. The explanatory comments can be written to a log or displayed for a human user. The status numbers are often coded as follows:

1yz Preliminary reply, more replies will follow.

2yz Completed.

3yz More information required. In the case of FTP, this is typically the start of a dialog. In the case of HTTP, it is often a redirect.

4yz Request not completed; trying again makes sense. This is a transient problem like a deadlock, timeout, or file system problem. In the case of HTTP, this is also used for an authentication problem.

5yz Request not completed because it's in error; trying again doesn't make sense. This a syntax problem or other error with the request.

The middle digit within the response provides some additional information.

x0z The response message is syntax-related.

x1z The response message is informational.

x2z The response message is about the connection.

x3z The response message is about accounting or authentication.

x5z The response message is file-system related.

These codes allow a program to specify multi-part replies using 1 *yz* codes. The status of a client-server dialog is managed with 3 *yz* codes that request additional information. 4 *yz* codes are problems that might get fixed. 5 *yz* codes are problems that can never be fixed (the request doesn't make sense, has illegal options, etc.)

Note that protocols like FTP (RFC 959) provide a useful convention for handling multi-line replies: the first line has a '-' after the status number to indicate that additional lines follow; each subsequent lines are indented. The final line repeats the status number. This rule allows us to detect the first of many lines, and absorb all lines until the matching status number is read.

Part VI

Projects

Projects to Build Skills

Programming language skills begin with the basic syntax and semantics of the language. They advance through the solution of small exercises and are refined through solving more complete problems.

"Real-world" applications, used every day in business and research, are less than ideal for learning a programming language. The business-oriented problems often have a very narrow in focus; the solutions are dictated by odd budgetary constraints or departmental politics. Reasearch problems are also narrowly focused, often lacking a final "application" to surround the interesting parts of the programming and create a final, finished product.

This part provides several large exercises that provide for more advanced programming than the smaller exercises at the end of each section. These aren't real-world in scope, but they are quite a bit larger than the small exercises at the end of each chapter.

These are ranked in order of difficulty.

CHAPTER

THIRTYNINE

AREAS OF THE FLAG

From Robert Banks, *Slicing Pizzas, Racing Turtles, and Further Adventures in Applied Mathematics* [Banks02].

This project is simple: it does not use loops, if-statements or any data structures. This exercise focuses on expressions and assignment statements.

Facts about the American flag. The standard dimension is the *width* (or hoist). This is the basic unit that all others are multiplied by. A flag that is 30 inches wide will simply have 30 inches multiplied by all of the other measurements.

- Width (or *hoist*) $W_f = 1.0$
- Length (or *fly*) $L_f = 1.9 \times W_f$
- Width of union (or *canton*) $W_u = \frac{7}{13} \times W_f$
- Length of union $L_u = 0.76 \times W_f$
- Radius of a star $R = 0.0308 \times W_f$

These are other facts; they are counts, not measurements.

- Number of red stripes $S_r = 7$
- Number of white stripes $S_w = 6$
- Number white stars $N_s = 50$
- Width of a stripe $W_s = \frac{1}{S_r + S_w} \times W_f$

39.1 Basic Red, White and Blue

Red Area. There are 4 red stripes which abut the blue field and 3 red stripes run the full length of the flag.

We can compute the area of the red, since it is 4 short rectangles and 3 long rectangles. The short rectangle areas are the width of a stripe (W_s) times the whole length (length of the fly, L_f) less the width of the blue union (W_u). The long rectangle areas are simply the width of the stripe (W_s) times the length of the fly (L_f).

$$Red = 4 \times W_s \times (L_f - L_u) + 3 \times W_s \times L_f.$$

White Area. There are 3 white stripes which abut the blue field, 3 whie stripes run the full length of the flag, plus there are the 50 stars.

We can compute the basic area of the white using a similar analysis as area of the red, and adding in the areas of the stars, $50S$. We'll return to the area of the stars, last.

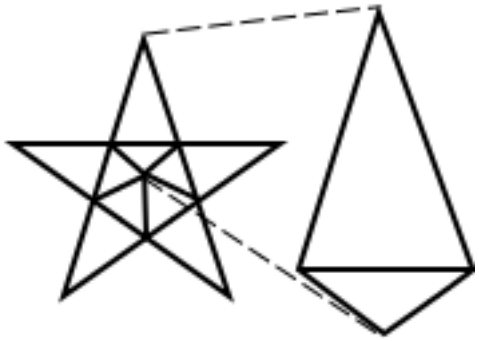
$$White = 3 \times W_s \times (L_f - L_u) + 3 \times W_s \times L_f + 50S.$$

Blue Area. The blue area is the area of the union, less the area of the stars, $50S$.

$$Blue = (L_u - W_u) - 50S.$$

39.2 The Stars

Area of the Stars. A 5-sided star (pentagram) can be analyzed as 5 kites of 2 triangles. The area of each kite, K, is computed as follows.



The inner angles of all five kites fill the inside of the pentagram, and the angles must sum to 360 °, therefore each inner angle is $\frac{360}{5} = 72$.

Angles of any triangle sum to 180 °. The lower triangle is symmetric, therefore, the other two angles must sum to 180. The lower triangle has two side angles of $(180 - 72)/2 = 54$.

We see that straight lines contain an outer triangle and two inner triangles. We know the inner triangles add to $54 + 54 = 108$; a straight line is 180. Therefore, the outer triangle has two 72 °corners and a 36 °peak. The area of the two triangles can be computed from these two angles.

$$a = 36$$
$$b = 72$$

Recall that the radius of a star, R is $0.0308 \times W_f$.

Here's one version of the area of the kite.

$$K = \frac{\sin\frac{a}{2} \times \sin\frac{b}{2}}{\frac{1}{2} \times \sin(a+b)} \times R^2$$

Here's the other version of the area of the kite.

$$K = \frac{\sin\frac{b}{2}}{\phi^2} \times R^2$$

Note that the math library `math.sin()` and `math.cos()` functions operate in radians, not degrees. The conversion rule is π radians = 180 degrees. Therefore, we often see something like $\sin(a \times \pi/180)$ for an angle, `a`, in degrees.

The Golden Ratio is $\phi = \frac{1+\sqrt{5}}{2}$ (about 1.61803).

The total area of a star is

$$S = 5 \times K$$

Given a specific width of a flag (in feet), we can compute the actual areas of each color.

Check Your Results. Blue is 18.73% of the total area.

CHAPTER

FORTY

BOWLING SCORES

Bowling is played in ten frames, each of which allows one or two deliveries. If all ten pins are bowled over in the first delivery, there is no second delivery.

Each frame has a score based on the delivery in that frame, as well as the next one or two deliveries. This means that the score for a frame may not necessarily be posted at the end of the frame. It also means that the tenth frame may require a total of three deliveries to resolve the scoring.

- **Rule A**. The score for a frame is the total pins bowled over during that frame, if the number is less than ten (an open frame, or error or split depending some other rules beyond the scope of this problem).
- **Rule B**. If all ten pins are bowled over on the first delivery (a strike), the score for that frame is 10 + the next two deliveries.
- **Rule C**. If all ten pins are bowled over between the first two deliveries (a spare), the score for that frame is 10 + the next delivery.

A game can be as few as twelve deliveries: ten frames of strikes require two additional deliveries in the tenth frame to resolve the rule B scoring. A game can be as many as twenty-one deliveries: nine open frames of less than 10 pins bowled over during the frame, and a spare in the tenth frame requiring one extra delivery to resolve the rule C scoring.

There is a relatively straight-forward annotation for play. Each frame has two characters to describe the pins bowled during the delivery. The final frame has three characters for a total of 21 characters.

Rule A: If the frame is open, the two characters are the two deliveries; the total will be less than 10. If a delivery fails to bowl over any pins, a `"-"` is used instead of a number.

Rule B: If the frame is strike, the two characters are `"X "`. No second delivery was made.

Rule C: If the frame is a spare, the first character is the number of pins on the first delivery. The second character is a `"/"`.

For example:

```
"8/9-X X 6/4/X 8-X XXX"
```

This can be analyzed into ten frames as follows:

Frame	First delivery	Second delivery	Scoring rule	Frame Score	Total
1	8	/, must have been 2	C- spare = 10 + next delivery	19	19
2	9	-, 0	A- open = 9	9	28
3	10	(not taken)	B- strike = 10 + next 2 deliveries	26	54
4	10	(not taken)	B- strike = 10 + next 2 deliveries	20	74
5	6	/, must have been 4	C- spare = 10 + next delivery	14	88
6	4	/, must have been 6	C- spare = 10 + next delivery	20	108
7	10	(not taken)	B- strike = 10 + next 2 deliveries	18	126
8	8	-, 0	A- open = 8	8	134
9	10	(not taken)	B- strike = 10 + next 2 deliveries	30	164
10	10	10 and 10	B- strike = 10 + next 2 deliveries, two extra deliveries are taken during this 10th frame.	30	194

Each of the first nine frames has a two-character code for each delivery. There are three forms:

- '`"X "`'.
- '`"n/"`' where n is `-` or 1-9.
- '`"nm"`' where n and m are `-` or 1-9. The two values cannot total to 10.

The tenth frame has a three-character code for each of the deliveries. There are three forms:

- '`"XXX"`'.
- '`"n/r"`' where n is `-`, 1-9 and r is `X`, `-`, 1-9.
- '`"nm "`' where n and m are `-` or 1-9. The two values cannot total to 10.

Write a `valid(game)()` function that will validate a 21-character string as describing a legal game.

Write a scoring method, `scores(game)()`, that will accept the 21-character scoring string and produce a sequence of frame-by-frame totals.

Write a reporting method, `scoreCard(game)()`, that will use the validation and scoring functions to produce a scorecard. The scorecard shows three lines of output with 5 character positions for each frame.

- The top line has the ten frame numbers: 2 digits and 3 spaces for each frame.
- The second line has the character codes for the delivery: 2 or 3 characters and 3 or 2 spaces for each of the ten frames.
- The third line has the cumulative score for each frame: 3 digit number and 2 spaces.

The game shown above would have the following output.

```
 1    2    3    4    5    6    7    8    9   10
8/   9-   X    X    6/   4/   X    8-   X    XXX
 19   28   54   74   88  108  126  134  164  194
```

CHAPTER

FORTYONE

MUSICAL PITCHES

A musician will call the frequency of a sound its *pitch*. When the frequencies of two pitches differ by a factor of two, we say they harmonize. We call this interval between the two pitches an *octave*. This perception of harmony happens because the two sounds reinforce each other completely. Indeed, some people have trouble telling two notes apart when they differ by an octave.

This trivial example of harmony is true for all powers of two, including $..., 1/8, 1/4, 1/2, 1, 2, 4, 8, ...$

Classical European music divided that perfectly harmonious "factor of two" interval into eight asymmetric steps; for this historical reason, it is called an octave. Other cultures divide this same interval into different numbers of steps with different intervals.

More modern European music further subdivides the octave, creating a 12-step system. The most modern version of this system has 12 equally spaced intervals, a net simplification over the older 8-step system. The pitches are assigned names using *flats* (♭) and *sharps* (♯), leading to each pitch having several names. We'll simplify this system slightly, and use the following 12 names for the pitches within a single octave:

- A
- A ♯
- B
- C
- C ♯
- D
- D ♯
- E
- F
- F ♯
- G
- G ♯

The eight undecorated names (A through G and an A with a frequency double the original A) form our basic octave; the additional notes highlight the interesting asymetries. For example, the interval from A to B is called a whole step or a second, with A ♯ being half-way between. The interval from B to C, however is only a half step to begin with. Also, it is common to number the various octaves as though the octaves begin with the C, not the A. So, some musicians consider the basic scale to be C, D, E, F, G, A, B, with a C in the next higher octave. The higher C is twice the frequency of the lower C.

The tuning of an instrument to play these pitches is called its *temperament*. A check on the web for reference material on tuning and temperament will reveal some interesting ways to arrive at the tuning of a musical instrument. It is suprising to learn that there are many other ways to arrive at the 12 steps of the scale. This demonstrates that our ear is either remarkably inaccurate or remarkably forgiving of errors in tuning.

We'll explore a number of alternate systems for deriving the 12 pitches of a scale. We'll use the simple equal-temperament rules, plus we'll derive the pitches from the overtones we hear, plus a more musical rule called the *circle of fifths*, as well as a system called *Pythagorean Tuning*.

Interesting side topics are the questions of how accurate the human ear really is, and can we really hear the differences? Clearly, professional musicians will spend time on ear training to spot fine gradations of pitch. However, even non-musicians have remarkably accurate hearing and are easily bothered by small discrepencies in tuning. Musicians will divide the octave into 1200 cents. Errors on the order of 50 cents, 1/24 of the octave, are noticable even to people who claim they are "tone deaf". When two tunings produce pitches with a ratio larger than 1.0293, it is easily recognized as out of tune.

These exercises will make extensive use of loops and the list data structure.

41.1 Equal Temperament

The equal temperament tuning divides the octave into twelve equally sized steps. Moving up the scale is done by multiplying the base frequency by some amount between 1 and 2. If we multiply a base frequency by 2 or more, we have jumped to another octave. If we multiply a base frequency by a value between 0 and 0.5, we have jumped into a lower octave. When we multiply a frequency by values between 0.5 and 1, we are computing lower pitches in the same octave. Similarly, multiplying a frequency by values between 1 and 2 computes a higher pitch in the same octave.

We want to divide the octave into twelve steps: when we do a sequence of twelve multiplies by this step, we should arrive at an exact doubling of the base frequency.

The steps of the octave, then, would be $b, b \times s, b \times s \times s, ..., b \times s^{12}$.

This step value, therefore is the following value.

$$s = e^{\frac{\log 2}{12}}$$

If we multiply this 12 times for each of the 12 steps, we find the following.

$$s^{12} = e^{12 \times \frac{\log 2}{12}} = 2$$

For a given pitch number, p, from 0 to 88, the following formula gives us the frequency. We can plug in a base frequency, b of 27.5 Hz for the low A on a piano and get the individual pitches for each of the 88 keys.

$$f = b \times 2^p = b \times e^{p \times \frac{\log 2}{12}} \tag{41.1}$$

Actual piano tuning is a bit more subtle than this, but these frequencies are very close to the ideal modern piano tuning.

Equal Temperament Pitches. Develop a loop to generate these pitches and their names. If you create a simple tuple of the twelve names shown above (from A to G ♯), you can pick out the proper name from the tuple for a given step, `s`, using '`int( s % 12 )`'.

Check Your Results. You should find that an "A" has a pitch of 440, and the "G" ten steps above it will be 783.99 Hz. This 440 Hz "A" is the most widely used reference pitch for tuning musical instruments.

41.2 Overtones

A particular musical sound consists of the fundamental pitch, plus a sequence of *overtones* of higher frequency, but lower power. The distribution of power among these overtones determines the kind of instrument we hear. We can call the overtones the spectrum of frequencies created by an instrument. A violin's frequency spectrum is distinct from the frequency spectrum of a clarinet.

The overtones are usually integer multiples of the base frequency. When any instrument plays an A at 440 Hz, it also plays A's at 880 Hz, 1760 Hz, 3520 Hz, and on to higher and higher frequencies. While we are not often consciously aware of these overtones, they are profound, and determine the pitches that we find harmonious and discordant.

If we expand the frequency spectrum through the first 24 overtones, we find almost all of the musical pitches in our equal tempered scale. Some pitches (the octaves, for example) match precisely, while other pitches don't match very well at all. This is a spread of almost five octaves of overtones, about the limit of human hearing.

Even if we use a low base frequency, b, of 27.5 Hz, it isn't easy to compare the pitches for the top overtone, $b \times 24$, with a lower overtone like $b \times 8$: they're in two different octaves. However, we can divide each frequency by a power of 2, which will normalize it into the lowest octave. Once we have the lowest octave version of each overtone pitch, we can compare them against the equal temperament pitch for the same octave.

The following equation computes the highest power of 2, p_2, for a given overtone multiplier, m, such that $\frac{f}{2} < b \times 2^{p_2} \leq f$.

$$p_2 = \left\lfloor \frac{\log m}{\log 2} \right\rfloor \tag{41.2}$$

Given this highest power of highest power of 2, p_2, we can normalize a frequency by simple division to create what we could call the *first octave pitch*, f_0.

$$f_0 = \frac{f}{2^{p_2}} \tag{41.3}$$

The list of first octave pitches arrives in a peculiar order. You'll need to collect the values into a list and sort that list. You can then produce a table showing the 12 pitches of a scale using the equal temperament and the overtones method. They don't match precisely, which leads us to an interesting musical question of which sounds "better" to most listeners.

Overtone Pitches. Develop a loop to multiply the base frequency of 27.5 Hz by values from 3 to 24, compute the highest power of 2 required to normalize this back into the first octave, p_2, and compute the first octave values, f_0. Save these first octave values in a list, sort it, and produce a report comparing these values with the closest matching equal temperament values.

Note that you will be using 22 overtone multipliers to compute twelve scale values. You will need to discard duplicates from your list of overtone frequencies.

Check Your Results. You should find that the 6th overtone is 192.5 Hz, which noralizes to 48.125 in the fist octave. The nearest comparable equal-tempered pitch is 48.99 Hz. This is an audible difference to some people; the threshold for most people to say something sounds wrong is a ratio of 1.029, these two differ by 1.018.

41.3 Circle of Fifths

When we look at the overtone analysis, the second overtone is three times the base frequency. When we normalize this back into the first octave, it produces a note with the frequency ratio of 3/2. This is almost

as harmonious as the octave, which had a frequency ratio of exactly 2. In the original 8-step scale, this was the 5th step; the interval is called a *fifth* for this historical reason. It is also called a *dominant*. Looking at the names of our notes, this is "E", the 7th step of the more modern 12-step scale that starts on "A".

This pitch has an interesting mathematical property. When we look at the 12-step tuning, we see that numbers like 1, 2, 3, 4, and 6 divide the 12-step octave evenly. However, numbers like 5 and 7 don't divide the octave evenly. This leads to an interesting cycle of notes that are separated by seven steps: A, E, B, F ♯, C ♯, ...

We can see this clearly by writing the 12 names of notes around the outside of a circle. Put each note in the position of an hour with A in the 12-o'clock position.

You can then walk around the circle in groups of seven pitches. This is called the *Circle of Fifths* because we see all 12 pitches by stepping through the names in intervals of a fifth.

This also works for the 5th step of the 12-step scale; the interval is called a *fourth* in the old 8-step scale. Looking at our note names, it is the "D". If we use this interval, we create a *Circle of Fourths*.

Write two loops to step around the names of notes in steps of 7 and steps of 5. You can use something like '`range( 0, 12*7, 7 )`' or '`range( 0, 12*5, 5 )`' to get the steps, `s`. You can then use '`names[s % 12]`' to get the specific names for each pitch.

You'll know these both work when you see that the two sequences are the same things in opposite orders.

Circle of Fifths Pitches. Develop a loop similar to the one in the overtones exercise; use multipliers based on 3/2: 3/2, 6/2, 9/2, ... to compute the 12 pitches around the circle of fifths. You'll need to compute the highest power of 2, using (41.2), and normalize the pitches into the first octave using (41.3).

Save these first octave values in a list, indexed by '`s % 12`'; you don't need to sort this list, since the pitch can be computed directly from the step.

Rational Circle of Fifths. Use the Python rational number module, `fractions` to do these calculations, also.

Check Your Results. Using this method, you'll find that "G" could be defined as 49.55 Hz. The overtone analysis suggested 48.125 Hz. The equal temperament suggested 48.99 Hz.

41.4 Pythagorean Tuning

When we do the circle of fifths calculations using rational numbers instead of floating point numbers, we find a number of simple-looking fractions like 3/2, 4/3, 9/8, 16/9 in our results. These fractions lead to a geometrical interpretation of the musical intervals. These fractions correspond with some early writings on music by the mathematician Pythagoras.

We'll provide one set of commonly-used list of fractions for Pythagorean tuning. These can be compared

with other results to make the whole question of scale tuning even more complex.

A	1 : 1
$A\sharp$	256 : 243
B	9 : 8
C	32 : 27
$C\sharp$	81 : 64
D	4 : 3
$D\sharp$	729 : 512
E	3 : 2
F	128 : 81
$F\sharp$	27 : 16
G	16 : 9
$G\sharp$	243 : 128

Pythagorean Pitches. Develop a simple representation for the above ratios. A list of tuples works well, for example. Use the ratio to compute the frequencies for the various pitches, using 27.5 Hz for the base frequency of the low "A". Compare these values with equal temperament, overtones and circle of fifths tuning.

Check Your Results. The value for "G" is $27.5 \times 16 \div 9 = 48.88$ Hz.

41.5 Five-Tone Tuning

The subject of music is rich with cultural and political overtones. We'll try to avoid delving too deeply into anything outside the basic accoustic properties of pitches. One of the most popular alternative scales divides the octave into five equally-spaced steps. This tuning produces pitches that are distinct from those in the 12 pitches available in European music.

The original musical tradition behind the blues once used a five step scale. You can revise the formula in (41.1) to use five steps instead of twelve. This will provide a new table of frequencies. The intervals should be called something distinctive like "V", "W", "X", "Y", "Z" and "V" in the second octave.

Five-Tone Pitches. Develop a loop similar to the 12-tone Equal Temperament (*Equal Temperament*) to create the 5-tone scale pitches. Note that the 12-tone scale leads to 88 distinct pitches on a piano; this 5-tone scale only needs 36.

Compare 12-Tone and 5-Tone Scales. Produce a three column table with the 12-tone pitch names and frequencies aligned with the 5-tone frequencies. You will have to do some clever sorting and matching. The frequencies for "V" will match the frequencies for "A" precisely. The other pitches, however, will fall into gaps.

The resulting table should look like the following

name 12	freq.	name 5	freq.
A	440.0	V	440.0
A#	466.16		
B	493.88		
		W	505.42

CHAPTER

FORTYTWO

WHAT CAN BE COMPUTED?

This project will look at Finite State Machines, one of the foundations of computing. We'll provide some background on why these are important in Background. In The Turing Machine we'll discuss the Turing Machine in some detail. We'll provide an example in Example Machine.

The essential exercise is to write the necessary Python software to emulate a Turing Machine. We'll look at the implementation closely in Turing Machine Implementation. Exercise 1 is the first set of programming exercises.

In *Test Machines* we'll look at some basic Turing Machine specifications that we can use for testing. Exercise 2 will implemnet some of those additional machines to act as confirmation and as unit tests.

As a digression, we'll provide additional background in Consequences. This background answers some of the questions raised in the Background section.

We can then look at further applications of Finite State Machines in Other Applications. This includes some simple lexical scanning and parsing applications.

We'll look at some variations on the implementation of our Turning Machine in Alternative Specifications

42.1 Background

In the 1930's – at the very dawn of digital computation – mathematician Alan Turing wondered what numbers could be computed by a digital computer. Indirectly, he was wondering what *should* a computer be designed to do. What was a sensible set of constraints or parameters around computer and programming language?

At that time "computer" was a person's job title. A mathematician, like Alan Turing, would create worksheets for people to use in computing a particular result. Turing worked on code breaking during World War II, and his "computers" were people who carried out rather complex analyses of coded messages. Turing prepared the instructions and worksheets for his computers to decode intercepted messages.

The question of computable numbers – to modern programmers – can seem a bit silly. The unthinking answer is that digital computers can represent any number.

But we have a bit of a problem. Mathematicians have identified a pretty wide variety of numbers. Can we represent all rational fractions? What about all irrational decimals? What about all complex numbers? Are there yet other kinds of numbers that a computer can't represent?

The essential question is "what numbers *should* we be able to compute with Python?"

Python. This essential computability question defines how we design computer hardware and how we design programming languages. The first step, then is to define what is computable. Clearly, a language like Python must have some minimal set of features. Further, there must be some standard of "computability" that a

language designer must respect in creating the language. In the next section, we'll look at the subject of computability.

Once we agree on what is computable, we can then match a given programming language (e.g., Python) against the definition to see if our programming language is complete. This sounds like a daunting, heavy-weight mathematical proof, but actually, it's relatively simple. In this section, we'll construct the proof that Python is a complete language. Really.

The definition of "computable" is based on a hypothetical model of a "computer". We can (and will) build that hypothetical computer model in Python. The Python program that implements the hypothetical computer is the constructive proof that the Python language completely fits the hypothetical model of computability.

The essential notion of computability is based on the idea of computable numbers. So we'll look at those briefly.

Numbers. A common mistake is to claim that there are just "numbers". This is clearly untrue. We can easily define "natural" numbers with a pleasant set of axioms. We can say that we have a first number, call it "0". We can define a successor numbers, and the properties of equality and create an infinite set of numbers. Yes, there are an infinite set of numbers. But we have this concept of successor, so – in principle – we can count this set.

Interestingly, this set doesn't include negative numbers. Okay, fine, we'll add negative numbers to our infinite set of natural numbers, and we have a larger infinite set of numbers. Turns out, we can work out a mapping from natural numbers to signed numbers. This makes the set of signed integers "countably infinite".

The `long` class is a physical implementation of this abstact concept of signed natural number. Also, the `decimal.Decimal` class, with a fixed decimal point, is essentially the same kind of number.

This set of integers doesn't include any fractions. We can easily define an infinite set of fractions using any two of our infinite set of natural numbers. This gives us a set of rational numbers that's obviously also infinite. It seems to be a larger set, but we can work out a mapping from natural numbers to rational fractions. This makes the rational numbers "countably infinite", also.

The `Rational` class (see *Rational Numbers*) is an implementation of this abstract concept of rational number.

Yet More Numbers. The set of rational numbers, however, still isn't the final word. We can define some "algebraic numbers", which are solutions to equations that aren't rational nunmbers. For instance, solving this polynomial for x, $x^2 - 2 = 0$. The answer is $x = \sqrt{2}$; no rational number can satisfy this. This means that there must be "irrational" numbers.

We can combine the irrational and rational numbers into a big set of numbers, commonly called "real" numbers.

If we start writing down numbers as long strings of decimal digits (or binary bits) we can – with some cleverness – create numbers that we cannot easily map to the natural numbers. This means that infinite decimal fractions form a larger set of numbers that's "uncountably infinite". Rats.

The `float` class is a finite implementation these infinite binary fractions. Since the `float` class is actually finite, it suffers from some practical limitations, but, in spirit, it is intended to follow this kind of number.

We're still not done. solving this polynomial for x, $x^2 + 1 = 0$, leads us to `complex` numbers.

Okay. Fine, there are a lot of numbers. The first question is, "are all of these computable?" Essentially, we are also asking "can we define 'computable'?" We'd really like a constructive definition of computable that matches our vague notions of what a computer *should* do.

Profound Limitations. For purposes of simplification, we need to set aside the "finite" part of physical computers and discuss a hypothetical infinite computer. Why should talk about theoretical computers?

The idea behind this is to divorce a simple, formal definition of computer from any specific and complex piece of hardware. If we try to discuss specific pieces of hardware, we have lots of weird limitations and

gotchas based on limited memory, available power, limited desktop space, dissipation of heat, radio-frequency interference, laws of physicas, etc.

The point is to first talk about what's *possible* before talking about what's practical. Before we even start, we need to know if there any profound limitations on what's possible. Since the answer is "yes", there are theoretical limitations, we need to know exactly what those limitations are.

Goals. Fundamentally, the overall goal has two parts.

1. Show that there is a Turing Machine which can compute any particular mathematical function. This defines the theoretical possibilities for computable numbers. We'll skip over this.
2. Create a Python implementation of a Turing machine. This will establish that the Python language is – in principle – capable of all the theoretical computations.

We'll trust the mathematicians that the Turing Machine's computable numbers are a good match for what we understand numbers to be. It turns out that the match isn't perfect; we'll look at this briefly in Consequences.

42.2 The Turing Machine

To talk about computability, we need a general-purpose (and simple) model for a computer. We need something that we can define clearly and completely. We also need something that captures what we mean by "compute". We need input, output, state change, and some kind of "program" to control those state changes.

We'll call our theoretical computer a Turing Machine, naming it after mathematician Alan Turing.

The essential feature of all computation is state change. We introduced the idea in *Variables, Assignment and Input*. Therefore, a hypothetical computer must have some current internal state and some rules for changing the internal state based on inputs.

This internal state is as simple as flag or marker that identifies which transition rules are active. If we were to number each rule, the state would be the current rule number. If we had a person following instructions on a worksheet, we might ask them to put a removable sticky-note on the step they were following so they wouldn't lose their place.

In addition to internal state, we need some form of input, output and (possibly) working memory. Turing's idea was to use an infinitely long tape for this. [Infinite? Yes. It's an abstraction; we need to define the set of countably infinite numbers, so we need an infinite tape.]

The idea is that we can mark the tape with some values, start the machine processing. When it stops, we can look at the tape to see the answer.

Alphabet. Our machine must be able to record state on the tape. We need to define some alphabet of symbols. A minimal alphabet is two distinct symbols and nothing more. We could use '`X`' and '`O`' or ☒ and ⊙. We could use a larger alphabet of the 128 ASCII characters that Python uses. Or we could use the vast library of Unicode symbols.

The only restriction is that the symbols are distinct and the alphabet of symbols is limited and known in advance. For now, we'll stick to just two symbols.

The Tape. Our Turing machine, then, has as it's visible component, a tape which shuttles back and forth under a read/write station. Or, we could think of a little read/write device that walks up and down a long tape laid out on the floor of a vast building.

There are some great YouTube videos of Turning Machines. Feel free to watch those for a better sense of that a Turing Machine might be like.

The interesting part is the "current" position of the read/write device relative to the tape itself. Here's a sample tape with a few symbols. We'll use brackets to show where the read/write device is positioned.

♢ ♢ ♢ [♣] ♠ ♢ ...

Clearly, this alphabet includes at least the symbols: ♢, ♣, ♠.

Also, the current position is the fourth one on the tape.

The Rules. Our Turning Machine has an internal state to remember where it is, an infinite tape that is input, output and working memory. It also has some rules for deciding what to do. To keep things simple, each rule includes the following things:

- **Symbol**. This is the symbol to be matched against the current symbol on the tape. Since the alphabet is finite, we'll have one rule per symbol.
- **Write**. Write a new symbol or do no writing, leaving the tape unchanged. A purist could argue that writing the matched symbol back to the tape is the same as not writing.
- **Move**. The machine can move the tape forward one, backward one, or not at all.
- **Next State**. This next state is the same or different collection of rules.

This can be simplified. It can also be made more complex. We'll look at some alternatives below. For now, this will give us enough to work with.

For a give state, we have a set of rules that specifies the moving and writing for each possible symbol. If we have a small alphabet of just two symbols, each state has only two rules. If we have a larger alphabet, each state must have a larger number of rules.

Halting. It's sometimes helpful to have a special rule to stop the machine from further processing. This halt rule is simply a special case rule that doesn't have a next state. Instead of going to a next state, the machine stops working.

A rule that doesn't write, doesn't move and specifies no state change must halt, since the machine will stay in that state forever.

42.3 Example Machine

Let's use a very small alphabet of ☒ and ⊙.

We'll define a very simple machine to check the "parity" of a tape. We want to be sure that number of ☒ symbols is even. If it's odd, we'll write an extra ☒ symbol. If it's even, we'll write an extra ⊙.

This kind of algorithm is used with 7-bit ASCII characters to create 8-bit even-parity for transmission across noisy wires. If the received 8-bit value does not have even parity, the character is ignored.

Here are the two states.

1. **Even**. If ☒: write nothing, move tape forward, change to state **1**.

   If ⊙: write nothing, move tape forward, stay in state **0**.

   If blank: write ⊙, change to state **2**.

2. **Odd**. If ☒: write nothing, move tape forward, change to state **0**.

   If ⊙: write nothing, move tape forward, stay in state **1**.

   If blank: write ☒, change to state **2**.

3. **Halt**. For all symbols, write nothing, do not move, change to state **2**.

Let's look at how this works with a sample tape.

1. The machine starts in the **State 0**. The tape has five symbols, and we're positioned at the start. This is the starting condition.

   [☒] ☒ ⊙ ☒ ⊙ ...

2. The state is **State 0**. The symbol is ☒, so the machine moves the tape forward and switches to **State 1**.

   ☒ [☒] ⊙ ☒ ⊙ ...

3. The state is **State 1**. The symbol is ☒, so the machine moves the tape forward and switches to **State 0**.

   ☒ ☒ [⊙] ☒ ⊙ ...

4. The state is **State 0**. The symbol is ⊙, so the machine moves the tape forward and stays in **State 0**.

   ☒ ☒ ⊙ [☒] ⊙ ...

5. The state is **State 0**. The symbol is ☒, so the machine moves the tape forward and switches to **State 1**.

   ☒ ☒ ⊙ ☒ [⊙] ...

6. The state is **State 1**. The symbol is ⊙, so the machine moves the tape forward and stays in **State 1**.

   ☒ ☒ ⊙ ☒ ⊙ [ ] ...

7. The state is **State 1** and the tape is blank: the machine moves th etape forward, writes ☒ and changes to **State 0**.

   ☒ ☒ ⊙ ☒ ⊙ [☒] ...

8. The state is **State 0** and the tape is blank: the machine writes a ⊙ and changes to **State 2**.

   ☒ ☒ ⊙ ☒ ⊙ ☒ [⊙] ...

9. In **State 2**, the machine halts. There are an even number of ☒ on the tape.

   ☒ ☒ ⊙ ☒ ⊙ ☒ [⊙] ...

42.4 Turing Machine Implementation

Our job is to write a Python script that simulates this kind of Turing Machine. The existence of such a script is proof that the Python language does everything a Turing Machine does. (Separately, we need to prove that a Turing Machine does everything that a mathematician could ever want.)

We'll need a model of the tape. A Python list can accomplish this nicely, we can populate the list with symbols like this:

```
tape = [ 'X', 'X', 'O', 'X', 'O', None, None, None ]
```

By adding a bunch of blank cells at the end of the tape, we can simplify our implementation. Theoretically, we have an infinite number of blank cells on the tape; therefore a well-written Turing Machine program will simply appned empty cells to the list as long as necessary. To get started, though, it's easy to simply pad the tap with blank cells.

We'll need a model of the rules. Each rule can be encoded as a tuple (or namedtuple) that has the required state change: the tape movement, symbol to write and the next state.

```
Rule = namedtuple( 'Rule', ['write', 'move', 'state'] )
```

For the `write` attribute, we can provide the symbol to be written, or `None` if nothing is to be written.

For the `move` attribute, we can use the values `+1`, `-1` or `None`.

For the `state` attribute, we can provide the number of the next state, or `None` if the machine should halt.

We can then code each state of our machine as a dictionary of rules that map a symbol on the tape to a state change tuple that shows what to do.

```
rule_0_map = {
    'X': Rule(None,+1,1),
    'O': Rule(None,+1,0),
    None: Rule(None,None,None) }
```

We can then code our transition rules as a whole as a dictionary that maps rule numbers to rules.

```
transitions = {
    0: rule_0_map,
    1: rule_1_map,
}
```

In order to simulate a Turing Machine, we need the following things:

- The initial tape.
- The transitions, which is a dictionary that maps a state to a set of rules. Each rule maps a tape symbol to a state change.
- A starting state number and starting tape position.

A relatively simply Python function can then step through this Turning machine cycle until the machine halts.

Turing Machine Function

Let T be a tape, a list of symbols.

Let M be the complete set of machine states and rules, $M = \{S_0, S_1, S_2, ...\}$. Each state is set of rules mapping from a symbol, C, to a state change, $S_n = \{C_0 \rightarrow \langle w, m, r \rangle_0, C_1 \rightarrow \langle w, m, r \rangle_1, ...\}$. Each state change, $\langle w, m, r \rangle$ specifies what symbol to write, w, what direction to move, m, and the next state, r.

1. **Initialize**. Set the initial tape position, P to 0, the start of the tape. Set the current state, S to state 0.
    1. **Cycle**. While the machine's state is not the halt state of `None`.

(a) **Eval**. Set C to the symbol at the current position, P, on the tape, T.

Given current state, S, and current symbol, C, determine which state change to use.

(b) **Apply**. Given the state change, $\langle w, m, r \rangle$, do the following.

- If indicated, write the requested symbol, w, in the new position. This updates the tape, T and the current position, P.
- Move the tape in the appropriate direction. This updates the current position, P: next is $m = +1$, previous is $m = -1$. No movement is `None`.

  Moving the tape to the next position may require extending the tape's `list` object to add a blank cell.
- Set the current state, S, to the next current state, r.

(c) **Log**. Optionally, print the current state of the machine to a log.

2. **Display**. Print the final state and final content of the tape.

42.5 Exercise 1

1. Define a function that implements the basic Turing Machine.

   `turing`(*transitions, tape*)
   Accepts a dictionary of transition rules and an input tape. Starts in rule 0 with tape at position 0. Executes the various transitions until the machine reaches a transition where the next state is None, then it halts.

   Prints a log showing the tape as it moves and changes.

2. Create a set of transitions to do the "Even X" processing. If the number of "X"s on the tape even, halt. If the number of "X"'s on the tape is odd, append an "X" and halt.

42.6 Test Machines

The point of defining this Turing Machine is to define what's Computable. Let's start by computing various kinds of natural numbers.

Let's say the input will encode numbers of as a sequence of `"X"` terminated by at least one `"O"`.

For example,

- Zero is a tape with '`["O"]`'.
- One is a tape with '`["X", "O"]`'.

First, consider creating a machine to do a simple "add 1" operation.

Add 1 Machine

1. If symbol is '`["O"]`': don't move, write '`["X"]`', change to state 2.

   If symbol is '`["X"]`': move to the next cell, stay in state 1.

2. For all symbols, move to the next cell, write "O", change to state 3.
3. For all symbols, halt.

Second, consider creating a machine to do a simple "subtract 1" operation.

Subtract 1 Machine

1. If symbol is '`["O"]`': Move to the previous cell, switch to state 2. Note that if the tape has zero, this will fall of the front of the tape, breaking the machine.

   If symbol is '`["X"]`': move to the next cell, stay in state 1.

2. For all symbols, write '`["O"]`', change to state 3.

3. For all symbols, halt.

We can see that with an "add 1" machine and a "subtract 1" machine, we can do a great deal of mathematics on natural numbers.

Add Two Numbers. Consider a machine that will add two numbers. We'd start with a tape that encoded two numbers, for example '`["X", "X", "O", "X", "X", "X", "O"]`'.

This machine would terminate with a sum with some extra '`"O"`' symbols. A result like '`["O", "O", "O", "X", "X", "X", "X", "X", "O"]`' would be expected.

We can implement this by combining our "add 1" and "subtract 1" machines. We need to an "add 1" to the right-hand number and a "subtract 1" on the left-hand number until the left-hand number vanishes in a flurry of '`"O"`' symbols.

Subtract Two Numbers. We can also subtract two numbers. We'd start with a tape that encoded two numbers, for example '`["X", "X", "O", "X", "X", "X", "O"]`'.

This machine would do "subtract 1" from each number until one of them has been reduced to zero. Depending on the locations of the '`"O"`' symbols we have a positive or negative result.

Yet More Math. Multiplication is repeated addition. Given two numbers, call them, l and r, we'd do this via (1) copy r to the end of the tape and (2) subtract 1 from l until r was reduced to zero.

You can also think of this machine a having three numbers on the tape: l and r and p. The machine would start by creating an extra '`"O"`' at the end of the tape to, effectively set p to zero. Then the cycle is "add r to p" and "subtract 1 from l", both of which we've already implemented.

Division, similarly, is repeated subtraction. Given two numbers, call them, l and r, create a third number, q at the end of the tape. To divide l and r, subtract r from l and add 1 to q. This is repeated until l is less than r.

Note that "comparison" is easily done via subtraction. However, the subtraction defined above is "destructive", in that it updates both numbers. One way to handle this is to make a complete copy of l and r for comparison purposes.

Optimization. Note that these naive repeated additional or repeated subtraction algorithms are inefficient. The point is to define what's computable in principle. Once we know what's computable, we can work at optimization later.

42.7 Exercise 2

1. Build the "add 1" and "subtract 1" machines.

2. Build a "test driver" program. This will exerise a given machine with particular inputs and check the outputs.

You'll need a function to create an input tape from a simple tuple. A tuple like '`(2, 3)`' should create a tape of '`["X", "X", "O", "X", "X", "X", "O"]`'.

You'll need a function to summarize the resulting tape into a simple tuple. A tape like '`["X", "X", "X", "O", "X", "X", "O"]`' should produce the tuple '`(2, 3)`'.

You can then define a machine, and an input tape. The resulting tape can be easily checked for the right answer.

Once we have the test driver, we can explore some alternate implementations. We can also explore some alternate definitions of Turing Machine processing rules.

42.8 Better Implementations

The initial implementation (using various kinds of strings and integers) suffers from a number of problems. We can (and will) use the **State** design pattern to fundamentally restructure the definition of a machine.

Machine. A `Machine` is a class definition that includes several attributes and methods.

- The `Tape`. The tape on which the Machine is currently working. This object can be responisble for tape's current position, plus the next and previous movements. Additionally, this class can handle growing the tape so that the next operation always works.
- The collection of states. Each state is an instance of the `State` class. Each `State` object is a collection of `Rule` objects.
- The current `State`. This is a variable that contains the machine's current state.
- `Machine.next()`, `Machine.prev()` methods to update the position of the tape.
- `Machine.write()` method to change the symbol on the tape.
- A `Machine.run()` method that accepts a tape, a state collection, and an identifier for a starting state. It steps through the machine's operating cycle with the given tape, printing a log of the tape at each step.

State. A `State` is a class definition that includes a rule for each symbol. We used a simple dictionary in the first implementation. A subclass of dictionary will be fine. We don't need to extend it, so we can have something like

```
class State( dict ):
    pass
```

State Change. We can use the **Command** design pattern to define some reusable command objects. We'll need a bunch of Command classes and instances. Each `StateChange` object is given a particular machine to update.

We can define an abstract super class called `StateChange`. Each specific state change is a polymorphic subclass to make specific changes to the Machine's Tape.

- `Write`. A `StateChange` subclass with a `Next.__call__( self, machine )()` method which calls '`machine.write(self.symbol)`'.
- `No_Write`. A `StateChange` subclass with a `Next.__call__( self, machine )()` method which does nothing.
- `Next`. A `StateChange` subclass with a `Next.__call__( self, machine )()` method which updates the machine by calling '`machine.next()`'.

- `Prev`. A `StateChange` subclass with a `Next.__call__( self, machine )()` method which updates the machine by calling '`machine.prev()`'.
- `Stay`. A `StateChange` subclass with a `Next.__call__( self, machine )()` method which does nothing.

Rule. Each `Rule` has several parts that we initially encoded as strings. Given these **Command** class definitions above, we can create a bunch of individual objects that slightly simplify our machine definition.

```
write_X = Write("X")
write_O = Write("O")
nothing = No_Write()
next = Next()
prev = Prev()
stay = Stay()
halt = None
```

Now we can create `Rule` objects using these objects instead of string literals. Instead of checking the rule's attributes for string values, we can directly invoke the rule's attributes, since they're callable objects.

A rule would now look like this.

```
rule_1_map = {
    'X': Rule(nothing, next, 0),
    'O': Rule(nothing, next, 1),
    None: Rule(write_x, next, halt) }
```

In our machine, we can then revise how we evaluate the rules. Instead something like this:

```
if rule.move == "next": machine.next()
elif rule.move == "next": machine.next()
else:
    assert rule.move is None
if rule.write is not None:
    machine.write( rule.write )
```

We can do the following:

```
rule.move( machine )
rule.write( machine )
```

Eliminating the **if** statements will result in a net speedup as well as a simplification.

Tape. The `Tape` class has define the tape as a list. It can also implement the next and previous, including a feature to extend the tape as necessary. This class can handle current position of the tape, also.

42.9 Exercise 3

1. Define the required classes for an object-based Turing Machine implementation.
    - Machine
    - State
    - StateChange
    - Rule

- Tape

2. Define a function that implements this new Turing Machine.

   `turing_obj`(*transitions, tape*)
   Accepts a dictionary of transition rules built using objects instead of strings and an input tape. Starts in rule 0 with tape at position 0. Executes the various transitions until the machine reaches a transition where the next state is None, then it halts.

   Prints a log showing the tape as it moves and changes.

3. Using your existing test driver from *Exercise 2*, assure yourself that the new machine works as well as the old machine.

42.10 Consequences

As we noted above, the set of real numbers is uncountably infinite. However, this Turing Machine definition of numbers can be shown to be countably infinite. This means that there are some real numbers which cannot be computed.

In spite of this gap between the two orders of infinity, there are enough real numbers that can be computed that it's fairly difficult to define the kinds of numbers which are not computable. Also, the set of computable numbers is closed under ordinary arithmetic operations: given two computable numbers the sum, difference, product or quotient are also computable.

What's more important is that our two implementations of Turing Machines prove that Python can easily work with all computable numbers. Consequently, the Python language (like all other programming languages) is "Turing Complete" and suitable for use doing anything that involves numbers.

Since we can encode almost anything as a number, we can create Python programs to process this domain of "almost anything". There are – at the fringes of mathematics – some things which cannot be encoded as numbers. That's way beyond the scope of this book. If you're interested, though, you can research the "Halting Problem", "Chaitin's Constant" and "The Busy Beaver Problem" for some things which are clearly not computable and things which may not be computable.

42.11 Other Applications

Some simple variations on the basic Turing Machine act as a pattern recognizers. These Finite State Machines are the typical solution to a large number of problems.

As an example, consider a machine to recognize simple dates in the form '`mm/dd/yyyy`'. We'll tolerate a single digit month or a single digit day. But we must have all four digits for the year.

Clearly, we'll have to expand our set of symbols to include all Unicode characters. Also, it's simpler if we work with "character classes" (i.e., digits) instead of patiently listing each symbol.

We can – if necessary – prove that a list of symbols is equivalent to a single symbol by patiently building the equivalent Turing Machine. The individual rule is simply repeated for each symbol in the class.

Also, we're not so much interested in processing a vague, general "Tape". We're interested in processing a specific string. However, a string – for our purposes – is a sequence and therefore is almost equivalent to a list.

Finally, we're never going to write. It's a read-only tape of symbols.

Instead of writing, we're going to holt in one of two states: an accepting state or a rejecting state. If we halt in an accepting state, the string of characters matched the desired pattern.

Short-Hand. We'll use a short-hand to define the Turing Machine that matches the above string. We'll just write the symbol, and the next state like this: '`digit: 1`'. We'll assume that we always move to next position on the input tape.

Further, for all other characters, not given explicitly in the rules, the machine simply halts in a "rejecting" state.

Pattern Matcher

1. digit: 1.
2. digit: 2. "/": 3.
3. "/": 3.
4. digit: 4.
5. digit: 5. "/": 6.
6. "/": 6.
7. digit: 7.
8. digit: 8.
9. digit: 9.
10. digit: 10.
11. At this point, we're at the end of the input string. We can halt, accepting the string as matching the pattern.

Building the Machine. One can see that the state transitions in this kind of simple pattern-matching machine are so simple that a short-hand notation could be used.

For example: '`"\d\d?/\d\d?/\d\d\d\d"`' would describe the pattern. In this case, '`"\d"`' stands for "match a digit and advance to the next state". And '`"\d?"`' stands for "match a digit and advance to the next state or look ahead to the next character and advance to the next state if it will match."

Refer back to the section on *Complex Strings: the re Module*. In essence, a regular expression pattern defines a kind of finishte-state machine to match the given string as if it was a specialized one-way tape.

42.12 Alternative Specifications

There are number of alternative formulations for the Turing Machine.

Two-way infinite tapes. Above, we assumed that the tape had an end and went infinitely far to the right. This has a nice parallel with the Python `list` structure. When the transition rule attempted a "next" at the end of the tape, we simply appended a new, empty cell to the list.

We can change this to allow the tape to stretch infinitely far to right or the left. To allow the tape to go infinitely far to the left, we have several choices:

- Continue to model the the tape as a `dict`. However, when we attempt to go to the previous cell from position 0, we need to insert a new, empty cell at position 0 and leave the position number alone.
- Model the tape as a `dict` and use `dict.setdefault()` to be sure that a new position has a proper empty cell before processing.

This is a little bit like creating a tape with a bunch of empty cells before and after the relevant data for the problem at hand.

Two-dimensional tapes. Instead of using a one-dimensional infinite tape, we could consider a two-dimensional magnetic "surface", which can be moved left, right, up and down.

This changes our "tape" dramatically. Rather than a simple list, we should probably use a `dict` with a two-tuple as the key. Our initial state would be at position '`(0,0)`' on the surface.

Our movement rules, would look something like this.

```
class Right( StateChange ):
    def __call__( self, machine ):
        x, y = machine.position
        machine.position = x+1, y

class Left( StateChange ):
    def __call__( self, machine ):
        x, y = machine.position
        machine.position = x-1, y
```

The contents of the surface, then, would be available as '`surface.setdefault( position, None )`'. This would return any value that was on the surface, and create an empty cell if necessary.

Multi-Step movement of the head. Above, we simplified the tape movements to be one-step. Either previous and next, or up, down, left and right. We can also change the definition to permit multiple-step movements instead of single-step movements.

This would extend our basic state change class definitions to accept a parameter with the distance to move.

In most cases, there isn't an easy way to make use of this extension. Most of the processing we can imagine requires stepping over each symbol one at time. We might, however, slightly simpliify some pattern recognition with multiple-position skips.

Multiple tapes. An interesting extension is to add a second tape. In this case, we have two input symbols and two sets of transitions. Either tape can be moved and either tape can write a new symbol.

You might use one tape for input and one tape for the results. In this case, and "Add 1" operation would copy all the input symbols to the output tape, and then write one extra symbol to the output tape.

Arbitrary Alphabet. As we noted in Other Applications, it's sensible to allow a much larger alphabet than just two symbols.

Simpler State Changes. We defined our machine to do both a tape movement and a write. We specified that the tape movement could be next, previous or none. We also said that there could be an optional write of a new symbol.

This can be broken down into finer steps. We can, for example, separate the moving and the writing and say that a rule has the following attributes:

- A current symbol on the tape to match.
- A change: either move the tape, or write.
- Next State.

This would create additional states in some machines because we would have to separate writing from moving the tape.

42.13 Exercise 4

Pick one of these alternate formalation for the Turing Machine.

- Two-way infinite tapes.
- Two-dimensional tapes.
- Multi-Step movement of the head.
- Multiple tapes.
- Simpler State Changes.

1. Implement a new Turing Machine with this alternate formulation.
2. Revise your test cases from Exercise 2 to fit your new machine formulation.
3. Create an additional test simply to exercise each feature of your new machine.

There is an important question raised by the alternative formulations of the Turing Machine. Do these alternatives allow more computable numbers?

It turns out we can find a way to build any of these machines using any other machine. They are all provably identical.

CHAPTER

FORTYTHREE

MAH JONGG HANDS

The game of Mah Jongg is played with a deck of tiles with three suits with ranks from one to nine. There are four sets of these 27 tiles. Additionally there are four copies of the four winds and three dragons. This gives a deck of 136 tiles.

The three suits are dots, bamboo and "characters" (wan, 万 simplified or 萬 traditional). The ranks are the numbers one to nine. [One story is that the dots are chinese coins, the "bamboo" are stacks of 100 coins that and the "wan" represents 10,000 coins.] Since these tiles have ranks, they can form a variety of interesting combinations including matches and sequences.

The winds and dragons are collectively called "honors". There are four winds: East (東), South (南), West (西), and North (北). There are three dragons: White (白), Red (中), and Green (發). These honors tiles don't have ranks, merely names. Since there are four of each, these tiles can only participate in matching; there's no sequence of winds combination.

In some variations of the game there are also jokers, seasons and flowers. We'll leave these out of our analysis for the moment.

43.1 Tile Class Hierarchy

We can define a parent class of `Tile`, and two subclasses: `SuitTile` and `HonorTile`. These have slightly different attributes.

The `SuitTile` class has suit and rank information.

The `HonorTile` class merely has a unique name.

The superclass can define a basic comparison function, `__eq__()`, that compares `self.getName()` to `other.getName()` to see if the other tile has the same name. For `SuitTile`, the name includes rank and suit.

The `SuitTile` class, however, needs to define methods for `__lt__()`, `__le__()`, `__gt__()` and `__ge__()` to compare rank and suit.

The `HonorTile` class can simply return False for the various `__lt__()` and `__gt__()`. The implementation of `__ge__()` and `__le__()` must simply use `__eq__()`.

class `Tile()`

`__init__`(*self, name*)
Build this tile from the given name.

`__str__`(*self*)
Returns the `Tile.getName()` value.

`__eq__`(*self, other*)
This is simply '`self.getName() == other.getName()`'.

`__ne__`(*self, other*)
This is simply '`self.getName() != other.getName()`'.

`getSuit`(*self*)
Returns `NotImplemented`; each subclass must override this.

`getRank`(*self*)
Returns `NotImplemented`; each subclass must override this.

`getName`(*self*)
Returns the tile's name.

class `SuitTile`(*Tile*)

`__init__`(*self, rank, suit*)
Initializes a tile with rank and suit instead of name.

`getSuit`(*self*)
Returns this tile's suit

`getRank`(*self*)
Returns this tile's rank

`getName`(*self*)
Returns this tile's full name, including suit and rank.

`__lt__`(*self, other*)
Compares rank and suit.

`__le__`(*self, other*)
Compares rank and suit.

`__gt__`(*self, other*)
Compares rank and suit.

`__ge__`(*self, other*)
Compares rank and suit.

class `HonorTile`(*Tile*)

`getSuit`(*self*)
Returns `None`.

`getRank`(*self*)
Returns `None`.

`getName`(*self*)
Returns this tile's full name.

`__lt__`(*self, other*)
Returns `False`.

`__le__`(*self, other*)
Returns the value of `HonorTile.__eq__()`.

`__gt__`(*self, other*)
Returns `False`.

`__ge__`(*self, other*)
Returns the value of `HonorTile.__eq__()`.

If we use the names `"Bamboo"`, `"Character"` and `"Dots"`, this makes the suits occur alphabetically in front of the honors without any further special processing. If, on the other hand, we want to use Unicode characters for the suits, we should add an additional sort key to the `Tile` that can be overridden by `SuitTile` and `HonorsTile` to force a particular sort order.

Note that the two ranks of one and nine have special status among the suit tiles. These are called *terminals*; ranks two through eight are called *simples*. Currently, we don't have a need for this distinction.

Build The Tile Class Hierarchy. First, build the tile class hierarchy. This includes the `Tile`, `SuitTile`, `HonorTile` classes. Write a short test that will be sure that the equality tests work correctly among tiles.

43.2 Wall Class

You hould also define a Mah Jongg `Wall` class which holds the initial set of 136 tiles. We can create additional subclasses to add as many as a dozen more tiles to include jokers, flowers and seasons.

Shuffling and Dealing

Mah Jongg tiles are too large to manipulate like playing cards. They are shuffled by stirring them face down in the middle of the table. Then the tiles are stacked to make a wall with four sides. Each side is a row 17 tiles long and two tiles tall. Since this is a gambling game, there are fairly colorful procedures for establishing where people will sit, who will deal first, which of the four sides will be dealt from and where along the side the dealing will begin.

class `Wall()`

`__init__`(*self*)
Create the set of 136 tiles. This is four copies of the following tiles:

- The twenty-seven combinations of each suit (dot, bamboo, and character) and each rank (one through nine).
- The seven honor tiles (east, south, west, north, red, white, green).

`__str__`(*self*)
Display information about the wall.

`shuffle`(*self*)
Shuffles the wall tiles.

`deal`(*self*)
Return the next undealt tile. This will not enumerate through all of the tiles. Generally, six tiles will remain undealt.

The wall is nearly identical with a deck of playing cards. See *Advanced Class Definition Exercises* for more guidance on this class design.

Build The Wall Class. Design and implement the `Wall`. Write a short test that will be sure that it shuffles and deals tiles properly.

43.3 TileSet Class Hierarchy

A winning Mah Jongg hand generally as 14 tiles in five scoring *sets*. Exactly one of these stes must be a pair. The remaining sets are generally four groups of three tiles.

Under some circumstances, there can one ore more 4-of-a-kind sets, and the hand will also be larger. This can happen when you are holding three-of-a-kind and draw the fourth. Your hand must be extended by one tile to become 15 tiles in size. Clearly, this can only happen four times, leading to an upper limit of a four groups of four tiles.

There are four varieties of set:

- Pair. Two matching tiles; either honor tiles with the same name, or suit tiles with the same rank and suit.
- Three of a kind. Three matching tiles.
- Sequence of three in a row of the same suit. Only suit tiles can participate in a sequence. The same suit is an essential feature.
- Four of a kind.

The most common winning hands have 14 tiles: 4 sets of three and a pair.

A Mah Jongg `Hand` object, then, is a list of `Tile`s. This class needs a method, `mahjongg()` that returns `True` is the hand is a winning hand. The evaluation is rather complex, because a tile can participate in a number of sets, and several alternative interpretations may be necessary to determine the appropriate use for a given tile.

Consider a hand with 2, 2, 2, 3, 4 of bamboo. This is either a set of three 2's and a non-scoring 3 and 4, or it is a pair of 2's and a sequence of 2, 3, 4.

The `mahjongg()` method, then must create five `TileSet` objects, assigning individual `Tile`s to the `TileSet`s until all of the `Tile`s find a home. The hand is a winning hand if all sets are full, there are five sets, and one set is a pair.

We'll cover the design of the `TileSet` classes in this section, and return to the design of the `Hand` class in the next section.

The Set Class Hierachy. We can create a class hierarchy around the four varieties of `TileSet`: pairs, threes, fours and straights. A `PairSet` holds two of a kind: both of the tiles have the same name or the same suit and rank. A `ThreeSet` and `FourSet` are similar, but have a different expectation for being full. A `SequenceSet` holds three suit tiles of the same suit with adjacent ranks. Since we will sort the tiles into ascending order, this set will be built in ascending order, making the comparison rules slightly simpler.

We'll define a `TileSet` superclass to hold a sequence of `Tile`s. We will be able to add new tiles to a `TileSet`, as well as check to see if a tile could possibly belong to a `TileSet`. Finally, we can check to see if the `TileSet` is full. The superclass, `TileSet`, is abstract and returns `NotImplemented` for the `full()` method. The sublasses will override this methods with specific rules appropriate to the kind of set.

class `TileSet()`

`__init__`(*self*)
Create a new, empty set of Tiles.

`__str__`(*self*)
Representation of the contents of this set.

`canContain`(*self, aTile*)
The superclass `canContain()` method returns `True` if the list is empty; it returns `False` if the list

is full. Otherwise it compares the new tile against the last tile in the list to see if they are equal. Since most of the subclasses must match exactly, this rule will be used.

The sequence subclass must override this to compare suit and rank correctly.

`add`(*self, aTile*)
The `add()` method appends the new tile to the internal list. A `pop()` function can remove the last tile appended to the list.

`full`(*self*)
The superclass will return `NotImplemented`. Each subclass must override this.

`fallback`(*self, tileStack*)
The superclass `fallback()` pushes all of the tiles from the `TileSet` back onto the given stack. The superclass version pushes the tiles and then returns `None`. Each subclass must override this to return a different fallback `TileSet` instance.

`pair`(*self*)
The superclass `pair()` method returns `False`. The `PairSet` subclass must override this to return `True`.

An important note about the `fallback()` method is that the stack that will be given as an argument in `tileStack` is part of the `Hand`, and is maintainted by doing '`tileStack.pop(0)`' to get the first tile, and '`tileStack.insert( 0, aTile )`' to push a tile back onto the front of the hand of tiles.

We'll need the following four subclasses of `TileSet`.

class `FourSet`(*TileSet*)
Specializes `TileSet` for sets of four matching tiles. The `full()` method returns `True` when there are four elements in the list.

The `fallback()` method pushes the set's tiles onto the given `tileStack`; it returns a new `ThreeSet` with the first tile from the `tileStack`.

class `ThreeSet`(*TileSet*)
Specializes `TileSet` for sets of three matching tiles. The `full()` method returns `True` when there are three elements in the list.

The `fallback()` method pushes the set's tiles onto the given `tileStack`; it returns a new `SequenceSet` with the first tile from the `tileStack`.

class `SequenceSet`(*TileSet*)
Specializes `TileSet` for sets of three tiles of the same suit and ascending rank.

The `canContain()` returns `True` for an empty list of tiles, `False` for a full list of tiles, otherwise it compares the suit and rank of the last tile in the list with the new tile to see if the suits match and the new tile's rank is one more than the last tile in the list.

The `full()` method returns `True` when there are three elements in the list.

The `fallback()` method pushes the set's tiles onto the given `tileStack` ; it returns a new `PairSet` with the first tile from the `tileStack`.

class `PairSet`(*TileSet*)
The `full()` method returns `True` when there are two elements in the list.

The `fallback()` method is inherited from the superclass method in `TileSet`; this method returns None, since there is no fallback from a pair.

This subclass also returns `True` for the `pair()` method.

The idea of these class definitions is that the Hand can attempt to use a `FourSet` to collect a group of tiles. If this doesn't work out, we put the tiles back into the hand, and try a `ThreeSet`. If this doesn't work out,

we put the tiles back and try a SequenceSet. The last resort is to try a PairSet. There is no fallback after a pair set, and the hand cannot be a winner.

43.4 Hand Class

A Mah Jongg Hand object, then, is a list of Tiles The `mahjongg()` creates an assignment of individual TileSets It checks these sets to see if all of them are full, if there are five of them and if one of the five is a pair. If so, it returns `True` because the hand is a winning hand.

If we sort the tiles by name or suit, we can more effectively assign tiles to sets. The first step in the `mahjongg()` method is to sort the tiles into order. Then the tiles can be broken into sets based on what matches between the tiles.

Hand Scoring

The `mahjongg()` function examines a hand to determine if the tiles can be assigned to five scoring sets, one of which is a pair.

1. **Sort Tiles**. Sort the tiles by name (or suit) and by rank for suit tiles where the suit matches. We will treat the hand of tiles as a tile stack, popping and pushing tiles from position 0 using '`pop(0)`' and '`insert(0,tile)`'.
2. **Stack of TileSets**. The candidate set definition is a stack of TileSet objects. Create an empty list to be used as the candidate stack. Create a new, empty FourSet and push this onto the top of the candidate stack.
3. **Examine Tiles**. Use the `examine()` function to examine the tiles of the hand, assigning tiles to TileSets in the candidate stack. When this operation is complete, we may have a candidate assignment that will contain a number of TileSets, some of which are full, and some are incomplete. We may also have an empty stack because we have run out of fallback TileSets.
4. **While Not A Winner**. While we have TileSets in the candidate stack, use the `allFull()` to see if all TileSets are full, there are five sets, and there is exactly one pair. If we do not have five full TileSets and a single pair, then we must fallback to another subclass of TileSet.
   (a) **Retry**. Use the `retry()` method to pop the last candidate TileSet, and use that TileSet's `fallback()` to create a different TileSet for examination. Save this TileSet in `n`.
   (b) **Any More Assignments?** If the result of `retry()` is `None`, there are no more fallbacks; we can return `False`.
   (c) **Examine Tiles**. Append the TileSet, `n`, returned by `retry()` to the candidate stack. Use the `examine()` function to examine the tiles of the hand, assigning tiles to TileSets. When this operation is complete, we may have a candidate assignment that will contain a number of TileSets, some of which are full, and some are incomplete.
5. **Winner?** If we finish the loop normally, it means we have a candidate set assignment which has five full sets, one of which is a pair. For some hands, there can be multiple winners; however, we won't continue the examination to locate additional winning assignments.

The `allFull()` function checks three conditions: all TileSets are full, there are five TileSets, and is one TileSet is a pair. The first test, all TileSets are full, can be done with the built-in `all()` function, looking something like the following '`all( s.full() for s in sets )`'.

Examine All Tiles

The `examine()` method requires a non-empty stack of candidate `TileSet`s, created by the `mahjongg()` method. It assigns all of the remaining tiles beginning with the top-most candidate `TileSet`. Initially, the entire hand is examined. After each retry, some number of tiles will have been pushed back into the hand for re-examination.

1. **While More Tiles**. If the tile stack in the `Hand` is empty, we are done, all tiles have been assigned to Sets.
   (a) **Next Tile**. Pop the next unexamined tile from the tile stack, assigning it to the variable `t`.
   (b) **Topmost Set Full?** If the topmost set on the set stack is full, push a new, empty `FourSet` onto the top of the set stack. (This is also a handy place to use a **print** statement to watch the progress of the evaluation.)
   (c) **Topmost Set Can Contain?** If the top-most `TileSet` can contain Tile `t`, add this tile to the set. We're done examining this tile.
   (d) **Topmost Set Can't Contain**. Put the tile `t` back into the stack of tiles to be examined. Use the `retry()` function to pop the `TileSet` from the stack, and fallback to another subclass of `TileSet`.
   (e) **Another Retry?** If the result of the `retry()` is `None`, we've run out of alternatives, return from this function. Otherwise, append the new `TileSet` created by `retry()` to the stack of candidate sets.

Retry a TileSet Assignment

The `retry()` method requires at least one `TileSet` in the assignments. This will pop that `TileSet`, pushing the tiles back into the hand. It will then use the popped `TileSet`'s `fallback()` method to get another flavor of `TileSet` to try.

1. **Pop**. Pop the top-most TileSet from the TileSet stack, assign it to `s`. Call `s fallback()` method to get a new top-most `TileSet`, assign this to `n`.
2. **Out Of Fallbacks?** While the TileSet stack is not empty and `n` is `None`, there was no fallback.
   (a) **Pop Another**. Pop the top-most set from the set stack, assign it to `s`. Call `s fallback()` method to get a new top-most `TileSet`, assign this to `n`.
3. **Done?** If `n` is `None` and the set stack is empty, the hand is incomplete and we are out of fallback sets. Otherwise, append `n` to the stack of TileSets.

43.5 Some Test Cases

The following test case is typical.

```
Bamboo: 2, 2, 2, 3, 4, 5, 5, 5
Dots: 2, 2, 2
Green Dragon |times| 3
```

In this case, we will attempt to put the "2 Bamboo" tiles into a TileSet of four. No other tile will fill this TileSet. After looking at the remaining tiles, we'll pop that incomplete TileSet, and put them into a TileSet of three. This will be full, so we'll move on.

The "3 Bamboo" will be put into a set of four. No other tile can fill this set, so we'll pop it, and put the "3 Bamboo" into a set of three. Again, no other tile can fill this set, so we'll pop that, and fill back to a Sequence. This set will be filled with the 4 and 5.

The remaining two "5 Bamboo" tiles will be put into a set of four (which won't be filled), a set of three (which won't be filled), a straight (which won't be filled) and finally a pair.

The three "2 Dots" tiles will be put into a set of file (which won't be filled) and a set of three. The fate awaits the three green dragon tiles.

The final set stack will have a three set, a straight, a pair, and two three sets. This meets the rules for five full sets, one of which is a pair.

```
def testHand1():
    t1= [ SuitTile( 2, "Bamboo" ), SuitTile( 2, "Bamboo" ),
        SuitTile( 2, "Bamboo" ), SuitTile( 3, "Bamboo" ),
        SuitTile( 4, "Bamboo" ), SuitTile( 5, "Bamboo" ),
        SuitTile( 5, "Bamboo" ), SuitTile( 5, "Bamboo" ),
        SuitTile( 2, "Dot" ), SuitTile( 2, "Dot" ),
        SuitTile( 2, "Dot" ), HonorsTile( "Green" ),
        HonorsTile( "Green" ), HonorsTile( "Green" ), ]
    h1=  Hand( *t1 )
    print h1.mahjongg()
```

More Complex. The following test case is a little more difficult.

```
Bamboo: 2, 2, 2, 2, 3, 4
Green Dragon |times| 3
Red Dragon |times| 3
North Wind |times| 2
```

The initial run of four "2 Bamboo" tiles will be put into a set of four.

The next "3 Bamboo" and "4 Bamboo" tiles will be put into a four set (which won't be filled), a three set and straight. None if this will be successful.

We then pop the initial set of four "2 Bamboo" tiles and replace that with a set of three. The "2 Bamboo" will be tried in a set of four, and a set of three before it winds up in a sequence. This sequence will allow the "3 Bamboo" and the "4 Bamboo" to be added.

The remaining honors will be tried against four sets and then three sets before the hand is found to be valid.

Another Test. Here's a challenging test case with two groups of tiles that require multiple retries.

Here's a summary of the hand.

```
Bamboo: 2, 2, 2, 3, 4, 5, 5, 5
Dots:  2, 2, 2, 2, 3, 4
```

Here's the test fixture.

```
def testHand2():
    t2= [ SuitTile( 2, "Bamboo" ), SuitTile( 2, "Bamboo" ),
        SuitTile( 2, "Bamboo" ), SuitTile( 3, "Bamboo" ),
        SuitTile( 4, "Bamboo" ), SuitTile( 5, "Bamboo" ),
        SuitTile( 5, "Bamboo" ), SuitTile( 5, "Bamboo" ),
        SuitTile( 2, "Dot" ), SuitTile( 2, "Dot" ),
        SuitTile( 2, "Dot" ), SuitTile( 2, "Dot" ),
        SuitTile( 3, "Dot" ), SuitTile( 4, "Dot" ), ]
```

```
    h2=  Hand( *t2 )
    print h2.mahjongg()
```

Ideally, your overall unit test looks something like the following.

```
import unittest
class TestHand_1(unittest.TestCase):
    def setUp( self ):
        Create the hand
    def testHand1_should_mahjongg( self ):
        self.assert_( h1.mahjongg() )
        self.assertEqual( str(h1.sets[0]), "ThreeSet['2B', '2B', '2B']" )
        self.assertEqual( str(h1.sets[1]), "SequenceSet['3B', '4B', '5B']" )
        self.assertEqual( str(h1.sets[2]), "PairSet['5B', '5B']" )
        self.assertEqual( str(h1.sets[3]), "ThreeSet['2D', '2D', '2D']" )
        self.assertEqual( str(h1.sets[4]), "ThreeSet['Green', 'Green', 'Green']" )

class TestHand_2(unittest.TestCase):
    def setUp( self ):
        Create the hand
    def testHand2_should_mahjongg( self ):
        self.assert_( h2.mahjongg() )
        ... check individual TileSets

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

A set of nine interesting test cases can be built around the following set of tiles: 3 ×1's, 2, 3, 4, 5, 6, 7, 8, and 3 ×9's all of the same suit. Adding any number tile of the same suit to this set of 13 will create a winning hand. Develop a test function that iterates through the nine possible hands and prints the results.

43.6 Hand Scoring - Points

A hand has a point value, based on the mixture of `TileSet`s. This point value is used to resolve the amount owed to the winner by the losers in the game. There is a subtlety to this evaluation that we have to gloss over, and that is the rules about for *concealed* and *exposed* or *melded* TileSets. For now, we will assume that all TileSets are concealed.

Exposed and Melded Sets

During the play of Mah Jongg, a player will drawn a tile from the `Wall` and evaluate their hand. If the hand is a winner, the game is over. Otherwise, the player will discard a tile.
With some minor restrictions, a player can draw the last tile discarded by another player to make a complete set; the player must expose the set to do draw the discard.
If the player completes a set with a tile drawn from the wall, they do not have to expose it, so the set is concealed. Concealed sets are worth more than exposed sets.
There are number of variations in the rules for drawing discarded tiles and exposing sets. We'll avoid much of this complexity, and focus on assigning point values to the sets using just the rules for concealed sets.

We need to expand our definition of `SuitTile`. There are two different score values for `SuitTile`s: the terminals (one and nine) have one score, and the simples (two through eight) have a different score. This will lead to two subclasses of `SuitTile`: `TerminalSuitTile` and `SimpleSuitTile`.

A winning hand has a base value of 20 points plus points assigned for each of the four scoring sets and the pair.

TileSet	Simples	Terminals or Honors
SequenceSet	0	0
ThreeSet	4	8
FourSet	16	32

The PairSet is typically worth zero points. However, the following kinds of pairs can add points to a hand.

- A pair of dragons is worth 2 points.
- A pair of winds associated with your seat at the table is worth 2 points.
- A full game consists of four rounds. Each round has a *prevailing* wind. Within each round, each of the players will be the dealer. A pair of the round's prevailing winds is worth 2 points.
- A *double wind* pair occurs when your seat's wind is also the prevailing wind. A pair of this wind is worth 4 points.

There are a few more ways to add points, all related to the mechanics of play, not to the hand itself.

Update the Tile Class Hierarchy. You will need to add two new subclass of SuitTile: `TerminalSuitTile` and `SimpleSuitTile`.

You will want to upgrade Wall to correctly generate the various `HonorsTile`, `TerminalSuitTile` and `SimpleSuitTile` instances.

You may also want to create a *Generator* for tiles. A function similar to the following can make programs somewhat easier to read.

```
def tile( *args ):
    """tile(name) -> HonorsTile
    tile( rank, suit ) -> SuitTile
    """
    if len(args) == 1:
        return HonorsTile( *args )
    elif args[0] in ( 1, 9 ):
        return TerminalSuitTile( *args )
    else:
        return SimpleSuitTile( *args )
```

Update the TileSet Class Hierarchy. You will need to add at least one new method to the TileSet classes.

class `TileSet()`

`points`(*self, prevailingWind, myWind*)
Examine the first Tile of the TileSet to see if it is `simple()` or not, and return the proper number of points.

The two wind parameters aren't used for most TileSet subclasses.

In the case of PairSet, however, the first Tile must be checked against two rules. If *prevailingWind* is the same as *myWind* and the same as the tile's name, this is worth 4 points. If the tile's `lucky()` method is `True` (a dragon, or one of the two winds), then the value is 2 points.

Update the Hand Class. You'll want to add at least one new method to the Hand class.

class Hand()

points(*self, prevailingWind, myWind*)
Compute the total number of points for a hand.

pointReport(*self, prevailingWind, myWind*)
Print a small scorecard for the hand, showing each set and the points awarded.

You will want to revise your unit tests, also, to reflect these changes. You'll also need to add additional unit tests to check the number of points in each hand.

Test Cases. For the first test cases in the previous *Some Test Cases*, here are the scores.

Set	Points
Winning	20
ThreeSet['2B', '2B', '2B']	4
StraightSet['3B', '4B', '5B']	0
PairSet['5B', '5B']	0
ThreeSet['2D', '2D', '2D']	4
ThreeSet['Green', 'Green', 'Green']	8
Points	36

For the second test cases in *Some Test Cases*, here are the scores. The assumption here is that we're not sitting at North, and we're not playing the final four hands (where the *prevailing* wind is North.)

Set	Points
Winning	20
ThreeSet['2B', '2B', '2B']	4
StraightSet['2B', '3B', '4B']	0
ThreeSet['Green', 'Green', 'Green']	8
ThreeSet['Red', 'Red', 'Red']	8
PairSet['N', 'N']	0
Points	36

For the third test cases in *Some Test Cases*, here are the scores.

Set	Points
Winning	20
ThreeSet['2B', '2B', '2B']	4
StraightSet['3B', '4B', '5B']	0
PairSet['5B', '5B']	0
ThreeSet['2D', '2D', '2D']	4
StraightSet['2D', '3D', '4D']	0
Points	28

Be sure to add a test case with *lucky tiles* (dragons or winds) as the pair.

43.7 Hand Scoring - Doubles

The point value for a hand can be doubled a number of times for a variety of rare achievements. Most of these rules of these are additional properties of `TileSet`s that are summarized by the `Hand`.

Each non-pair `TileSet` that contains lucky tiles is worth 1 double (2 ×). In the case of the player's wind being the prevailing wind, a `TileSet` of this wind is worth 2 doubles (4 ×)

A hand of four `ThreeSet` or `FourSet` (i.e., no `SequenceSet`) merits a double. Depending on how the hand was played and how many of these triples were concealed or melded, the hand can have a second double, or

possibly even pay the house limit, something we'll look into in *Limit Hands*. For now, we are ignoring these mechanics of play issues, and will simply double the score if there are no SequenceSets.

A hand that has three consecutive SequenceSets in the same suit is doubled. There are many rule variations on this theme, including same-rank sequences from all three suits, same-rank ThreeSet s or FourSets from all three suits. We'll focus on the three-consecutive rule for now.

If the hand is worth exactly 20 points (it is all SequenceSets and an unlucky PairSet), then it merits one double for being all non-scoring sets.

There are six different consistency tests. These are exclusive and at most one of these conditions will be true.

1. If the hand is all terminals and honors (no simples), it is doubled.
2. If each set in the hand has one terminal or an honor in it, the hand is doubled. A hand could have four SequenceSet s, each of which begins with one or ends with nine, and a pair of honors or terminals to qualify for this double.
3. If the hand is all simples (no terminals or honors), it is doubled.
4. If all of the SuitTiles are of the same suit, and all other tiles are HonorsTiles, this is doubled.
5. If all of the SuitTiles are of the same suit, and there are no HonorsTiles, this is doubled four times (16?).
6. If the hand contains TileSets of all three dragons, and one of those sets is a PairSet, this is called the *Little Three Dragons*, and the hand's points are doubled.

There are a few more ways to add doubles, all related to the mechanics of play, not to the hand itself.

Update TileSet Class Hierarchy. You'll need to add the following functions to the TileSet classes.

class `TileSet()`

`lucky`(*self, prevailingWind, myWind*)
: For the ThreeSet or FourSet subclasses, this returns `True` for a complete set with lucky tiles (dragons, the prevailing wind or the player's wind.)

  Other subclasses of TileSet return `False`.

`triplet`(*self*)
: Returns `True` for a ThreeSet or FourSet. Other subclasses of TileSet return `False`.

  This is used to see if a hand is all threes or fours, which merits a double. The name "triplet" isn't literally true; a literally true function name would be cumbersome.

`sequenceSuit`(*self*)
: Returns the suit of a SequenceSet. For this class only, it should be based on the `suit()` method described below.

  Other subclasses of of TileSet return `None`.

`sequenceRank`(*self*)
: Returns the lowest rank of a SequenceSet.

  Other subclasses of of TileSet return `None`.

`allSimple`(*self*)
: Returns `True` if the TileSet contains only simple tiles.

`noSimple`(*self*)
: Returns `True` if the TileSet contains no simple tiles. This is an all terminals and honors TileSet.

This is not the opposite of `allSimple()`. A `SequenceSet` could have a mixture of Terminal and Simple tiles, so there are three cases: allSimple, noSimple and a mixed bag.

`oneTermHonor`(*self*)
Returns `True` if the `TileSet` contains one terminal or honor. Since we only have a `simple()` function, this means there is one non-simple `Tile` in the `TileSet`.

`suit`(*self*)
If all tiles have the same value for `Tile.getSuit()`, return that value. If there is a mixture of suits, or suits of `None`, return `None`.

`bigDragon`(*self*)
For the `ThreeSet` class or `FourSet` class, return `True` if all tiles are Dragons.

Other subclasses of TileSet return `False`.

`littleDragon`(*self*)
For the `PairSet` class, return `True` if all tiles are Dragons.

Other subclasses of TileSet return `False`.

Update Hand Class. You'll need to add the following functions to the `Hand` classes.

class `Hand()`

`luckySets`(*self, prevailingWind, myWind*)
Returns the number of lucky sets. This function also checks for the double wind conditions where *prevailWind* is the same as *myWind* and one of the `TileSet`s has this condition and throws an additional doubling in for this.

`groups`(*self*)
Returns `1` if all `TileSet`s have the `triple()` property `True`.

`sequences`(*self*)
Returns `1` if three of the `TileSet`s have the same value for `sequenceSuit()`, and the values for `sequenceRank()` are 1, 4, and 7.

`noPoints`(*self*)
Returns `1` all of the `TileSet`s are worth zero points.

`consistency`(*self*)
Returns `1` or `4` after checking for the following conditions:

- If `allSimple()` is true for all `TileSet`s, return `1`.
- If `noSimple()` is true for all `TileSet`s, return `1`.
- If `oneTermHonor()` is true for all `TileSet`s, return `1`.
- If every `TileSet` has the same value for `suit()` and there is no `TileSet` where `suit()` is `None`, return `4`.
- If every `TileSet` has the same value for `suit()` or the value for `suit()` is `None`, return `1` .
- If there are two `TileSet`s for which `bigDragon()` is true, and one `TileSet` for which `littleDragon()` is true, return `1`.

The sum of the double functions is the total number of doubles for the hand. This is given by code something like the following.

```
doubles = hand.luckySets( wind_prevail, wind_me ) + hand.groups() + hand.sequences() + hand.noPoints() + hand.consi
final_score = 2**doubles * base_points
```

An amazing hand of all one suit with three consecutive sequences leads to 5 doubles, 32 ×the base number of points.

class `Hand()`

`doubleReport`(*self*)
Prints a small scorecard for the hand, showing each double that was awarded. You can then write a `scoreCard()` which produces the `pointReport()`, the `doubleReport()` and the final score of $2^d \times p$, where d is the number of doubles and p is the base number of points.

The total score is often rounded to the nearest 10, as well as limited to 500 or less to produce a final score. This final score is used to settle up the payments at the end of the game.

Loser's Pay

There are a number of variations on the payments at the end of the game. The simplest version has all losers paying an equal amount to the winner. Generally, if the dealer wins, the payments to the dealer are doubled, and when the dealer loses, the payment to the winner is doubled.
There are some popular scoring variations that penalize the player who's discard allowed another player to win.

43.8 Limit Hands

At the end of a hand of Mah Jongg, the winner is paid based on the final score of the hand. Generally, the final score is limited to 500 points. There are, however, some extraordinary hands which simply score this limit amount. These conditions are checked first; if none of these are true, then the normal hand scoring is performed.

- The *Big Three Dragons* hand has three `TileSet`s for which the `bigDragon()` function is true.
- The *Little Four Winds* hand has three `ThreeSet`s or `FourSetss` for which the `wind()` function is true and a `PairSet` for which `wind()` is true.
- The *Big Four Winds* hand has four `ThreeSet`s or `FourSets` s for which the `wind()` function is true.
- The *All Honors* hand has all `TileSet`s composed of `HonorsTile`s; these will all have either `wind()` or `dragon()` true.
- The *All Terminals* hand has all `TileSet`s composed of `TerminalSuitTile`s.
- An additional hand that pays the limit also breaks many of the rules for a winning hand. This is the *Thirteen Orphans* hand, which is one each of the various terminals and honors: three dragons, four winds, three one's, three nine's and any other of the thirteen terminal and honor tiles. This requires a special-case test in `Hand` that short-cuts all of the evaluation algorithm.

An interesting limit hand is the *Nine Gates* hand, which is 3?1's, 2, 3, 4, 5, 6, 7, 8, and 3?9's all of the same suit. Any other tile of this suit will create a winning hand that pays the limit. Just considering the hand outside the mechanics of play, it would get four doubles because it is all one suit, plus the possibility of an additional double for consecutive sequences. The Nine Gates hand is only a limit hand if the player draws it as a completely concealed hand.

There are a few other limit hands, including all concealed triplets, or being dealt a winning hand. These, however, depend on the mechanics of play, not the hand itself.

Update Set Class Hierarchy. You'll want to add `wind()` and `dragon()` methods to the `TileSet` hierarchy. These return `True` if all `Tile`s in the `TileSet` are a wind or a dragon, respectively.

Update Hand Class. You can add six additional methods to `Hand` to check for each of these limit hands. The final step is to update the `finalScore()` to check for limit hands prior to computing points and doubles.

CHAPTER

FORTYFOUR

CHESS GAME NOTATION

See *Chessboard Locations* for some additional background.

Chess is played on an 8x8 board. One player has white pieces, one has black pieces. Each player's pieces include eight pawns, two rooks, two knights, two bishops, a king and a queen. The various pieces have different rules for movement. Players move alternately until one player's king is in a position from which it cannot escape but must be taken, or there is a draw. There are a number of rules that lead to a draw, all beyond the scope of this problem. White moves first.

A game is recorded as a log of the numbered moves of pieces, first white then black. The Portable Game Notation (PGN) standard includes additional descriptive information about the players and venue.

There are two notations for logging a chess game. The newer, *algebraic* notation and the older *descriptive* notation. We will write a program that will process a log in either notation and play out the game, showing the chess board after each of black's moves. It can also be extended to convert logs to completely standard PGN notation.

44.1 Algebraic Notation

We'll present the formal definition of algebraic notation including Algebraic Notation (LAN) and Short Algebraic Notation (SAN). We'll follow this with a summary and some examples. This section will end with some Algorithm R, used to resolve which of the available pieces could perform a legal move.

Definition. Algebraic notations uses letters `a-h` for the files (columns across the board) from white's left to right, and numbers for the ranks (rows of the board) from white (1) to black (8).

Piece symbols in the log are as follows:

Piece	Symbol	Move Summary
Pawn	(omitted)	1 or 2 spaces forward
Rook	R	anywhere in the same rank or same file
Knight	N	2 in one direction and 1 in the other ("L-shaped")
Bishop	B	diagonally, any distance
Queen	Q	horizontal, vertical or diagonal, any distance
King	K	1 space in any direction

The game begins in the following starting position.

White	Black	Piece
a1	a8	rook
b1	b8	knight
c1	c8	bishop
d1	d8	queen
e1	e8	king
f1	f8	bishop
g1	g8	knight
h1	h8	rook
a2-h2	a7-h7	pawns

There are two forms of algebraic notation: short (or standard) algebraic notation (SAN), where only the destination is shown, and long algebraic notation (LAN) that shows the piece, the starting location and the destination.

Long Notation. The basic syntax for LAN is as follows:

```
[ P ] f r m f r [ n ]
```

P The piece name (omitted for pawns).

f The file (a-h) moving from and to.

r The rank (1-8) moving from and to.

m The move (`-` or `x`).

n any notes about the move (`+`, `#`, `!`, `!!`, `?`, `??`). The notes may include `=` and a piece letter when a pawn is promoted.

Short Notation. Short notation omits the starting file and rank unless they are essential for disambiguating a move. The basic syntax is as follows:

```
[ P ] [ m ] [ d ] f r [ n ]
```

P The piece name (omitted for pawns).

m The move is only specified for a capture (`x`).

d The discriminator: either a file (preferred) or a rank or both used to choose which piece moved when there are multiple possibilities.

f The file (a-h) moving to.

r The rank (1-8) moving to.

n any notes about the move (`+`, `#`, `!`, `!!`, `?`, `??`). The notes may include `=` and a piece letter when a pawn is promoted.

Additional Syntax. In both notations, the castle moves are written `O-O` or `O-O-O` (capital letters, not numbers). Similarly, the end of a game is often followed with a `1-0` (white wins), `0-1` (black wins), `1/2-1/2` (a draw), or `*` for a game that is unknown or abandoned.

Each turn is preceeded by a turn number. Typically the number and a `.` preceeds the white move. Sometimes (because of commentary), the number and `...` preceed the black move.

The PGN standard for notes is `$` and a number, common numbers are as follows:

- $1 good move (traditional "!")
- $2 poor move (traditional "?")
- $3 very good move (traditional "!!")

- $4 very poor move (traditional "??")

Legal Moves. Each piece has a legal move. This is a critical part of processing abbreviated notation where the log gives the name of the piece and where it wound up. The legal moves to determine which of two (or eight) pieces could have made the requested move. This requires a simple search of pieces to see which could have made the move.

- **Pawn**. A pawn moves forward only, in its same file. For white, the rank number must increase by 1 or 2. It can increase by 2 when it is in its starting position; rank 2. For black, the rank number must decrease by 1 or 2. It can decrease by 2 when the pawn is in it's starting position of rank 7.

  A pawn captures on the diagonal: it will move into an adjacent file and forward one rank, replacing the piece that was there.

  There is one origin for all but the opening pawn moves: one rank back on the file in which the pawn ended its move.

  There is one origin for an opening pawn move that lands in rank 4 or 5: two ranks back on the file where the pawn ended its move.

  There are two possible origins for any pawn capture (one position on a file adjacent to the one in which the pawn ended its move).

- **Rook**. A rook moves in ranks or files only, with no limit on distance. There are 16 possible origins for any rook move, including the entire rank or the entire file in which the rook ended its move.

- **Knight**. A knight makes an "L-shaped" move. It moves two spaces in one direction, turns 90-degrees and moves one more space. From g1, a knight can move to either f3 or h3. The rank changes by 2 and the file by 1; or the file changes by 2 and the rank changes by 1. There are 8 places a knight could start from relative to its final location.

- **Bishop**. A bishop moves diagonally. The amount of change in the rank must be the same as the change in the file. There are 16 places a bishop can start from on the two diagonals that intersect the final location.

- **Queen**. The queen's move combines bishop and rook: any number of spaces diagonally, horizontally or vertically. There are 16 places on the diagonals, plus 16 more places on the horizontals and verticals where the queen could originate. Pawns that reach the opposite side of the board are often promoted to queens, meaning there can be multiple queens late in the game.

- **King**. The king is unique, there is only one. The king can only move one space hoizontally, vertically or diagonally.

- **King and Rook**. The king and a rook can also engage in a move called *castling*: both pieces move. When the king and the closest rook (the one in file h) castle, this is *king side* and annoted `O-O` . The king moves from file e to file g and the rook from fiel h to file f. When the king and the queen's side rook (the one in file a) castle, this is annotated `O-O-O` . The king moves from file e to file c and the rook move from file a to file d.

  Castling can only be accomplished if (a) neither piece has moved and (b) space between them is unoccupied by other pieces. Part a of this rule requires that the game remember when a king or rook moves, and eliminate that side from available castling moves. Moving the rook in file a eliminates queen-side castling; moving the rook in file h eliminates king-side castling. Moving the king eliminates all castling.

Summary and Examples. Here's a suymmary of the algebraic notation symbols used for annotating chess games. This is followed by some examples.

Symbol	Meaning
a-h	file from white's left to right
1-8	rank from white to black
R, N, B, Q, K	rook, knight, bishop, king, queen
-	move (non-SAN)
x	capture; the piece that was at this location is removed
+	check, a note that the king is threatened
#	checkmate, a note that this is the reason for the end of the game
++	checkmate (non-SAN), a note that this is the reason for the end of the game
=	promoted to; a pawn arriving at the opposite side of the board is promoted to another piece, often a queen.
0-0	castle on the king's side; swap the king and the rook in positions e1 and h1 (if neither has moved before this point in the game)
0-0-0	castle on the queen's side; swap the king and the rook in positions e1 and a1 (if neither has moved before this point in the game)
e.p.	en passant capture (non-SAN), a note that a pawn was taken by another pawn passing it. When a pawn's first move is a two space move (from 7 to 5 for black or 2 to 4 for white) it can be captured my moving behind it to the 6th rank (white taking black) or 3rd rank (black taking white).
ep	en passant capture (non-SAN), see `e.p.`
?, ??, !, !!	editorial comments (non-SAN), weak, very weak, strong, very strong

Here's parts of an example game in abbreviated notation:

1. `e4 e5`. White pawn moves to e4 (search e3 and e2 for the pawn that could do this); black pawn moves to e5 (search e6 and e7 for a pawn that could do this)
2. `Nf3 d6`. White knight moves to f3 (search 8 positions: g1, h2, h4, g5, e5, d4, d2, e1 and g1 for the knight that could do this); black pawn moves to d6 (search d7 and d8 for the pawn).
3. `d4 Bg4`. White pawn moves from d4 (search d3 and d2 for the pawn); black bishop moves to g4 (search the four diagonals: f5, e6, d7, c8; h5; h3; f3, e3, and d3 for the bishop that could do this).
4. `dxe5 Bxf3`. A white pawn in d takes a piece at e5, the pawn must have been at d4, the black pawn at e5 is removed; a black bishop takes a piece at f3 (search the four radiating diagonals from f3: e4, d5, c6, b7, a8; g4, h5; g2, h1; e2, d1).
5. `Qxf3 dxe5`. The white queen takes the piece at f3; the black pawn in d4 takes the piece in e5.

Here's a typical game in abbreviated notation:

```
1.c4 e6 2.Nf3 d5 3.d4 Nf6 4.Nc3 Be7 5.Bg5 0-0 6.e3 h6 7.Bh4 b6
8.cxd5 Nxd5 9.Bxe7 Qxe7 10.Nxd5 exd5 11.Rc1 Be6 12.Qa4 c5
13.Qa3 Rc8 14.Bb5 a6 15.dxc5 bxc5 16.0-0 Ra7 17.Be2 Nd7
18.Nd4 Qf8 19.Nxe6 fxe6 20.e4 d4 21.f4 Qe7 22.e5 Rb8
23.Bc4 Kh8 24.Qh3 Nf8 25.b3 a5 26.f5 exf5 27.Rxf5 Nh7
28.Rcf1 Qd8 29.Qg3 Re7 30.h4 Rbb7 31.e6 Rbc7 32.Qe5 Qe8
33.a4 Qd8 34.R1f2 Qe8 35.R2f3 Qd8 36.Bd3 Qe8 37.Qe4 Nf6
38.Rxf6 gxf6 39.Rxf6 Kg8 40.Bc4 Kh8 41.Qf4 1-0
```

Here's a small game in full notation:

```
1.f2-f4 e7-e5 2.f4xe5 d7-d6 3.e5xd6 Bf8xd6 4.g2-g3 Qd8-g5
5.Ng1-f3 Qg5xg3+ 6.h2xg3 Bd6xg3#
```

44.2 Algorithms for Resolving Moves

Algebraic notation is terse because it is focused on a human student of chess. It contains just enough information for a person to follow the game. Each individual move cannot be interpreted as a stand-alone (or "context-free" statement). Each move's description only makes sense in the context of the game state established by all the moves that came before it. Therefore, in order to interpret a log of chess moves, we also need to maintain the state of the chess board.

Given that we have a model of the chess board, Algorithm G can locate the pieces and execute the moves an entire game.

Algorithm G

(Resolve chess moves in SAN notation, playing out the entire game.) We are given a block of text with a sequence of chess turns. Assume that line breaks have been removed and the game ending marker has been removed from the block of text.

1. **Parse turn into moves**. Locate move number, white move and black move. Lines that don't have this form are some kind of commentary and can be ignored.
2. **Parse each move**. For each move, parse the move. Identify the piece (`R`, `B`, `N`, `Q`, `K`, pawn if none of these). Identify the optional file (`a` - `h`) or rank (`1` - `8`) for the source. Identifty the optional `x` for a capture. Identify the destination file (`a` - `h`) and rank (`1` - `8`). Identify any other material like `+` or `#` for checks, `=` x for promotions, or `!`, `!!` , `?` , `??` for editorial comments.
3. **Castling?** If the move is simply `0-0` or `0-0-0`, move both the king (in file e) and the appropriate rook. For `0-0` it is the rook in file h moves to f, the king moves from e to g. For `0-0-0` it is the rook in file a moves to d, the king moves from e to c.
4. **Fully specified from location?** If a two-character from-position is given, this is the starting location. Execute the move with step 7.
5. **Partially specified from location?** If a one-character from-position is given (a-h or 1-8), restrict the search for the source to this rank for file. Use the piece-specific version of Algorithm S with rank or file restrictions for the search. After the starting location is found, execute the move with step 7.
6. **Omitted from location?** Search all possible origins for the from-position for this piece. Each piece has a unique search pattern based on the piece's movement rules. Use the piece-specific version of Algorithm S with no restrictions for the search. After the starting location is found, execute the move with step 7.
7. **Execute move**. Move the piece, updating the state of the board, removing captured pieces. Periodically during game processing, print the board position. The board, by the way, is always oriented so that a1 is a dark square in the lower-left.
8. **Next move**. Loop to step 2, processing the black move after the white move in this turn. If the black move is omitted or is one of the ending strings, skip the black move.
9. **Next turn**. Loop to step 1, processing the next turn. If the turn number is omitted or is one of the ending strings, this is the end of the game.

We have to design six different kinds of searches for possible starting pieces. These searches include pawns, rooks, knights, bishops queens and the king. We'll provide formal algorithms for pawns and rooks, and informal specifications for the other pieces.

Algorithm P

(Search for possible pawn starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

1. **First move**. If the destination is rank 4 (white) or rank 5 (black), search two spaces back for the first move of a pawn (from rank 7 or rank 2). If moving this piece will not put the king into check, this is the stating location.
2. **Previous space**. Search the previous space (rank -1 for white, rank +1 for black) for a move. If moving this piece will not put the same color king into check, this is the stating location.
3. **Capture**. Search the adjacent files one space back for a pawn which performed a capture. If moving this piece will not put the same color king into check, this is the stating location.
4. **Error**. If no source can be found, the game notation is incorrect.

Algorithm R

(Search for possible rook starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

1. **To Right**.

1. **Initialize**. Set $r \leftarrow +1$.
2. **Loop**. Target position has file offset by r from destination.
3. **On Board**. If this is off the board, or a non-rook was found, break from this loop.

   If moving this piece will not put the king into check, return this position as the stating location.
4. **Loop**. Increment r. Continue this loop.

1. **To Left**.
   (a) **Initialize**. Set $r \leftarrow -1$.
   (b) **Loop**. Target position has file offset by r from destination.
   (c) **On Board**. If this is off the board, or a non-rook was found, break from this loop.

   If moving this piece will not put the king into check, return this position as the stating location.
   (d) **Loop**. Decrement r. Continue this loop.
2. **Toward Black**.
   (a) **Initialize**. Set $r \leftarrow +1$.
   (b) **Loop**. Target position has rank offset by r from destination.
   (c) **On Board**. If this is off the board, or a non-rook was found, break from this loop.

   If moving this piece will not put the king into check, return this position as the stating location.
   (d) **Loop**. Increment r. Continue this loop.
3. **Toward White**.
   (a) **Initialize**. Set $r \leftarrow -1$.
   (b) **Loop**. Target position has rank offset by r from destination.

(c) **On Board**. If this is off the board, or a non-rook was found, break from this loop.

If moving this piece will not put the king into check, return this position as the stating location.

(d) **Loop**. Decrement r. Continue this loop.

4. **Error**. If no source can be found, the game notation is incorrect.

Algorithm N

(Search for possible knight starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

There are as many as eight possible starting positions for a knight's move.

1. **Adjacent File**. Four of the starting positions have a file offset of +1 or -1 and rank offsets of +2 or -2.

   If the position is on the board, the piece is a knight, and moving this piece will not put the king into check, then this is the origin for this move.

2. **Adjacent Rank**. Four of the starting positions have file offsets of +2 or -2 and rank offsets of +1 or -1.

   If the position is on the board, the piece is a knight, and moving this piece will not put the king into check, then this is the origin for this move.

Algorithm B

(Search for possible bishop starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

Search radially out the diagonals until edge of board or an intervening piece or the correct bishop was found.

This algorithm is similar to the rook algorithm, except the offsets apply to *both* rank and file. Applying +1 to both rank and file moves north-east; applying -1 to both rank and file moves south-west. Applying +1 to rank and -1 to file moves south east; applying -1 to rank and +1 to file moves north west.

When an opposing piece is found, the search along that diagonal ends.

If the position is on the board, the piece is a bishop, and moving this piece will not put the king into check, then this is the origin for this move.

Algorithm Q

Search for possible queen starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

Search radially out the ranks, files and diagonals until edge of board or an intervening piece or the correct queen was found. This combines the bishop and rook algorithms.

When an opposing piece is found, the search along that rank, file or diagonal ends.

If the position is on the board, the piece is a queen, and moving this piece will not put the king into check, then this is the origin for this move.

Algorithm K

Search for possible king starting locations.) Given a destination location, piece color, and optional restrictions on starting rank or starting file.

Search the 8 adjacent locations. These are all combinations of -1, 0, +1 for rank offset and -1, 0, +1 for file offset. Omit checking the combination with a 0 offset to rank and a 0 offset to file.

If the position is on the board, the piece is the king, this is the starting position.

44.3 Descriptive Notation

Descriptive notation uses a different scheme for identifying locations on the board. Each file is named for the pieces at it's top and bottom ends as the game begins. The board is divided into King's side and Queen's side. The files are KR, KKt, KB, K, Q, QB, QKt, QR. These are known as a, b, c, d, e, f, g, h in Algebraic notation.

The ranks are counted from the player's point of view, from their back row to the far row. Consequently, white's row 1 is black's row 8. White's Q1 is Black's Q8; Black's KB5 is White's KB4.

The notation has the following format:

```
piece [ (file rank) ] move [file rank] [note]
```

The symbol for the *piece* to be moved is one of p, B, N, R, Q, K.

If capturing, the *move* is `x`, followed by the symbol of the captured piece. Examples: pxp, NxQ. A search is required to determine which piece can be taken.

If not capturing, the *move* is `-`, followed by *file rank* to name the square moved to, from the perspective of whoever is moving, black or white

If 2 pieces are both be described by a move or capture, write the location of the intended piece in parentheses. Examples: `p(Q4)xR` means pawn at queen's rook four takes Rook, `N(KB3)-K5` means knight at KB3 moves to K5

Special moves include king's side castling, designated `O-O`, Queen's side castling, designated `O-O-O`.

Notes. If a pawn captures *en passant* or *in passing* it is designated `ep` in the *note*. A move resulting in a check of the king is followed by `ch` in the *note*. `!` means `good move`; `?` means `bad move` in the *note* .

If the pawn in front of the king is moved forward two spaces, it is described as `P-K4`. If the pawn in front of the queenside knight is moved forward one space, it is `P-QN3`. If a knight at K5 captures a rook on Q7, it would be `NxR` or if clarification is needed, `NxR(Q7)` or `N(K5)xR`.

44.4 Game State

In order to process a log, a model of the chess board's current position is essential. In addition to the basic 64 squares containing the pieces, several additional facts are necessary to capture the game state. The current state of a chess game is a 6-tuple of the following items:

Piece Placement. An 8-tuple shows pieces in each rank from 8 down to 1. Pieces are shown as single letters, upper case for white (PRNBQK), lower case for black (prnbqk). Pieces are coded P for pawn, R for rook, N for knight, B for bishop, Q for queen and K for king. Empty spaces are shown as the number of contiguous spaces.

The entire rank can be coded as a 1-8 character string. 8 means no pieces in this rank. 4p3 means four empty spaces (a-d), a black pawn in file e, and 3 empty spaces (f-h).

The entire 8-tuple of strings can be joined to make a string delimited by `/` 's. For example `rnbqkbnr/pp1ppppp/8/2p5/4P3/5N2/PPPP1PPP/RNBQKB1R`.

Active Color. A value (`w` or `b`) showing who's turn to move is next. This color is *active* because this player is contemplating their move. The starting position, for instance, has an active color of `w`, because white moves first.

Castling Availability. A string with 1 to 4 characters showing which castling moves are still allowed. If none are allowed, a `-` is shown. White codes are capital letters, black are lower case. When king side castling is possible, a K (white) or k (black) is included. When queen side caslting is possible a Q (white) or q (black) is included. At the start of the game, there are four characters: `KQkq`. As the game progress and kings castle or are moved for other reason, or rooks are moved, the string reduces in size to `-`.

En Passant **Target**. Either `-` or a square in rank 6 or 3. When a pawn's first move advances two spaces (from 7 to 5 for black or 2 to 4 for white), the skipped-over space is named here on the next turn only. If an opposing pawn moves to this space, an *En Passant* capture has occured. If no *En Passant* vulnerability, a `-` is given.

Half Move Count. How many 1/2 moves since a pawn was advanced or a piece captures. This is zero after a pawn moves or a piece is captured. This is incremented after each 1/2 move (white or black) where no pawn moves and no piece is captured. When this reaches 50, the game is technically a draw.

Turn. This is the turn count, it increments from 1, by 1, after black's move.

44.5 PGN Processing Specifications

There are three parts to a PGN processing program: the parsing of a PGN input file, the resolution of moves, and maintenance of the game state. Each can be dealt with separately with suitable interfaces. Each of these modules can be built and tested in isolation.

First, some preliminaries. In order to resolve moves, the game state must be kept. This is a dictionary of locations and pieces, plus the five other items of information that characterize the game state: active color (`w` or `b`), castling availability, *en passant* target, half-move draw count and turn number. The board has an interface that accepts a move and executes that move, updating the various elements of board state.

Moves can use the Command design pattern to separate king-side castle, queen-side castle, moves, captures and promotions. The Board object will require a fully-specified move with source location and destination location. The source location is produced by the source resolution algorithm.

A well-defined Board object could be used either for a single-player game (against the computer) or as part of a chess game server for two-player games.

Second, the hard part. Resolution of short notation moves requires several algorithms to locate the piece that made the move. Based on input in algebraic notation, a move can be transformed from a string into a 7-tuple of `color`, `piece`, `fromHint`, `moveType`, `toPosition`, `checkIndicator` and `promotionIndicator`.

- The `color` is either `w` or `b`.
- The `piece` is omitted for pawns, or one of `RNBQK` for the other pieces.
- The `fromHint` is the from position, either a file and rank or a file alone or a rank alone. The various search algorithms are required to resolve the starting piece and location from an incomplete hint.
- The `moveType` is either omitted for a simple move or `x` for a capturing move.
- The `toPosition` is the rank and file at which the piece arrives.

- The `checkIndicator` is either nothing, `+` or `#`.
- The `promotionIndicator` is either nothing or a new piece name from `QBRK`.

This information is used by Algorithm G to resolve the full starting position information for the move, and then execute the move, updating the board position.

Finally, input parsing and reporting. A PGN file contains a series of games.

Each game begins with identification tags of the form `[Label "value"]`. The labels include names like `Event`, `Site`, `Date`, `Round`, `White`, `Black`, `Result`. Others labels may be present.

After the identification tags is a blank line followed by the text of the moves, called the "movetext". The movetext is supposed to be SAN (short notation), but some files are LAN (long notation). The moves should end with the result (`1-0`, `0-1`, `*`, or `1/2-1/2`), followed by 1 or more blank lines.

Here's a sample game from a recent tournament.

```
[Event "25th European Club Cup 2009"]
[Date "2009.10.04"]
[Round "1"]
[Board "1"]
[White "Aronian, Levon"]
[Black "Docx, Stefan"]
[Result "1-0"]

1.d4 d6 2.Nf3 g6 3.e4 Bg7 4.Bc4 Nf6 5.Qe2 0-0 6.0-0 Bg4 7.Rd1 Nc6 8.h3 Bxf3
9.Qxf3 Nd7 10.c3 e5 11.Be3 a6 12.Na3 exd4 13.cxd4 Qh4 14.Rac1 Nf6 15.Bd3 Rfe8
16.Rc4 Nd7 17.Bb1 Rad8 18.b4 Nb6 19.Rcc1 d5 20.e5 Qe7 21.Nc2 Nc4 22.a3 b5 23.Ba2
Nb8 24.Re1 c6 25.Qg3 Qf8 26.h4 Nd7 27.h5 Ra8 28.Rcd1 a5 29.Bc1 Qe7 30.Bb1 Qe6
31.hxg6 fxg6 32.Rd3 axb4 33.Nxb4 c5 34.Nc2 Qc6 35.f4 Qb6 36.Qf3 Rad8 37.Ne3 Nxe3
38.dxc5 Nxc5 39.Bxe3 Qa5 40.Bd2 Qb6 41.Qf2 Re6 42.Rh3
```

Design Considerations. In order to handle various forms for the movetext, there have to be two move parsing classes with identical interfaces. These polymorphic classes implement long-notation and short-notation parsing. In the event that a short-notation parser object fails, then the long-notation parser object can be used instead. If both fail, the file is invalid.

A PGN processing program should be able to read in a file of games, execute the moves, print logs in various forms (SAN, LAN and Descriptive), print board positions in various forms. The program should also be able to convert files from LAN or Descriptive to SAN. Additionally, the processor should be able to validate logs, and produce error messages when the chess notation is invalid.

Additionally, once the basic PGN capabilities are in place, a program can be adapted to do analysis of games. For instance it should be able to report only games that have specific openings, piece counts at the end, promotions to queen, castling, checks, etc.

Part VII

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FORTYSEVEN

PRODUCTION NOTES

The following toolset was used for production of this book.

- Python 2.6.3.
- Sphinx 0.6.3.
- Docutils 0.5.
- Komodo Edit 5.2.2.
- pyPDF 1.12.
- MacTeX-2008.

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