Python for Linguists

(Draft)

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Contents

Preface

This is a book on how to program for linguistic purposes using the Python programming language. In this chapter, we outline our goals, justify using Python to achieve them, and explain how best to use this book.

Why do linguists need to learn how to program?

Programming is an extremely useful skill in many areas of linguistics and in other language-related fields like speech and hearing sciences, psychology, psycholinguistics, quantitative literary studies, etc.

Within linguistics, it used to be the case that programming skills were really only required for computational linguists, but this is far from true these days. Programming is being used in phonology, syntax, morphology, semantics, pragmatics, psycholinguistics, phonetics, discourse analysis, essentially every area of linguistic investigation.

This change reflects broader methodological changes in the field, a response to the fact that: i) more and more data are available electronically; and ii) that we have much richer techniques for examining and manipulating massive amounts of electronic data.

Here are some examples of what you can do with fairly modest programming skills:

- Build a simple list of occurring words from a text file written in some language along with the frequency of those words.
- Find items for psycholinguistic or phonetic experiments from text resources, e.g. imagine you need frequent two-syllable words that begin with a three-

consonant cluster and don't otherwise contain nasals.

- Construct every possible one-syllable word given a set of possible onsets, vowels, and codas.
- Construct every possible two-word compound given some list of words.
- Find the average number of words per sentence from some text corpus and find the longest sentence in that corpus.
- Build a model of syllabification for some language and syllabify candidate words.
- Find the average length and amplitude for some set of sound files.

These are just a teeny sample of the sorts of things that programming might help you do as part of your work with language.

Why is Python a good choice?

There are a wide variety of programming languages you might choose to learn and work with. Every language has its virtues, the things that make it a good choice for this or that purpose. The important thing is that the choice of language is a function of three basic factors.

First, what is it that you want to do? Some languages are optimized for different sorts of goals, e.g. writing applications, developing system tools, scripting.

Second, what kind of programming experience do you have? Some languages are relatively easy to pick up and others…not so much.

Finally, what kind of programming style do you want to use? Different languages lend themselves to different kinds of programming approaches, e.g. procedural, functional, object-oriented, parallel, etc.

In this book, we assume that you want to write programs that will let you answer questions about language, programs that may only be run by you. Thus programming languages like `java`, objective `c`, or `c#` that allow you to write full applications, are not optimal choices.

In addition, we assume that you have little or no prior programming experience. Thus interesting and challenging programming systems like `Haskell`, `Lisp`, or

`Prolog` are best left for later.

In this book, we will use the Python programming language. There are specific reasons for this choice:

- Python is *extremely* widely used, so you most likely have friends who use it who can help you if needed and there are myriad resources on the web that can help as well.
- Python has stable and clear semantics. This means that the meaning and use of Python elements is clearly defined and you can rely on your programs working as you intend. Similarly, program examples in this text should work exactly as advertised on your system.
- Modules. There are tons and tons of optional modules that others have written with useful functions and objects to simplify your programming tasks.
- Python is practical. Python is widely used in many areas so your language-related programming skills may help you in other domains.
- NLTK. The Natural Language Toolkit is a freely available suite of modules that are tailored for working with language. You can use these for very high-level statistical natural language processing or for very simple language-related tasks.

There are some challenges to working with Python too. The biggest is that Python is an object-oriented (OO) programming language and using it requires that you at least understand what objects are. The language lends itself to an OO programming style, but you need not do this at first.

Our approach in this book is to first ignore OO aspects of the language. As we proceeed, we introduce what you need to know of the OO system to make full use of the language. Finally, in the latter part of the book, we explain OO programming in depth. Ultimately, we leave it up to you to decide how much of OO-style programming is necessary or appealing for your programming goals.

How this book is different

There are any number of booklength introductions to Python out there. How is this book different?

First, this book is written for linguists and other people who work with language data. What this means in the beginning is that the examples we give are examples that should make sense to you. If you have very specific programs you want to write right away, you may even find some snippet here that (almost) does what you want and can be easily adapted to your purposes.

We continue with the language focus throughout the book. This means that, rather than trying to learn some programming concept exemplified in a program that has no relation to your goals, you can learn critical concepts with programs that are comprehensible and hopefully useful as well.

Many chapters conclude with an extended example intended to exemplify how a larger program should be developed, using the concepts learned in the chapter, and, of course, with a focus on some language-related task. All chapters conclude with exercises and all exercises are linguistic in their orientation as well.

Another consequence of this approach is that we take a linguistic approach to the structure of Python. As much as possible, we treat it as a language with a syntax and a semantics.

Overview of the book

The structure of this book is roughly as follows.

First, we introduce the basic syntax and semantics of the language: the primitive elements of the language and how those elements can be combined to make legal statements and larger structures.

As we introduce those, we elaborate the imperative semantics of the language, how we can use the specific Python language components covered to achieve different programming goals.

We next consider specific language-related tasks in depth: searching text, manipulating txt, internet data, and text encodings.

Finally, we conclude with discussions of Python objects and OO programming generally and a brief treatment of GUI programming.

How to use the book

The most important thing about using this book is that you should run the programs as you proceed. You can either download them from the course website[1] or type them in yourself.

If you have the patience for it, it is much better to type them in. This will really help you to notice aspects of the code you might not otherwise see and to make the coding more familiar to you. This will be frustrating and you will make errors as you type things in, but it's figuring out these errors that will really help you learn the material.

Another really useful thing to do as you proceed is to play with the code. Tweak it in different ways, either to do something you'd rather it do or just to see what happens. (As you'll see below, the only time you *don't* want to do this is with file input–outut operations where you can accidentally damage or lose things on your computer.)

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Incomplete

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Thanks to Diane Ohala and Joey Rousos-Hammond for their support throughout.

All errors are my own.

[1] `http://www.u.arizona.edu/~hammond/`

Chapter 1

Interacting with Python and basic functions

In this chapter, we introduce the different ways you can interact with Python generally and some simple things you can do right from the get go.

We start with how to install Python and issues concerned with different versions of the language. We turn next to how to invoke the interactive environment and the things you can do there. Finally, we very briefly outline what it means to write a program.

1.1 Installing & using Python

Python is a programming language. It is a way for you to talk to your computer, a way for you to get your computer to do things for you. It's basically a specialized language that is optimized for clarity for you and for converting into the internal language that your computer actually uses. You might think of it as a solution to a translation problem. You speak one language and your computer speaks another. Python is a compromise language between the two. For you to program, you must translate your intentions into Python. For the computer to respond appropriately, it must translate Python into its own internal language.

To use Python it is not enough to simply translate your goals into Python. Rather, you must also install specialized software on your computer that will translate your

Python code into what the computer can work with. We will refer to this software as a *Python installation*.

Sometimes this software is automatically part of your operating system. For example, Python is part of every MacOS and Linux installation. Sometimes this software has to be installed by you. Sometimes this software is free; some companies charge for it. My recommendation is that you at least start with a free version. If, later on when you really know what you're doing with Python, some proprietary version offers features that you feel are necessary, then that's the time a purchase may be warrented.

A related issue here is that there are different versions of Python. The language was first released in 1991 and there are a number of different versions since then offering changes and improvement. As I write this now, the current version is 3.6.2.

When you install Python, you may have a choice about versions. My recommendation is that you install someing in the version 3 family. There are significant differences between version 2 and 3 and version 3 is what we use here.

In general, you want the most recent version possible, but there are sometimes reasons not to do that. Some 3rd party modules are not available for all versions, and so if there is a particular module that is important to you, you may want to make sure you have a version of Python that works with it.

For linguists, the NLTK package, the Natural Language Toolkit, is often an important part of what they want to do with Python. As of this writing, NLTK does not yet work with version 3.6, so if you want to use NLTK, the most recent version of Python that you can install is 3.5.[1]

There are a number of free versions of Python that are available for Mac and Windows. For example, one widely used version is Anaconda[2]. Another widely used system is ActiveState[3]. Python.org[4] maintains a list of Python distributions and distribute their own as well. I've already mentioned that Python is part of any MacOS, but if need a specific version of Python for your purposes, you can get

[1] I'm actually using 3.4 on my own systems at this point because the last time I installed Python, NLTK would only work with 3.4.

[2] `https://www.continuum.io`

[3] `https://www.activestate.com`

[4] `https://wiki.python.org/moin/PythonDistributions`

those from MacPorts[5] or Homebrew[6].

1.2 The interactive environment

There are at least four ways you can invoke Python:

1. **interactive environment** terminal or Python window
2. **idle** Python integrated development environment
3. **edit & run** write a program that you run in the terminal window
4. **jupyter notebooks** write code that runs interactively in a web browser

Ultimately, we will want to write programs that we then run, but at this stage we will confine our attention to the interactive environment. This will allow us to play with Python so we can understand the basics before we move on to writing programs.

If Python is on your system—or you've properly installed it—you can start the interactive environment by simply typing `python` in the terminal window on a Mac or choosing Python from the start menu on Windows. This will produce this response:

```
$ python
Python 3.4.6 ...
Type "help", "copyright", "credits" or
"license" for more information.
>>>
```

The version of Python that you're using is displayed along with additional system information. All of this is followed by the prompt >>>. Your commands are typed at that prompt.

Before going any further, let's set out the most most important commands that work here:

Quit: `quit()`. Type this at the >>> prompt to exit the interactive environment. Typing `^d` (`control-d`) has the same effect.

[5] `https://www.macports.org`
[6] `https://brew.sh`

Help: `help()`. Typing this enters the on-line help system where you can get help on many aspects of using Python. While this is extremely helpful, the responses it provides may not be terribly useful at this stage. You exit this system and return to the interactive environment with the `return` key.

Interrupt: `^c` (`control-c`). When we start playing with the system, you will occasionally get stuck in the middle of a command or while some command is running. If you do get stuck, if some command seems to be running forever, you can often regain control and return to the >>> prompt by typing `^c`.

1.3 Basic interactions

We will generally interact with Python by writing programs and then running them from the command-line. At this point, let's try to understand Python a bit better in the interactive environment. In this environment, you can type legal Python statements and they are immediately evaluated. For example, you can perform mathematical calculations like multiplication, addition, and exponation:

```
>>> 4 * 7
28
>>> 3 + 2.9
5.9
>>> 9 ** -3
0.0013717421124828531
>>> 7 - 15
-8
```

As linguists, we will want to operate on words and sentences and these must be entered in single or double quotes. In general terms, we will refer to these as *character strings*.

```
'This is a sentence'
"This is another one"
```

Interestingly, some of the mathematical operators above can be used with character strings as well and have different effects. With numbers + is addition, but with strings it concatenates. With numbers * is multiplication, but with a string and a number it repeats the string:

```
>>> 'phon' + 'ology'
'phonology'
>>> 'phon' * 6
'phonphonphonphonphonphon'
```

There are some functions that operate directly on strings. The `len()` function returns the number of characters in a string.

```
>>> len('phonetics')
9
```

The `type()` function can operate on strings or numbers and returns the general "type" of the object it applies to.

```
>>> type(3)
<class 'int'>
>>> type(7.2)
<class 'float'>
>>> type('phoneme')
<class 'str'>
```

Python distinguishes integer numbers from floating point numbers (numbers with a decimal point) from character strings.

Note now that the quotes surrounding a character string are essential and distinguish strings from other types. If you leave them out, Python will typically give you an error:

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

If you put them in with numbers, then you change the basic type of the object. Consider the difference here:

```
>>> 7 + 4
11
>>> '7' + '4'
'74'
```

Recall that the + operator can apply to strings or numbers, but has different effects with each. When it applies to numbers, it performs addition. When it applies to

strings, it performs string concatenation. We see here that when numbers are put in quotes they are treated as strings, rather than as numbers.

There are functions for converting back and forth between character strings, integers, and floating point numbers:

```
>>> int('7')
7
>>> float('3.6')
3.6
>>> str(17)
'17'
```

Operators and functions can be combined as well. For example:

```
>>> (7 + 4) * 2
22
>>> str(7) + str(4)
'74'
>>> int(str(7)) ** 3
343
```

The format we've used for functions is to invoke the function by putting parentheses after its name, e.g. `str()`. There is another kind of function that we will frequently have need of that has a different syntax. These are *methods*, functions that are very specifically associated with some particular datatype. We'll have a lot more to say about these in Chapter 11, but for now, we just want to alert you that they exist and show you their syntax. To invoke one of these, the method name and parentheses are suffixed to the relevant object with a period. For example the string method `upper()` returns an uppercase version of a string. We invoke it as follows:

```
>>> 'this is not a pipe'.upper()
'THIS IS NOT A PIPE'
```

There are methods that take additional arguments as well. For example, `count()` returns the number of instances of its argument in the string.

```
>>> 'this is not a pipe'.count('i')
3
```

1.4 Edit & run

In general, one uses Python to write programs to be run from the command-line. For example, we can write a silly little program that concatenates two strings and prints the output. We would edit a text file, say with the name `interact1.py` to contain the following:

```
print(4+7)
print('that should be 11')
```

interact1.py

Some parts of this are familiar from what we've covered so far, but some are not. We've added the `print()` function here which simply prints its argument. Don't worry yet about the details; at this point, we just want several lines of code for our program.

It's important that you create this file with a simple text editor, not a full-on word processor like Microsoft Word. For writing code, I use Vim myself on a Mac, but Emacs (or Aquamacs) is a very simple and free alternative. For Windows, there are various free ports of Emacs as well, but a number of other alternatives. It's most useful if the editor you use does *syntax colorizing*. This highlights different terms and strings in your Python code and makes it easier to spot errors. The code examples in this book are colorized in this way. There are all sorts of other bells and whistles that different text editors offer, but the only essential ones at this point are: i) that the program be able to edit simple text files; and ii) that it does syntax colorizing for Python.[7]

There are a number of ways to invoke the program, but the simplest is to type `python myprog.py` in the terminal or DOS window as follows:

```
> python myprog.py
11
That should be 11
```

If you invoke the program as above, it's important that the program be in the same directory that the terminal window is in. To find out what directory you are in, you can type `pwd` at the terminal prompt. To see if this program file is in that directory,

[7] I strongly encourage you do *not* spend money on a text editor, at least at this stage. There are a huge number of free options.

you can use the `ls` command at the terminal prompt. If it is not, you can either move it there or you can instruct the terminal to switch to another directory with the `cd` command (followed by the path to the directory you want to be in).

Once can also add comments to a code file. Comments are lines of code that remind the programmer of what the code does or should do. Comments are marked with a # on their left. Everything on the same line after that # have no effect on the program. For example, we might tweak our program above like this:

```
print(4+7) #this does some math

#the following prints a string
print('that should be 11')
```

interact2.py

Notice that comments can occur on their own line or on the right side of an actual line of code.

1.5 Summary

In this chapter we have discussed how to install Python and the different versions that exist. We've also talked about how to run Python code and exemplified some basic commands in the interactive environment. We also briefly exemplified how to write and run a program.

1.6 Exercises

1. Write commands that print out your first name, the number of characters in that name, your last name, the number of characters in that name, and then concatenates and prints the two names (with a space).
2. What's the difference between these?

   ```
   str(3 + 3) + '3'
   int('3') + int('3' + '3')
   ```

3. What's the difference between these?

```
'This is Mike'.upper().lower()
'This is Mike'.lower().upper()
```

4. Why does `upper('This is a cat')` not work?
5. What does `help(help)` do?
6. We used the mathematical operator `**` on page 4 above without explanation. Play around with it and say what it does.
7. In math, `6 + 2` and `2 + 6` *mean* the same thing. We've seen that + and * can be used with strings too. What happens if arguments are reversed when strings are involved? Do those expressions *mean* the same thing?

Chapter 2

Datatypes and variables

In this chapter, we look more closely at Python datatypes and variables. We'll discuss these:

- Numbers: integers and floats
- Strings
- Lists
- Tuples
- Dictionaries

This discussion cannot proceed without considering the notion of *mutability*. Basically, some kinds of data cannot be changed once they have been created while others can. This is really easy to overlook, and can lead to all sorts of errors.

2.1 Assignment

To fully understand the range of different types, it's useful to understand variable assignment first.

We've already discussed numbers and functions that can apply to numbers. For example, we can use all the usual mathematical operators:

```
>>> 3 * 4
12
>>> 7 - 15
-8
```

We can also store—and later recall—any value. We refer to this as *variable assignment*; we take some value and put it in a named location or recepticle. The syntax is simple: the name occurs on the left, the value on the right, and = goes in between. For example:

```
>>> x = 17
>>> bananas = 3.4
```

Note that this is not the same thing as equality. We're not asserting that `bananas` and `3.4` are the same thing; we're taking the value `3.4` and giving it the name `bananas`.

Once a variable name has been bound to a value, it can be used anywhere a value of that type can be used. For example:

```
>>> 3 + x
20
>>> bananas * 7
23.8
```

Variable names must begin with a letter or an underline. The remainder of the name can consist of any additional letters, underlines, or numbers. Variable names are case-sensitive and you should not use any of the reserved Python words:

```
False   class     finally  is        return
None    continue  for      lambda    try
True    def       from     nonlocal  while
and     del       global   not       with
as      elif      if       or        yield
assert  else      import   pass
break   except    in       raise
```

The right side of an assignment can include functions and variables. For example:

```
>>> oranges = bananas * 4
>>> bananas = bananas - 5
```

Notice that the latter statement confirms that even though assignment uses the

symbol =, it is not to be confused with some sort of equality test, for how could `bananas` be equal to itself minus 5? To test for equality, we use ==:

```
>>> 2 + 2 == 4
True
>>> 'hats' == 'hat' + 's'
True
```

Once we have covered control structures, we'll see that variables are essential in programming. For now, note that the choice of variable name is extremely important. While in principle, we can name our variables in many different ways, what we should always do is name our variables so that the name of the variable reminds us what kind of value we are storing in it. For example, if we had a variable that we stored somebody's age in, a very convenient name would be something like `age`. Far less useful would be a name like `theNumber`. While the last does imply that the variable contains a number, it does nothing to help us remember what number we have stored. Similarly, variable names like `a` are rather useless for the same reason.

At the beginning stages of programming, you will be tempted to name your variables cryptically, e.g. `a` or whimsically, e.g. `ernie` (a recent beloved pet), but really try to avoid this and develop good habits early. The best thing is to have variable names that will remind you of their contents.

2.2 Basic datatypes

We've already discussed basic datatypes in the previous chapter. Let's look a little more closely at them.

2.2.1 Numbers

For numbers, there are three basic types: integer, floating point, and complex. (As linguists, we're really only going to be using the first two, so we focus on them.) These are all represented in the usual way (though the suffix for complex numbers is `j`, not `i`). There are functions for converting to these to and from strings as well.

Type	Example	Convert from string
integer	`3`	`int('3')`
float	`7.2`	`float('7.2')`
complex	`2+4j`	`complex('2+4j')`

All of these can be converted to a string with the `string()` function.

2.2.2 Booleans

There is also a basic datatype for *booleans*, expressions that are true or false. This class includes only two basic members: `True` and `False`. It also includes the basic logical operators: `and`, `or`, and `not`. We can construct simple logical expressions with these:

```
>>> True and False
False
>>> not (False or False)
True
>>> not (not True)
True
```

Here and elsewhere, we use parentheses to make the scope of operations clear. The following are *not* equivalent.

```
>>> not (False or True)
False
>>> (not False) or True
True
```

We can, of course, also assign boolean values to variables can construct expressions over them as well:

```
>>> x = True
>>> y = False
>>> x and y
False
>>> (y or (not y))
True
```

We can also do comparisons on other datatypes that result in boolean values. For

example, we have the following numerical comparisons:

Comparison	Example
equality	`3 == 2 + 1`
inequality	`7 != 2`
greater than	`5 > 3`
greater than or equal	`5 >= 5`
less than	`2 < 7`
less than or equal	`5 + 6 <= 10 * 3`

These same operations can be used with strings, with different interpretations of course.

Comparison	Example
equality	`'hat' == 'hat'`
inequality	`'hat' != 'cat'`
follows alphabetically	`'hat' > 'cat'`
follows alphabetically or equal	`'Hat' >= 'hat'`
precedes alphabetically	`'Hat' < 'hat'`
precedes alphabetically or equal	`'hat' + 's' <= 'chair'`

We can build up fairly complex expressions now. For example:

```
>>> len('hat') > 7 - 2 or 7 - 2 == 3
False
>>> True and (8 = 4 + 4) and (True or False)
True
```

We've already seen that the `type()` function returns the type of an element. For example:

```
>>> type(3)
<class 'int'>
>>> type('3')
<class 'str'>
```

There is a boolean version of this as well `isinstance()` that we can use to test if some element or variable is of any particular type. For example:

```
>>> isinstance(3,int)
True
>>> isinstance(3.0,float)
```

```
True
>>> isinstance('hat',str)
True
>>> isinstance(3 == 4,bool)
True
>>> isinstance(3 + 4j,complex)
True
```

2.2.3 Strings

For linguists, strings are an extremely important datatype. As linguists, we are often concerned with sounds, words, and sentences, and these are typically most naturally represented as strings of characters.

Python offers what looks like three different kinds of strings. First, we have simple strings marked with single or double quotes. They are interchangeable:

```
>>> 'hat' == "hat"
True
```

A second type of string is a triple-quoted string, marked with three single or double quotes. Triple quotes allow a string to continue over multiple lines.

```
'''This is a string
that continues on
more than one line'''
```

You can use double quotes as well:

```
"""This is a string
that continues on
more than one line"""
```

If you assign such a string to a variable and then type the variable name, it looks like a single line:

```
>>> x = '''This is
more
than one line'''
>>> x
'this is\nmore\nthan one line'
```

This is true and false. It's true that a triple-quoted string is really the same as any other string; it differs only in that it allows the string to be defined over multiple lines. It is not the case, however, that the string above is a single line. The character `\n` represents a line break and will display as such when the variable is explicitly printed:

```
>>> print(x)
This is
more
than one line
```

In fact, one can use single or double quotes to specify a multi-line string if one enters `\n` directly:

```
>>> y ='this is more\nthan one\nline too'
>>> print(y)
this is more
than one
line too
```

Thus the way to think about triple-quoted strings is not that they are a different kind of string, but a convenient way to enter multi-line strings.

A similar issue arises with other special characters, e.g. tab. One cannot enter the tab character directly in either of the string types we've discussed in the interactive environment. Instead, a tab can be typed into either type of string as `\t`. Notice how the tab is not displayed properly when the name of the variable is typed, but only when the variable is given as an argument to `print()`.

```
>>> x = 'a\tfew\ttabs\there'
>>> x
'a\tfew\ttabs\there'
>>> print(x)
a    few    tabs    here
```

We've now got two cases where a special character, tab or newline, require special characters for them to be typed into strings: `\t` and `\n`. What if you actually want to type a backslash followed by a `t` or an `n`? With a single-, double-, or triple-quoted string, you have to enter a double backslash `\\`. If you assign the string to a variable name and then type that name, you see the double slash; if you invoke the variable with `print()`, then only a single slash is displayed:

```
>>> x = 'xyz\\nabc'
>>> x
'xyz\\nabc'
>>> print(x)
xyz\nabc
```

If you're entering strings with lots of special characters that require backslashes, this is where the *raw* string notation becomes useful. If you prefix a single- or double-quoted string with `r`, then backslash is interpreted as a backslash. Thus

```
>>> x = r'abc\nxyz'
>>> y = r"xyz\nabc"
>>> x
'abc\\nxyz'
>>> print(x)
abc\nxyz
>>> y
'xyz\\nabc'
>>> print(y)
xyz\nabc
```

Keep in mind that the *raw* string notation does not create a different kind of string either; rather it is a way of entering the string differently.

We have already seen functions and operators that apply to strings:

```
>>> x = '77'
>>> len(x)
2
>>> int(x)
77
```

We've also seen that there are *methods* that apply specifically to strings. Recall that there is a different syntax for methods. For example:

```
>>> x = 'a Hat'
>>> x
'a Hat'
>>> x.count('a')
2
>>> x.upper()
```

```
'A HAT'
>>> x.lower()
'a hat'
```

An extremely useful method for strings is `format()`. The basic idea is that you define a string with empty slots and then fill those slots later with the `format()` method. Slots are indicated with `{}`. So we can define a suitable string with one slot like this:

```
>>> x = '{} Mike'
```

We can then fill that slot any number of ways:

```
>>> y = x.format('Hello')
>>> y
'Hello Mike'
>>> z = x.format('Goodbye')
>>> z
'Goodbye Mike'
```

A string can have multiple slots. To fill them, the `format()` method can take multiple arguments.

```
>>> x = '{} Mike. {}?'
>>> x.format('Hello','How are you')
'Hello Mike. How are you?'
>>> x.format('Hwyl','Sut wyt ti')
'Hwyl Mike. Sut wyt ti?'
```

When a string does have multiple slots, then can be numbered (from 0). They are then filled in that order by the arguments to `format()`.

```
>>> x = 'one = {1}; two = {0}'
>>> x.format('dos','uno')
'one = uno; two = dos'
```

In fact, the slots can be named and specified in the call to `format()`.

```
>>> x = 'one = {uno}; two = {dos}'
>>> x.format(dos='dau',uno='un')
'one = un; two = dau'
```

Notice how the arguments to `format()` can come in either order since the naming disambiguates. The following has the same effect as the preceding.

```
>>> x.format(uno='un',dos='dau')
'one = un; two = dau'
```

Finally, one can do simple spacing and alignment with the `format()` method. You indicate the number of spaces to reserve for the argument with a preceding colon. If the argument supplied by `format()` is less than the space reserved, you indicate alignment to the left, right, or center with <, >, and ^ respectively.

```
>>> x = '-{:<10}-'
>>> x.format('hat')
'-hat       -'
>>> x = '-{:>10}-'
>>> x.format('hat')
'-       hat-'
>>> x = '-{:^10}-'
>>> x.format('hat')
'-   hat    -'
```

Notice how when there is an odd number of remaining spaces, the extra goes to the right.

There is a lot more that can be done with the `format()` method, but we set it aside for now.

Finally, there is a syntax for extracting part of a string. The syntax is to put one or more integers in square brackets after the string. Using a single integer in the square brackets extracts a single character. The characters in a string are counted from the left, starting at 0.

h	a	p	p	i	n	e	s	s
0	1	2	3	4	5	6	7	8

For example:

```
>>> x = 'happiness'
>>> x[1]
'a'
>>> x[5]
'n'
```

One can also refer to a sequence of characters by using two integers separated by a colon. The first index is the starting point of the sequence; the second index is just *after* the end of the sequence. Thus something like `[2:4]` starts at the item with index `2` and extends to just before the item with index `4`, thus the item with index `3`. Since indexing starts at `0`, this span goes from the third character in the string to the fourth character.

```
>>> x = 'abcde'
>>> x[2:4]
'cd'
```

Thus `x[n:n+1]` is the same as `x[n]`. If we have `x[n:m]` where `m < n+1`, we end up with an empty string. For example:

```
>>> x = 'abcde'
>>> x[2:2]
''
>>> x[2:1]
''
```

Interestingly, we can leave out either integer when the colon is present. Leaving out the first returns the entire string up to just before the integer that's present. Leaving out the second, gives the entire string starting from the first integer present. For example:

```
>>> x = 'abcde'
>>> x[2:]
'cde'
>>> x[:2]
'ab'
```

There are many more things we can do with strings, but these are the most critical.

2.2.4 Lists

Lists are an extremely important datatype: a single structure that holds a sequence of elements of whatever type you want. You can create a list by simply listing elements in square brackets. For example:

```
>>> x = [1,6,4,9]
>>> y = ['stops','fricatives','glides']
>>> z = [7,'hats',56,'chairs',6.802]
```

The `len()` command also applies to lists:

```
>>> len(x)
4
>>> len(y)
3
>>> len(z)
5
```

You can also index into a list, as with a string:

```
>>> x[1]
6
>>> y[0]
'stops'
>>> z[3:]
['chairs',6.802]
```

There are lots of methods for dealing with lists. For example, the `append()` method adds an element at the end of the list:

```
>>> x = ['rocks','paper']
>>> x
['rocks','paper']
>>> x.append('scissors')
>>> x
['rocks', 'paper', 'scissors']
```

The `pop()` method is quite interesting. It removes an element at a specified index position in a list. The method returns that element, altering the list at the same time.

```
>>> x = ['stops','fricatives','glides']
>>> x.pop(1)
'fricatives'
>>> x
['stops','glides']
```

The mirror-image method is `insert()`, which takes two arguments, the index and the element to insert. The element is inserted just *before* the index you specify.

```
>>> x = ['stops','fricatives','glides']
>>> x.insert(1,'hello!')
>>> x
['stops','hello!','fricatives','glides']
```

A function that will turn out to be quite useful later on is `range()`. This takes a single integer argument and returns a `range` object that represents the sequence from `0` up to that argument. This can be directly converted to a list with the `list()` function. For example:

```
>>> x = list(range(4))
>>> x
[0,1,2,3]
```

We also have the `sort()` and `reverse()` methods. The first sorts a list and the second reverses it. Note that `sort()` only works for a list of uniform objects that are sortable.

```
>>> x = [5,2,8,3]
>>> x.sort()
>>> x
[2,3,5,8]
>>> x = [5,2,8,3]
>>> x.reverse()
>>> x
[3,8,2,5]
```

Finally, we have the `in` operator which we can use to test for membership in a list:

```
>>> x = [5,2,8,3]
>>> 8 in x
True
>>> 7 in x
False
```

2.2.5 Tuples

Another datatype that you will see quite often is a *tuple*, a fixed sequence of elements, similar to lists in many ways. The key difference is that tuples are fixed in length and, once created, cannot be changed. (We will discuss this notion more in Section 2.3 below.)

You create a tuple with parentheses. An empty tuple is just parentheses: `()`. Larger tuples separate the members with commands, e.g. `(7,'hat',8.2)`. Interestingly, a tuple with one element must have a comma, unlike a list with a single element: `(3,)` vs. `[3]`.

```
>>> x = ()
>>> y = (7,'hat',8.2)
>>> z = (3,)
```

The `len()` function applies to tuples and you can index tuples just like lists.

```
>>> y = (7,'hat',8.2)
>>> len(y)
3
>>> y[2]
8.2
```

The `in` operator applies to tuples, just as it does to lists:

```
>>> x = (5,2,8,3)
>>> 8 in x
True
>>> 7 in x
False
```

Finally, we can convert a list to a tuple with `tuple()` or a tuple to a list with `list()`:

```
>>> x = [1,2,3]
>>> type(x)
<class 'list'>
>>> y = tuple(x)
>>> type(y)
<class 'tuple'>
```

```
>>> a = (1,2,3)
>>> type(a)
<class 'tuple'>
>>> b = list(a)
>>> type(b)
<class 'list'>
```

2.2.6 Dictionaries

One of the most useful datatypes for linguists are *dictionaries*. Dictionaries are effectively sets of pairs, where the first element in the pair can be used to "look up" the second. The set of first elements must thus be unique. A dictionary is marked with curly brackets where each pair of elements is separated with a colon. For example:

```
>>> d = {'cat':7,'chair':'hat','table':7}
```

Notice how `'cat'`, `'chair'`, and `'table'` are distinct, but `7`, `'hat'`, and `7` do not need to be. We refer to the first member of each pair as a *key* and the second as its *value*. We look up values by putting the key in square brackets after the name of the dictionary:

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> d['cat']
7
>>> d['chair']
'hat'
```

The `len()` function can apply to a dictionary and returns the number of pairs in the dictionary:

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> len(d)
3
```

We can add new pairs to a dictionary simply by assigning to a new key:

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> d['onion'] = 3.7
>>> len(d)
4
```

We can test for whether any specific item is a key in a dictionary with `in`. For example:

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> 'chair' in d
True
>>> 'hat' in d
False
```

Notice how `in` tests for membership in the dictionary keys, not the dictionary values.

Dictionary items can be altered or deleted.

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> d['cat'] = d['cat'] + 2
>>> d['cat']
9
>>> del(d['cat'])
>>> d
{'chair':'hat','table':7}
```

We can extract the keys, values, or key–value pairs from a dictionary. These are returned as specific datatypes, but all can be converted to lists with `list()`. For example:

```
>>> d = {'cat':7,'chair':'hat','table':7}
>>> list(d.keys())
['chair', 'cat', 'table']
>>> list(d.values())
['hat', 7, 7]
>>> list(d.items())
[('chair', 'hat'), ('cat', 7), ('table', 7)]
```

Finally, dictionaries can be used directly with the `format()` method for strings. There's a special operator for this `**`. The basic idea is that the slots in the string are named. The values that go in those slots are associated with the relevant keys of the dictionary. For example:

```
>>> d = {'uno':'eins','dos':'zwei','tres':'drei'}
>>> s = 'one = {uno} and three = {tres}'
```

```
>>> s.format(**d)
'one = eins and three = drei'
```

Notice that keys of the dictionary that are not named in the string are simply disregarded.

2.3 Mutability

An extremely important and unfortunately confusing concept is *mutability*. Some objects in Python can be changed and others cannot. To understand this fully though, we must understand several other notions: *garbage collection* and *naming*.

Whenever you create an element in Python, it occupies space in your computer's memory. As you create more and more elements, that memory fills. As you interact with Python, or as your later Python programs run, you run the risk of filling up your computer's memory. Python manages this memory for you automatically. As you create and manipulate elements, Python holds them in memory. When you cease to use some element, Python removes it, freeing up memory. This latter process is called *garbage collection*.

One way garbage collection applies is to named elements that are no longer used. For example, if you define `i` as `35` at some point in a program, use it, and then stop using it at some point. The garbage collector will detect that and free up that bit of memory.

Another instance where garbage collection applies is in a situation like the following:

```
>>> i = 7
...
>>> i = 'hat'
```

Here we have created an integer and named it `i`. Later, we create a string `'hat'` and name it `i`. The integer is now, in principle, floating around unnamed. The garbage collector detects this and frees up that memory accordingly.

In this case, it's important to be clear that `i` is not some data element that has changed. Rather, `i` named an integer and then that name is reassigned to a string. The integer element becomes available for garbage collection. Memory is allocated for the new string and it takes on the name `i`.

In this light, let's now consider *mutability*. Lists and dictionaries are mutable elements, elements that can be directly changed. Everything else we've discussed, integers, floating point numbers, complex numbers, booleans, strings, and tuples, are immutable, elements that cannot be changed.

Given the memory allocation discussion above, mutability can only be detected when an element has multiple parts. The idea would be that you could change some part of an element and leave the rest intact. This is possible for lists and dictionaries; they are mutable. Thus, we can define a list and then add or delete elements in that list, or change elements in the list. For example:

```
>>> x = ['Tom','Dick','Harry']
>>> x[1] = 'Mary'
>>> x
['Tom','Mary','Harry']
>>> x.append('Edna')
>>> x
['Tom','Mary','Harry','Edna']
```

We've already seen the `insert()` and `pop()` methods for lists in Section 2.2.4 above, which both allow us to change a list.

Dictionaries are also mutable. We can add, delete, or change items. For example:

```
>>> d = {'un':'un','deux':'?','trois':'tri'}
>>> d['quatre'] = 'pedwar'
>>> d['deux'] = 'dau'
>>> d
{'un':'un','deux':'dau','trois':'tri',
  'quatre':'pedwar'}
```

As noted above, for simple datatypes like numbers and booleans, we cannot see the effects of their immutability. Superficially, it seems like we can change them:

```
>>> x = 3
>>> x = 7
>>> x
7
>>> y = True
>>> y = False
>>> y
```

```
False
```

This is only apparent however. In both cases above, we are simply reassigning the names `x` and `y` to new elements. The old elements are unchanged, though available for garbage collection.

Strings and tuples have multiple parts, but are *not* mutable. For example, while we can refer to pieces of each with indexes, we cannot assign new values to just those indexed segments. For strings:

```
>>> x = 'abc'
>>> x[1] = 'd'
  Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  TypeError: 'str' object does not
  support item assignment
```

The same applies to tuples:

```
>>> x = ('a','b','c')
>>> x[1] = 'd'
  Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  TypeError: 'tuple' object does not
  support item assignment
```

Notice that we can reuse a name that was assigned initially to a string or tuple, but this is reusing the name, not changing the initial data structure.

```
>>> x = 'a first string'
>>> x = 'another string'
```

Notice then that methods for mutable and immutable elements differ in whether they change the object they are methods for or return a new element. On the one hand, the `reverse()` method for lists alters the list in place, reversing its elements. On the other hand, the `upper()` method for strings returns a new string with all uppercase letters *and leaves the initial string unaffected*.

```
>>> x = [1,2,3]
>>> x.reverse()
>>> x
[3,2,1]
```

```
>>> y = 'letters'
>>> y.upper()
'LETTERS'
>>> y
'letters'
```

Mutability may seem like a fine point, but try to keep it in mind as you proceed. It's extremely easy to forget and it can lead to all sorts of hidden bugs in your programs.

2.4 Exercises

1. Write three lines of code that: i) create a variable with the value 37; ii) create another variable with the value 4; iii) print out the result of multiplying those together.
2. Write three lines of code that: i) create a string *transformational*; ii) create a string *grammar*; concatenate those together and print the result. (Make sure there is a space between the two words!)
3. Explain what the following bit of code does and why it's a bad idea:

   ```
   yes = 'no'
   no = 'yes'
   ```

4. Write a single line of code that tests whether 7^3 is greater than 15×16.
5. Explain what's going on below; is `x` mutable?

   ```
   x = 'abc'
   x = x.upper()
   ```

6. Semitic morphology involves intercalating vowels and consonants to express morphological categories. For example, the Arabic root k,t,b occurs in at least the following forms: *katab-a* 'he wrote', *kaatab-a* 'he corresponded', *kutib-a* 'it was written', *kitab* 'book', *kuttaab* 'writers', *uktub* 'write!', etc.

   How might you use `format()` to describe this system? Give a sample representation for the root k,t,b and how `format()` could be used to express different categories.

7. We can also use `format()` to treat vowel harmony. Choose a simple vowel harmony system and show how this might work.

8. You can use the dictionary datatype in conjunction with the `format()` command to do translations between two languages. Choose two languages, construct a small dictionary for them, then create some strings that you can use your dictionary to do translations for.

Chapter 3

Control structures

We've learned a fair amount of Python, but our code so far is surely unsatisfying. Basically, our code so far can't really do any more than what we can type in. There is no *savings*, no extra bang for our buck. This changes in the current and following chapters where we go over control structures and then input–output.

So far, a program is just a sequence of statements, executed one after the other. In this chapter, we show how statements can be executed conditionally, how some statements can escape being executed and how others can be executed any number of times. In effect, this allows for much more effect than "what you type in". You'll see that we can do an infinite amount of stuff with a finite amount of code. In principle, the control structures we will learn are very simple, but—along with variable assigment (Section 2.1)—they are the heart and soul of a programming system, almost everything you need to know to write meaningful and useful programs of your own.

From here on, we will assume that all code is written as a program. That is, the code is typed into a file and then that file is run as a program. All programs in this book are available on the book website and the name of the relevant filename is given below each listing in parentheses.

3.1 Grouping and indentation

To make full use of control structures, we need to understand how Python groups statements together. To understand this, let's look at the `if` control structure. This structure, in it's simplest form, allows for conditional application. There is a test clause and then a block of one or more statements. If the test clause is true, the statements are executed. If it is not true, the statements are not executed. Here's an example:

```
#a single statement can occur on the
#same line
if 2+2 == 4: print('that was true')
```

control1.py

or:

```
#a single statement can occur
#indented on the next line
if 2+2 == 4:
   print('that was true')
```

control2.py

The test is introduced with the keyword `if` and terminates with a colon. If the statement block is a single statement, it can occur on the same line or the next. If it occurs on the next line, it must be spaced or tabbed in at least one space or tab. If there is no indentation, an error is produced. The example below demonstrates. Note that we have added a comment to the code to remind us that this file does not work. Comments are indicated with a # on the left side of the line and have no effect on the code. If you run this or any other program, comments have no effect.

```
#produces an error
if 2+2 == 4:
print('that was true')
```

control3.py

If there are multiple statements contingent on the test, then they must appear on separate lines *and* they must be tabbed or spaced in *the same amount*. Here's a well-formed example:

```
#multiple statements correctly indented
if 2+2 == 4:
   print('that was true')
   print('...really true')
```

control4.py

Here's an ill-formed example; the second statement has an extra space.

```
#produces an error
if 2+2 == 4:
   print('that was true')
    print('...really true')
```

control5.py

A similar error occurs if the first of the two statements has an extra indentation:

```
#produces an error
if 2+2 == 4:
    print('that was true')
   print('...really true')
```

control6.py

In principle, you can indent with either spaces or tabs, but *be careful and do not mix them!* For example, if you indent one line with a tab and then indent the next line with the right number of spaces so that they *look* aligned, this will typically generate an error. The problem is that Python has no way of knowing how wide you've set your tabs to display in your word processor.

Note that this tabbing has semantic consequences. Compare the following:

```
#block has two statements in it
if 2 + 2 == 5:
   print("that shouldn't happen")
   print('or this....')
```

control7.py

```
#block has one statement in it
if 2 + 2 == 5:
   print("that shouldn't happen")
print('or this....')
```

control8.py

In both cases, we test if `2 + 2 == 5`; that evaluates to false. In the first example, the two statements are not executed since they are in the block of contingent statements. In the second case, the second statement *is* executed. Since it is not indented, it is evaluated as outside of the `if` structure and thus not contingent on the `if` test.

This semantic effect also shows itself with nested `if` structures. In the following example, we first test if `2+2==4`. If that is true, which of course it is, then we execute the following three statements. We first print `'wow'`. Second, we execute another `if` structure. This second if structure tests if `7*7==48`, which is false. If it were true, we would print `'wow again'`. Finally, the third statement in the initial `if` structure's block prints `'wow a third time'`.

```
#nested if with following statement
if 2+2==4:
   print('wow')
   if 7*7==48:
      print('wow again')
   print('wow a third time')
```

control9.py

In the next example, we've spaced/tabbed in the final statement so that it is part of the nested `if` structure. It will only execute if both `if` tests evaluate to true.

```
#nested if with two-statement block
if 2+2==4:
   print('wow')
   if 7*7==48:
      print('wow again')
      print('wow a third time')
```

control10.py

Finally, in this third case, the final statement has no indentation. It therefore is executed regardless of the two tests.

```
#nested if with following independent statement
if 2+2==4:
   print('wow')
```

```
    if 7*7==48:
        print('wow again')
print('wow a third time')
```

control11.py

3.2 if

Let's now look a little more closely at the options for `if`. We've already seen that one or more statements can be contingent on some logical test. If the test evaluates to true, the block of statements then executes in order. If it is false, none of them is executed.

A very simple augmentation of the `if` structure is the `else` clause. This is a block of code that executes if the `if` test evaluates to false. The `else` statement follows the first block of code and is at the same level of indentation as the initial `if` clause. For example:

```
#only else block executes
if 2+2==5:
    print("this won't print")
else:
    print('but this will')
    print('...and so will this')
```

control12.py

If the `if` clause evaluates to true, the `else` block will not execute:

```
#else-block does not execute
if 2+2==4:
    print('this will print')
else:
    print("but this won't")
    print('...and neither will this')
```

control13.py

Finally, one can add any number of `elif` clauses to an `if` structure. These add additional *contingent* tests to the structure. The syntax is like this:

```
if test1
   block1
elif test2
   block2
elif test3
   block3
...
else
   blockn
```

We can represent graphically which blocks in the example above are executed depending on which tests evaluate to true:

test1	test2	test3	what applies?
True	True	True	block1
True	True	False	block1
True	False	True	block1
True	False	False	block1
False	True	True	block2
False	True	False	block2
False	False	True	block3
False	False	False	blockn

Notice how if `test1` is true, `block1` applies regardless of the truth or falsity of any other test. If `test1` is false and `test2` is true, `block2` applies regardless of whether `test3` is true. Finally, the `else` block only applies if all previous tests are false.

A final complication is that it may sometimes be convenient to have an empty block. Imagine you want to test a string for whether the first letter is `'a'`, but then do something in all other cases. One way to do this is to test for that, but then put your code in the `else` block. The problem with this is that you would then have an empty block following the `if` test. This is not allowed in Python. To deal with this possibility, Python has the `pass` statement which you can use to fill the block. For example:

```
#set a variable
x = 'hat'
#if clause with empty block
if x[0] == 'a':
```

```
    pass
else:
    print('doing something here....')
```

control14.py

Here the `print` statement only happens when the first letter of the string is *not* `'a'`.

3.3 Digression on printing

We will spend more time on this in Chapter 4, but let's add a little detail to how we can explicitly print something in Python using the `print()` command.

We've already seen that it can be given a string as an argument and prints that string to the screen:

```
>>> print('here is a string')
here is a string
```

It can also be given any number of strings; they are all printed to the screen:

```
>>> print('one','two','three')
one two three
```

Notice that the strings are separated by spaces. We can specify another separator or, indeed, no separator with the optional `sep` argument. If we include this argument, we specify its value with =. For example:

```
>>> print('one','two','three',sep='-')
one-two-three
>>> print('one','two','three',sep='')
onetwothree
```

Finally, notice that the default behavior for `print()` is to print its argument(s) and begin a new line. We can specify different behavior by giving a value to the optional `end` argument.

```
>>> print('one','two',sep='-',end='!')
one-two!>>>
```

We will exploit these options in the exemplification of the control structures to come.

3.4 for

The for control structure allows for multiple application of some fixed block of code. You specify a list or sequence of items and then iterate over the list applying the block once for each item in the list or sequence. The syntax is a for clause followed by an indented block of one or more statements. The for clause begins with the keyword for, then a variable name, then the in operator, then a list or sequence of items that can be iterated over, and finally a colon.

Here's a very simple example:

```
for i in [1,2,3]:
   print(i)
```

control15.py

Here we assign the variable i the values from the list [1,2,3] one by one. For each assignment, we apply the block. In this case, the block simply prints the value of i:

```
1
2
3
```

Note that nothing requires that we actually use the value i in the block. Thus the following works as well:

```
#value for i not used
for i in [1,2,3]:
   print('wow')
```

control16.py

This produces:

```
wow
wow
wow
```

Similarly, nothing prevents us from using the variable more than once per each iteration. For example:

```
#using the variable twice
for i in [1,2,3]:
   print('{} + 2 = {}'.format(i,i+2))
```

control17.py

We can iterate over strings as well. For example:

```
#printing letters separated by spaces
for i in 'tone':
   print(i,end=' ')
#add a return at the end
print()
```

control18.py

Here we print each letter separately. We end each print operation with a space rather than a return. Then, after all that printing, we get back to the beginning of the line by printing nothing. Since the default is to end each printed item with a return, printing nothing has the effect of starting a new line.

Recall the `range()` function from Section 2.2.4 above. We can iterate directly over the sequence of numbers it provides. For example, if we want to add up all the numbers from `0` to `4`, we can do it like this:

```
#set a variable
total = 0
#iterate and add to total
for i in range(5):
   total = total + i
#print the total
print(total)
```

control19.py

Here we first define a variable `total` and set its value to `0`. We then create a sequence from `0` to `4` (the integer value just before the value specified). Then on each iteration we reset the value of `total` to be equal to its current value plus the current value of `i`.

Let's chart this out to see how this works. First, we number the lines above so we can refer to where we are:

```
1 total = 0
2 for i in range(5):
3     total = total + i
4 print(total)
```

Now we step through the code line by line showing the values of `total` and `i` at each point.

line	total	i
1	0	NA
2	0	0
3	0	0
2	0	1
3	1	1
2	1	2
3	3	2
2	3	3
3	6	3
2	6	4
3	10	4
4	10	4

Notice how we go back and forth between lines 2 and 3 alternately resetting the values for `i` and `total`.

This is a fairly common programming technique, create a variable that we incrememtally change in some sort of loop. We can do some fairly interesting stuff with this. For example, we might do morphological recursion with this:

```
#initial prefix and word
prefix = 'anti'
word = 'missle'
#print the word
print(word)
#iterate 3 times
for i in range(3):
   #add a prefix to the word...
   word = prefix + '-' + word
```

```
    #...and print the new word
    print(word)
```

control20.py

This produces:

```
missle
anti-missle
anti-anti-missle
anti-anti-anti-missle
```

There are a couple of things that distinguish this from the previous example. First, notice that we are doing string concatenation, rather than addition. Second, notice that we are printing the `word` variable at each iteration, rather than just at the end. This then is an instance of the semantic effects of indentation in a real example. If we had not indented the final print statement, this would have simply printed the last line above.

As with `if`, we can nest `for` structures. Thus, we can augment our prefixation example above, so that it prefixes multiple words:

```
#define the prefix and 3 words
prefix = 'anti'
words = ['missle','racism','music']
#iterate over each word
for word in words:
    #print the word
    print(word)
    #for each word, iterate 3 times
    for i in range(3):
        #add the prefix to the current word
        word = prefix + '-' + word
        #print the new word
        print(word)
```

control21.py

Here we go through the words one by one. For each word, we prefix it three times. Here's the output:

```
missle
```

```
anti-missle
anti-anti-missle
anti-anti-anti-missle
racism
anti-racism
anti-anti-racism
anti-anti-anti-racism
music
anti-music
anti-anti-music
anti-anti-anti-music
```

The other thing to notice here is that `for` allows us to do potentially massive calculations with finite means. For example, if we wanted to sum numbers up to 10,000, this would be a trivial change to the code above.

```
#variable to accumulate additions
total = 0
#iterate a lot
for i in range(10000):
    #add i to total
    total = total + i
#print the total
print(total)
```

control22.py

Now that we have two control structures, `if` and `for`, we can combine them. Let's write some code to count the vowels in a string.

```
#define vowels
vowels = 'aeiou'
#variable to accumulate the vowel count
vowelCount = 0
#define the word
word = 'Appalachicola'
#go through the word letter by letter
for letter in word:
    #for each letter check if it's a vowel
    if letter in vowels:
```

```
        #if it is, add 1 to the total
        vowelCount = vowelCount + 1
#print the total
print(vowelCount)
```

control23.py

Here we first define vowels. We then set our count of vowels to 0. We define the word we will count vowels in. Next we iterate through each letter in the word assigning the current letter to the variable `letter`. We then test if that letter is a vowel with the `in` operator. If it is, we augment the value of `vowelCount` by one. If is not a vowel, that test fails, nothing happens and we go on to the next iteration. Finally, we print the value of `vowelCount`.

The operation where we augment a variable by some specific amount is frequent enough that there is a special operator for it: +=. The following does exactly the same thing as the preceding.

```
#define vowels
vowels = 'aeiou'
#variable to accumulate the vowel count
vowelCount = 0
#define the word
word = 'Appalachicola'
#go through the word letter by letter
for letter in word:
    #for each letter check if it's a vowel
    if letter in vowels:
        #if it is, add 1 to the total
        vowelCount += 1
#print the total
print(vowelCount)
```

control24.py

We can also nest a `for` loop inside of an `if` structure. Here we set up virtually the same initial variables. We then test if the first letter of the word is a vowel. Note that since we've defined vowels as lowercase letters, we must first convert the first letter to lowercase. If the word does begin with a vowel, we count all the letters. (Of course, we could have simply used the `len()` function!)

```
#define vowels
vowels = 'aeiou'
#set counter to zero
letterCount = 0
#define the word
word = 'Appalachicola'
#convert first vowel to lowercase
#is it a vowel?
if word[0].lower() in vowels:
   #if it is go through letter by letter
   for letter in word:
      #for each letter, add 1
      letterCount += 1
#do this if the word is not V-initial
else:
   print('Not vowel-initial')
#print the number of letters
print(letterCount)
```

control25.py

Make sure you understand the semantics of control structures like `if` and `for` and what it means for them to be nested in different ways. *Writing programs is mostly about figuring out the logic of the problem you want to solve and then recasting it in terms of nested control structures.*

3.5 `while`

Technically, the `for` control structure isn't necessary. Anything you can do with `for`, you can do with `while`, perhaps a bit awkwardly. The logic of `while` is that a statement or block of statements is iterated as long as some test holds true. The syntax is parallel to what we have seen already. There is the keyword `while`, followed by the test, an expression that returns a boolean value, followed by a colon. There is then an indented block of one or more statements. If there is only one statement, it can appear on the same line as the `while` test. Here it is schematically:

```
while x == y:
    dosomething(z)
    dosomethingelse(w)
```

Here we have a test for equality between some variables `x` and `y`. We then have a block of two statements. We first check the test. If it is true, we apply the statements in the block. We then go back and check the test again. If it is still true, we apply the statements again. We go through this loop until the test returns `False`.

This should seem a bit silly. If the test returns `True` then it should always return `True` and we should loop forever. That's not typically what we want! The way this structure is typically used is that the truth value of the test is changed during the block of statements so that it eventually becomes false. Here's a simple example:

```
#set counter
count = 0
#check value of counter
while count < 3:
    #increment counter
    #escape clause!
    count += 1
    print(count)
```

control26.py

First we define a variable `count` and store the number `0` in it. We then begin our `while` structure by testing whether `count` is less than `3`, which of course it is. If we did not alter the value of `count` in the block of statements, this would iterate forever. What we do though is to increment the value of `count` at each iteration. It will eventually reach `3`, the test will then fail, and the iteration will cease.

Again, we can diagram the program flow to see how this goes. First, we number lines:

```
1 count = 0
2 while count < 5:
3     count += 1
4     print(count)
```

Now we can examine the value of `count` at each step:

Line	`count`	Test	Printing
1	0	NA	
2	0	`True`	
3	1	NA	
4	1	NA	1
2	1	`True`	
3	2	NA	
4	2	NA	2
2	2	`True`	
3	3	NA	
4	3	NA	3
2	3	`False`	

It's important to keep track of what happens when. Very small changes can change the outcome; for example, imagine we reverse lines 3 and 4 like this:

```
#declare counter
count = 0
#check value of counter
while count < 3:
    #print the value
    print(count)
    #NOW increment the counter
    count += 1
```

control27.py

With this order, we print the numbers 0, 1, 2 instead.

It's also very easy to get this wrong and inadvertantly get an infinite loop. For example:

```
#error: infinite loop!
while count < 3:
    count = 0
    print(count)
    count += 1
```

control28.py

Here we've moved the initial assignment to `count` into the body of the `for` loop. This means that in every loop, we reset the variable to 0 and then add 1; it will thus

always be less than 3.

As with the other control structures we have seen, `while` can combine with itself and with other structures. Here is an example of `while` nested within `while`:

```
#define the word
word = 'alphabet'
#define the counter
count = 0
#iterate while the counter is
#less than the length of the word
while count < len(word):
    #print the current letter
    print(word[count])
    #increment the counter
    count += 1
    #start a new counter
    othercount = 1
    #check that the new counter is
    #less than the original one
    while othercount < count+1:
        #print ever larger prefixes of the word
        print('\t',word[0:othercount])
        #increment the other counter
        othercount += 1
```

control29.py

First we assign the string `'alphabet'` to the variable `word` and the integer `0` to the variable `count`. The outer `while` loop goes through the string letter by letter and prints them out. It increments the `count` variable on each loop to keep track of the iteration *and* to determine which letter to print. The inner `while` loop is a little more complex. It prints out prefixes (initial substrings) of the word based on the current letter determined by the outer `while` loop. Thus, for example, when the current letter is `'h'`, the inner `while` loops prints out `a`, `al`, `alp`, and `alph`.

Notice how the test for the inner `while` loop refers to the variable `count` as well as `othercount`, which change on the outer and inner loops respectively.

The `while` structure can, of course, combine with other control structures. For example, here is a case of `if` inside `while`:

```
#set the word
word = 'alphabet'
#define vowels
vowels = 'aeiou'
#set the counter
count = 0
#iterate
while count < len(word):
    #get the current letter
    letter = word[count]
    #is it a non-vowel
    if letter not in vowels:
        #if so, print it
        print(letter)
    #increment counter
    count += 1
```

control30.py

The `while` structure is very similar to the `for` structure and it's always possible to translate back and forth. For example, recall the first example of the `for` structure (page 38), repeated below:

```
for i in [1,2,3]:
    print(i)
```

We can translate this into a `while` structure like this:

```
i = 1
while i < 4:
    print(i)
    i += 1
```

control31.py

The upshot is that the choice between these typically depends on the which makes the code more intelligible to you as the programmer.

Finally, we note that the `while` structure also allows for a block of `else` statements. These are executed when the `while` test is or becomes false. The general syntax is as follows:

```
while ...:
    statement(s)
else:
    statement(s)
```

Here's a simple example:

```
#define vowels
vowels = 'aeiou'
#set the word
word = 'Winnepesaukee'
#create two counters
counter = 0
vowelcount = 0
#go through letter by letter
while counter < len(word):
    #is current letter a vowel?
    if word[counter] in vowels:
        vowelcount += 1
    #keep track of total number of letters
    counter += 1
#when counter is too big, do this:
else:
    print('There are',vowelcount,
        'vowels in this word')
```

control32.py

Here we go through the word letter by letter, asking whether the current letter is a vowel. If it is, we increment `vowelcount`. When we have reached the end of the word, we execute the `else` clause and print out the number of vowels.

3.6 `break` and `continue`

We can impose finer control on `for` and `while` with the `break` and `continue` statements. The `break` statement exits from the *smallest* enclosing `for` or `while` loop. The `continue` statement exits from the current iteration of the *smallest* enclosing `for` or `while` loop and moves to the next iteration. Here's an example

of break:

```
#define vowels and word
vowels = 'aeiou'
word = 'sthenic'
#set up a counter
counter = 0
#iterate through the word letter by letter
while counter < len(word):
    #if the current letter is a vowel,
    #exit the loop
    if word[counter] in vowels:
        break
    #don't forget to update the counter!
    counter += 1
#print value of counter when break occurred
print('The word begins with',
    counter,'consonant letters')
```

control33.py

Here we define a specific word and vowel letters. We then check whether each letter is a vowel. If it is, we break/exit from the while loop. We then print the value of counter, which is the number of letters iterated through to get to the break statement.

Note that it's fairly easy to make errors in getting the right count here. We start with counter set to 0, which allows us to use it to access each letter of the word, remembering that the indices of the word begin with 0.

We increment counter *after* the if structure. When the if structure test is true, the value of counter is the index of the first vowel letter, the index just past the last consonant letter. Since indices start at 0, this means that the value of counter when we exit is *also* the total number of consonants in the initial span.

Let's go through this line by line to see. First, we number each line:

```
1 vowels = 'aeiou'
2 word = 'sthenic'
3 counter = 0
4 while counter < len(word):
```

```
5     if word[counter] in vowels:
6        break
7     counter += 1
8  print('The word begins with',
9     counter,'consonant letters')
```

Now we step through the code, keeping track of the values of `counter` and `word[counter]`. We collapse sequences of steps together if the relevant values don't change.

Line	counter	word[counter]
1-2	NA	NA
3-6	0	's'
7	1	't'
4-6	1	't'
7	2	'h'
4-6	2	'h'
7	3	'e'
4-6	3	'e'
8-9	3	'e'

We iterate through the `while` loop three times, incrementing `counter` to 3. At that point, `word[counter]` is `'e'` and the `if` test is true and we break/exit from the `while` loop. The value of `counter` *at that point* is also the number of consonant characters at the beginning of the word.

The `break` statement also works with a `for` loop. For example, here is the equivalent to the previous example, replacing `while` with `for`:

```
#define vowels and word
vowels = 'aeiou'
word = 'sthenic'
#initialize counter
counter = 0
#go through all letters
for i in range(len(word)):
   #is current letter a vowel?
   if word[i] in vowels:
      #if so, exit the loop
      break
```

```
    #don't forget to update the counter
    counter += 1
#print result
print('The word begins with',
    counter,'consonant letters')
```

control34.py

The logic of the code above is exactly the same as the preceding.

With the `break` statement available to us to exit the `while` loop, we can use `while` tests that are always true, relying on the `break` statement to exit the loop when we want. For example:

```
#define vowels and the word
vowels = 'aeiou'
word = 'sthenic'
#initialize the counter
counter = 0
#iterate forever
while True:
    #is current letter a vowel?
    if word[counter] in vowels:
        #if so, exit
        break
    #remember to increment counter
    counter += 1
#print result
print('The word begins with',
    counter,'consonant letters')
```

control35.py

Note that the `while` test will always be true so the loop will continue forever unless the `if` test becomes true at some point so that `break` can be executed, exiting the `while` loop. Thus it's important that you be very sure `break` is contingent on a test that will be true at some point if the enclosing loop is always true.

The last few examples involve testing letters for whether they are vowel letters, thus the right question is what the code would do if it were fed words with different properties, e.g. a word with no vowel letters. We leave it as an exercise to determine

which examples will terminate gracefully and which will either not terminate and loop forever, or terminate with some error.

Slightly different behavior is obtained with the `continue` statement. As with `break`, it is used inside a `for` or `while` loop. What it does is exit the current iteration and goes on to the next iteration. Schematically, we have something like this:

```
for ...:
    some statements
    if ...:
        continue
    more statements
```

We have some iterative structure like `for`. We then have zero or more statements. Somewhere in the body we have a `continue` statement, typically in the body of some `if` structure. Following the `if`/`continue`, we have some number of additional statements. What happens is that the `for` licenses some number of iterations. At each iteration, the initial statements apply, then the `if` test occurs. If the `if` test is false, the `continue` statement is not executed and the additional following statements get to apply.

If the `if` test is true on some iteration, then the `continue` statement does apply and the statements following `if`/`continue` do not apply on that iteration. We continue with the next iteration, however, unlike with `break` where all iteration ends. Here's a simple example:

```
#define vowels and the word
vowels = 'aeiou'
word = 'sthenic'
#initialize counter
counter = 0
#go through each letter
for i in range(len(word)):
    #is the current letter a vowel?
    if word[i] in vowels:
        #if so, skip it
        continue
    #increment counter (only for non-vowels!)
    counter += 1
```

```
#print result
print('The word has',
   counter,'consonant letters')
```

control36.py

Here we set up some initial variables. We then enter a `for` loop based on the length of the string variable `word`. At each iteration, we test whether the current letter in the string is a vowel. If it is not a vowel, we increment the `counter` variable. If it is a vowel, we go to the next iteration, not incrementing the `counter` variable. In other words, the `counter` variable is incremented only when the current letter is not a vowel. Once we exit the iteration, we print the value of `counter`.

You can also use a `continue` statement inside of a `while` structure. The following relatively inefficient code snippet exemplifies this and has the same result as the preceding one.

```
#set up initial variables
vowels = 'aeiou'
word = 'Mississippi'
counter = 0
i = 0
#go through word letter by letter
while i < len(word):
   #is the current letter a vowel?
   if word[i] in vowels:
      #if so, increment letter count
      i += 1
      #...and exit current loop
      continue
   #otherwise, increment letter count
   i += 1
   #increment consonant count
   counter += 1
#print result
print('The word has',
   counter,'consonant letters')
```

control37.py

3.7 Making nonsense items

Let's use the control structures we've learned here to build a program that does something useful. A frequent task for psycholinguists is finding items for experiments, either items that directly exemplify some property we want to test or items that fill out an experiment and can be used to distract subjects from the true goal of the experiment.

Imagine what we want are CV monosyllables. We could just try to think of all possible monosyllables with a CV shape, but another way to go is to generate these programmatically. If we know what the possible consonants are and what the possible vowels are, we can generate a list of possible CV monosyllables quite simply. Here's a first pass:

```
#define vowels and consonants
vowels = 'aiu'
consonants = 'ptk'
#for every vowel
for v in vowels:
    #choose a consonant
    for c in consonants:
        #now print them together
        print(c,v,sep='')
```

control38.py

This program defines a set of consonants and a set of vowels and then prints out all possible combinations. As such, it's a bit silly. In the case at hand, there are only nine possible combinations and we could just as easily listed those out. This approach becomes more reasonable though if the number of consonants and vowels increases:

```
#define more Vs and Cs
vowels = 'aeiou'
consonants = 'ptkbdg'
#for every vowel
for v in vowels:
    #choose a consonant
    for c in consonants:
        #now print them together
```

```
        print(c,v,sep='')
```

control39.py

We might also want CVC syllables among our items. This is easy to do as well:

```
#define Vs and Cs
vowels = 'aeiou'
consonants = 'ptkbdg'
#for every vowel:
for v in vowels:
   #choose a consonant
   for o in consonants:
      #now choose another consonant
      for c in consonants:
         #print them together
         print(o,v,c,sep='')
```

control40.py

Imagine now we want to exclude cases where the two consonants are the same. That is, we do not want items like *dod* or *bab*. Again, this is straightforward:

```
#define Vs and Cs
vowels = 'aeiou'
consonants = 'ptkbdg'
#for every vowel, onset, coda
for v in vowels:
   for o in consonants:
      for c in consonants:
         #skip if onset == coda
         if o == c:
            continue
         #print combination
         print(o,v,c,sep='')
```

control41.py

We can extend this to items with more complex structure, e.g. complex onsets, complex codas, polysyllabic words, etc.

The same kind of logic can be used to construct nonsense sentences. Imagine we

want every possible SVO sentence in some (nonsense) language. We have a set of nouns and transitive verbs. We can combine them straightforwardly:

```
#every possible N and V
nouns = 'bla dor sna'
verbs = 'ha mog ge di'
#every possible SVO combo
for s in nouns.split():
   for v in verbs.split():
      for o in nouns.split():
         #print combination
         print(s,v,o)
```

control42.py

As in the word-based example above, this is kind of silly when the sets of elements we are combining are so small, but becomes more useful if we expand those sets.

What do we do if some of our verbs are intransitive? There are a number of ways to deal with this; here's a simple one:

```
#Ns, Vs, & intransitives
nouns = 'bla dor sna'.split()
verbs = 'ha mog ge di'.split()
ivs = 'ha ge'.split()
#for every N and V
for s in nouns:
   for v in verbs:
      #if the V is intransitive
      if v in ivs:
         print(s,v)
      #otherwise it's transitive
      else:
         for o in nouns:
            print(s,v,o)
```

control43.py

Finally, imagine the language has a reflexive pronoun *vi* that replaces the object if it is identical to the subject. We can incorporate this like this:

```
#Ns, Vs, intransitives
```

```
nouns = 'bla dor sna'.split()
verbs = 'ha mog ge di'.split()
ivs = 'ha ge'.split()
#for  every S+V combo:
for s in nouns:
   for v in verbs:
      #if the verb is intransitive:
      if v in ivs:
         print(s,v)
      #otherwise (transitives)
      else:
         for o in nouns:
            #if subject and object are identical
            if s == o:
               #replace O with reflexive
               o = 'vi'
            print(s,v,o)
```

control44.py

3.8 Summary

In this chapter, we have introduced and exemplified the main control structures of Python: `if`, `for`, and `while`. In conjunction with variable assignment, which we covered in Chapter 2, these constitute the heart and soul of programming in Python. Anything that is computable can be expressed with these bits. The challenge in any particular case is to break up the programming task at hand into small pieces that can be expressed with these structures. The remainder of this book will provide extensive examples of this.

3.9 Exercises

1. why does this fail?

```
if 2 + 2 == 5:
print('that shouldn't happen')
```

```
    print('or this....')
```

2. Augment the recursive prefixation example on page 41 to handle three distinct prefixes. Assume that only identical prefixes can cooccur.

3. Augment the recursive prefixation example above to handle three distinct prefixes. Now assume that all prefixes can cooccur and any word can have up to three prefixes.

4. What's wrong with the following code snippet?

```
count = 0
while count < 3:
   print(count)
   count = 1
```

5. Make a chart that shows how the following would work step by step if we define `word` to be `'cat'`.

```
1 word = 'alphabet'
2 count = 0
3 while count < len(word):
4    print(word[count])
5    count += 1
6    othercount = 1
7    while othercount < count+1:
8       print('\t',word[0:othercount])
9       othercount += 1
```

6. Why does the following code fail?

```
word = 'alphabet'
vowels = 'aeiou'
count = 0
while count < len(word):
   letter = word[count]
   if letter not in vowels:
      print(letter)
      count += 1
```

7. The five code examples on pages 47, 49, 50, 51, and 52 involve testing letters for whether they are vowel letters. What happens if the `word` variable has

no vowels?

8. The program `control41.py` on page 56 uses a `continue` statement. Using a `break` instead would be wrong; why?

Chapter 4

Input–output

With variables and control structures, we have the full power of Python available to us. However, to do anything useful, we must be able to run our programs on actual data. For us as linguists, this means words, sentences, texts, sounds, etc.

So far, the only data we've been able to have our programs manipulate are data that we've coded as part of our programs. For example, the various vowel-counting programs in the previous chapter required we code the words we want to count vowels in directly in our program. This is a problem in that we want to write programs like our vowel-counting programs that can count vowels in *any* word.

In this chapter, we learn how to write open-ended programs, programs that can respond to data entered by a user or that come from a file or set of files. In this chapter, we treat the following ways of inputting data:

Command-line Data can be entered on the command-line when the program is invoked.

Standard input Our programs can take input from other programs.

Keyboard input A user can enter data when prompted by the program.

File input–output A program can read data from or write data to files. We will focus on textual data, but this can also include binary data like sound files.

4.1 Command-line input

The simplest way to have your programs respond to new data is to enter that data on the command-line when you invoke the program. This is quite simple to do. There is a predefined list variable `sys.argv` that contains a list of all command-line arguments given when the program is invoked.

The trick to using `sys.argv` is that it is not, by default, available. To get access to it, you must `import` the `sys` module. As in many other programming languages, Python segregates extra functions and variables in different optional parts of the system. If you want access to these functions or variables, you must make them available to your program with an `import` statement at the beginning of your program. To make `sys.argv` available, we start a program with this:

```
import sys
```

If the relevant module is installed on your system, and the `sys` module is a required part of any Python installation, this makes all functions and variables in that module available in the following program. Here's a really simple example:

```
import sys

print(sys.argv)
```

io1.py

We can invoke this program from the command-line in different ways and get these results.

```
> python io1.py
['io1.py']
> python io1.py nouns
['io1.py','nouns']
> python io1.py 3
['io1.py','3']
> python io1.py this is a cat
['io1.py','this','is','a','cat']
> python io1.py '3 > 1'
['io1.py','3 > 1']
```

Note first that we are doing this at the terminal (Mac) or DOS (Windows) prompt,

not in the interactive environment. Second, notice that the first item of the list is always the name of the program. Third, from the quotes, we see that arguments are always interpreted as strings. Finally, certain characters need to be quoted on the command-line as they have special interpretations there that we do not want. For example, if we want to enter a command-line argument that contains a greater-than sign, we must quote it as above to prevent the operating system from interpreting it as redirecting output to a file.

We can use this mechanism to make our vowel-counting program completely flexible. Recall the vowel-counting program `control32.py` on page 49, and repeated below:

```
#define vowels
vowels = 'aeiou'
#set the word
word = 'Winnepesaukee'
#create two counters
counter = 0
vowelcount = 0
#go through letter by letter
while counter < len(word):
   #is current letter a vowel?
   if word[counter] in vowels:
      vowelcount += 1
   #keep track of total number of letters
   counter += 1
#when counter is too big, do this:
else:
   print('There are',vowelcount,
      'vowels in this word')
```

control32.py

We can minimally revise this as follows so that the relevant word comes from the command-line:

```
#make the sys.argv list available
import sys

#define vowels
```

```
vowels = 'aeiou'
#get the word from the command-line
word = sys.argv[1]
#proceed as before...
counter = 0
vowelcount = 0
while counter < len(word):
   if word[counter] in vowels:
      vowelcount += 1
   counter += 1
else:
   print('There are',vowelcount,
      'vowels in this word')
```

io2.py

Here we define `word` as `sys.argv[1]`, the second item in list of command-line arguments. Since the first item is the name of the program, this will be the first thing entered after that. We can results like the following:

```
> python io2.py hat
There are 1 vowels in this word
> python io2.py happiness
There are 3 vowels in this word
> python io2.py Appalachicola
There are 5 vowels in this word
```

The program will throw an error if it gets now additional command-line arguments. If it gets more than one, it will disregard all but the first. We can tweak the code to accommodate multiple arguments as follows:

```
#make sys.argv list available
import sys

#define vowels
vowels = 'aeiou'
#iterate over all words in the list
for word in sys.argv[1:]:
   #proceed as before
   counter = 0
```

```
vowelcount = 0
while counter < len(word):
   if word[counter] in vowels:
      vowelcount += 1
   counter += 1
else:
   print('There are',vowelcount,
      'vowels in',word)
```

io3.py

Recall that `[1:]` returns all items in a list except the first. This program loops over every word in `sys.argv` except for first, doing the same thing as the previous program.

This last program is a nice improvement over the preceding one, in that it allows us to count the (lower-case) vowel letters in any number of words. It suffers from several problems however. First, all words must be entered by hand. If you have a large number of words to treat, this can be prohibitive. A second problem is that there is, in fact, an upper bound on the number of words that can be entered like this. For example, under Windows, the maximum number of characters that can be entered on the command-line is just over 8000. It would, of course, be quite silly to do that much typing, but our point is that there is an upper bound.

There is another option available that looks a lot like command-line input but gets around these limitations: *standard input* (`stdin`). Any program can output material as what's referred to as *standard output* (`stdout`). That material is typically printed to the screen and all of our programs so far have provided output of this sort. That output can be read or given as input to other programs. As with command-line arguments, that material is available via a variable from the `sys` module: `sys.stdin`. We gain access to it by again importing the `sys` module. Here's a trivial example:

```
import sys

for l in sys.stdin:
    print(l)
```

io4.py

Note that `sys.stdin` is not a string variable. Instead, it is a *stream*, in effect, a

tunnel down which data come. To access that data, we can read it line by line using `for` as in this example.

To use this, we must execute some other command-line program and *redirect* its output to `io4.py`. On mac, linux, and windows, we do this by invoking one command and *piping* its output to our program with the `|` "pipe" symbol. The very simplest program we can use for this on any of these operating systems is the `echo` command. This command takes a string and prints it to standard output. If we type this with a string argument at the terminal or DOS prompt, it simply prints that argument:

```
> echo hat
hat
>
```

That's not too interesting in its own right, but that program and argument can be piped to our `io4.py` program like this:

```
> echo hat | python io4.py
hat

>
```

The outputs are slightly different as the piped version has an extra empty line. This is because the `echo` command adds a line, as does the Python `print()` command.

Notice that `echo` can send a whole string of words through the pipe, but it does so as a single string, in a single line:

```
> echo hat chair table | python io4.py
hat chair table

>
```

We can revise our vowel-counting program to take multiple words from `stdin` if we can split that string of words into individual words and then operate on each of them independently. This first step can be achieved with the string method `split()`. We can now tweak `io3.py` above to take multiple words as input from from `stdin`:

```
import sys
```

```
#define vowels
vowels = 'aeiou'
#get each line in stdin
for words in sys.stdin:
   #break it into words
   for word in words.split():
      #do the same as before to each
      counter = 0
      vowelcount = 0
      while counter < len(word):
         if word[counter] in vowels:
            vowelcount += 1
         counter += 1
      else:
         print('There are',vowelcount,
            'vowels in',word)
```

io5.py

Let's go through this line by line to understand. First, as in our previous versions, we define the set of vowels. We next read a line of text from `sys.stdin` and store that line in the string variable `words`. The `echo` command only gives us one line of text, so this part will only execute once. We then split that string into individual words with `words.split()`, storing those words one by one in the variable `word`. The rest of the code here simply repeats the same logic from the previous examples, executed on each word that the string is split into.

Here we have read from `sys.stdin` a line at a time using the `for` structure. However, as noted above, the `echo` command, as we've invoked it here, will feed only a single line of text into our program. We can confirm this by tweaking the code in `io5.py` to keep track of what line it's operating on. We do this in `io6.py`:

```
import sys

#vowels
vowels = 'aeiou'
#line number
line = 1
#for each line in stdin
```

```
for words in sys.stdin:
   #print the line number
   print('This is line',line)
   #increment the line count
   line += 1
   #break the line into words
   for word in words.split():
      #continue as before
      counter = 0
      vowelcount = 0
      while counter < len(word):
         if word[counter] in vowels:
            vowelcount += 1
         counter += 1
      else:
         print('\tThere are ',vowelcount,
            ' vowels in "',word,'"',sep='')
```

io6.py

There are several changes here. First, we've added an integer variable `line` to keep track of how many lines we're working on and what the current line is. Second, we've changed the final `print()` command so that it puts double quotes around the word it's working on.

If we invoke the program again feeding it input from `echo`, we can see that only a single line of text (with three words) is processed.

```
echo cat chair table | python io6.py
This is line 1
   There are 1 vowels in "cat"
   There are 2 vowels in "chair"
   There are 2 vowels in "table"
```

Notice that this doesn't help us really with the shortcomings of the command-line approach. First, all words still have to be entered by hand. Second, there is an upper bound on the number of words we can enter.

There are other programs, however, that we can feed to our programs via `stdin` that avoid these issues. Another program that sends its output to `stdout` is `cat` (or `type` on Windows). What this command does is print the contents of a file to

`stdout` (the screen). If the file is a parochial word processing file like Microsoft Word, the file contents will be largely uninterpretable. On the other hand, if the file is a plain vanilla text file (typically with the file extension `.txt`), then its output via `cat` is intelligible and can be fed usefully to a program like `io6.py`.

Let's first create a simple text file. Using a text editor, create a file called `test.txt` with these contents:

```
this is
a definite test
file
```

If the file is located in the same directory, we can then print its contents to the screen with this command:

```
cat test.txt
```

Under Windows, we would instead type:

```
type test.txt
```

We can feed the contents of this file to `io6.py` with one of the following then:

```
#mac or linux
cat test.txt | python io6.py
#windows
type test.txt | python io6.py
```

This produces the following output:

```
cat test.txt | python io6.py
This is line 1
   There are 1 vowels in "this"
   There are 1 vowels in "is"
This is line 2
   There are 1 vowels in "a"
   There are 4 vowels in "definite"
   There are 1 vowels in "test"
This is line 3
   There are 2 vowels in "file"
```

You can see here that `stdin` can accommodate multiple lines when the program feeding it data contains multiple lines.

You should also see that, since files can in principle contain any amount of data, that this mechanism allows us to feed an unbounded number of words into our vowel-counting program.

Variable assignment and control structures give us the full power of Python; unbounded input like this allows us to apply that power to a computational problem of any size.

4.2 Keyboard input

Another way to input data is to request it from the user. That is, you can write programs that pause at some point and wait for the user to enter data. The code for this is quite simple: there is a function `input()` that takes a single string argument and returns what the user types as a string. Here's an extremely simple example:

```
theInput = input('Type something: ')
print('You typed "',theInput,'"',sep='')
```

io7.py

The `input()` command prints its string argument to the screen. The program then waits for the user to type something. Once the user hits the return key, the program prints that back with double quotes.

Notice that the string that the `input()` command types does not end with a return or final space by default. The program above adds a space explicitly. If we wanted to, we could add a return instead by explicitly putting that in the string typed:

```
theInput = input('Type something:\n')
```

Notice too that whatever the user types is converted to a string. Thus, if the user types 3, it will be converted to `'3'`. Hence, if you want the user to enter numbers or other datatypes other than strings, you must include code to convert those. Here's a silly example:

```
#collect two numbers
n1 = input('Enter a number: ')
n2 = input('Enter another number: ')
```

```
#convert to integers and add
n3 = int(n1) + int(n2)
#return result
print('The sum is:',n3)
```

io8.py

Entering data like this has similar problems to command-line input: while, in principle one can enter any number of strings, the data have to be typed in by hand.

On the other hand, there is another potentially desirable aspect of entering data from the keyboard like this: the number and content of each input item can respond to the program's behavior with respect to earlier items. Here's a silly example of this:

```
import random

letters = 'abcdefghijklmnopqrstuvwxyz'

#get a random letter
letter = letters[random.randint(0,25)]

#loop until the user guesses correctly
while True:
    #prompt them to type a letter
    guess = input('Type a lower-case letter: ')
    #check that it's actually a letter
    if guess not in letters:
        print("That's not a lower-case letter.")
        continue
    #if they're right
    if guess == letter:
        print("That's right!")
        break
    #give them a hint if they're wrong
    if guess > letter:
        print("It's earler in the alphabet.")
    else:
        print("It's later in the alphabet.")
```

io9.py

This program is a guessing game for letters of the alphabet. The program randomly selects a letter and then the user can guess letters. The interest of the program here is that it gives the user feedback on whether their guess is before or after the selected letter. Thus the number of and content of each keyboard input is dependent on the program's response to earlier inputs.

There's a lot of code here, but the structure is fairly simple. First, we import from the `random` module to have access to a random number generator: `randint()`. This function generates a random integer between the two integer arguments we give it. Here the range is based on the length of the `letters` string, so we can use the output to index into that string, selecting a single random letter. Notice that the random number generated by `random.randint()` is immediately fed as an index to `letters`.

We then have an infinite `while` loop with a number of `if` tests. First, we prompt the user to enter a letter and then then test that letter. First, we test if the user actually entered a letter. If not, we prompt again. We then test if the user's letter matches the selected letter. If so, we let the user know and exit the loop. If it's a legal guess and doesn't match, we then tell the user whether their guess precedes or follows the selected letter alphabetically and continue to the next iteration.

There is one context in which `input()` can be awkward. We've seen that the function returns a string which we can then convert to a number if appropriate. What if we want the user to enter actual Python variables or functions? For example, imagine we have three variables `x`, `y`, and `z` and we want the user to select one so that the contents of the variable can be printed. Here's the *incorrect* code:

```
#not what we want!
x = 'Tom'
y = 'Dick'
z = 'Harry'

result = input('Type x, y, or z: ')

print(result)
```

io10.py

Here, we might get an interaction like this:

```
> 'Type x, y, or z: x
x
```

To get the right result, we must *evaluate* what the user enters as a Python expression. This can be done with the function `eval()`. Here is the revised code:

```
#set up three variables
x = 'Tom'
y = 'Dick'
z = 'Harry'
#collect user input
result = input('Type x, y, or z: ')
#evaluate and print result
print(eval(result))
```

io11.py

Now we get an interaction like this:

```
> 'Type x, y, or z: x
Tom
```

4.3 File input–output

The usual way to input or output large amounts of data is from or to files. The basic idea is that your program is written to respond to any amount of data. The file contains data of the appropriate sort and your program reads in that data and processes it either all at once or chunk by chunk.

Writing to files is, in principle, a dangerous operation. If you are not careful, you can accidentally overwrite important data. Therefore I recommend several things right at the outset:

1. Do *not* experiment with important files. Create toy files to play with.
2. When you do want to start working on your own files, again do *not* use those files directly. It's much safer to create copies of these files and work with those.
3. Finally, it's safest to create a new directory to learn file operations with. You can create new files there and you can copy (not move!) other files there.

These safeguards will reduce the chance of some catastrophic loss of data as you learn file operations.

In principle, these can be files of any sort, but it is simplest to start with simple text files. Let's begin with writing to a file. The basic logic is that you create a *stream* or *pathway* to a file, print to that stream, and then close the stream. Here's a very simple example of this:

```
#open the file stream
outFile = open('testfile.txt','w')
#write to it
outFile.write('some text!\n')
outFile.write('...and some more text!\n')
#close the stream
outFile.close()
```

io12.py

First, we create a stream called `outFile`. with the `open()` function. The first argument is the name of the file and the second argument indicates that we are writing to this file. We then write to that stream twice using the stream method `write()`. Notice that we've explicitly added returns (`\n`) at the end of each `write()` command so that each bit is on its own line in the file. Notice too that each successive `write` call adds to the existing file. Once we are done with writing to the file, we close the stream with the `close()` method.

To beat a dead horse, be careful here. The program above creates a file. If you were to name this file the same name as an existing file in the same directory, it would overwrite the existing file, destroying its contents. Again, create a new directory for file operations at this stage. Also, make sure to name your new test files in a way that is least likely to crash with your existing files.

Let's now look at file input. The system is basically the same. You create a file input stream, read from it, and then close the stream. In the following example, we read from the file we created in the previous example and print the result to the screen.

```
#open file stream
inFile = open('testfile.txt','r')
#read form it
stuff = inFile.read()
```

```
#close stream
inFile.close()
#print contents
print(stuff)
```

io13.py

Notice that the `read()` method reads in the entire context of the file. If you want to process the contents of the file in chunks, say lines, this is not optimal. You have two choices here. One possibility is to break the text into lines after you've read them all in as above. The following program shows how to do this:

```
#open file
inFile = open('testfile.txt','r')
#read file contents
stuff = inFile.read()
#close file
inFile.close()
#split file contents into lines
lines = stuff.split('\n')
#print lines and their lengths
for line in lines:
   print(len(line),': ',line,sep='')
```

io14.py

In this program we read the entire contents of the file in with the `read()` method. We then use the string method `split()` to break the file contents into lines. We then go through those lines one by one, calculating their length and printing the length and line.

The other possibility is to read lines from the stream and process them one by one.

```
#open file
inFile = open('testfile.txt','r')
#read from stream line by line
for line in inFile:
   #print length of line and the line
   print(len(line),': ',line,sep='',end='')
#close file stream
inFile.close()
```

io15.py

This second program produces very similar output. For very large files, this second approach can be more efficient.

So far, we've just looked at text files, but Python can handle specialized or proprietary file formats as well. We give two examples here: wave files and Microsoft Excel files.

Typically, processing files like this requires access to specialized modules that may not be part of your basic Python installation. These can be added on Mac or linux in two ways, either by general software management programs like MacPorts or Homebrew (for Mac) or by the Python-specific `pip` program. For Windows, `pip` is the normal route. In the following examples, we will make use of two such extra modules.

One common file format for linguists is sound files in `.wav` format. These files represent a waveform as a sequence of numbers indicating sound pressure changes over time. In addition, the file contains various sorts of metadata, e.g. sample rate, whether the sound is recorded in stereo, etc.

We can read in a wave file with a function from the `scipy` library, a specialized module for efficient math functions. There are a variety of things we can do with the data, but the simplest here is just to plot it with a function from `matplotlib` a specialized module for plotting.

```
#import from scipy and matplotlib
import scipy.io.wavfile,matplotlib.pyplot
#read sample rate and wave vector from file
x,y = scipy.io.wavfile.read('mha.wav')
#calculate duration
vdur = len(y)/x
#print duration
print('Duration of wave:',vdur)
#make a plot of the wave
matplotlib.pyplot.plot(y)
#show that plot
matplotlib.pyplot.show()
```

io16.py

This program reads in a wavefile using a function from the `scipy` module which

returns the sample rate (in samples per second) and a vector of numbers. Note that if we want to assign these to two different variables, we simply put both to the left of the assignment operator =. The example uses a wavefile `mha.wav` which is just a recording of the author pronouncing the vowel [a]. We calculate the duration of the wave by dividing the number of samples in the wave by the sample rate. Finally, we use several functions from the `matplotlib` module to create and show the waveform.

We can read in data from other filetypes as well. The following example shows how to use the `openpyxl` package to read in and examine an Excel spreadsheet.

```
#import module to handl xls/xlsx files
import openpyxl

#read in data
wb = openpyxl.load_workbook('test.xlsx',
   read_only=True)

#get the names of the excel 'sheets'
print(wb.get_sheet_names())
#get the first sheet
sheet = wb['Sheet1']
#print the contents of cell B2 on sheet1
print(sheet['B2'].value)
#go through all rows
r = 0
for c in sheet.rows:
   #print the row number
   print(r)
   #print all cells in each row
   for i in range(len(c)):
      print('\t',c[i].value)
   r += 1
```

io17.py

Here we first load in a simple spreadsheet we've created `test.xlsx` with a function from the `openpyxl` module. Excel spreadsheets contain multiple pages or *sheets* with grids of cells that can be filled with data of different types. We first extract the names of the sheets in this spreadsheet. We then extract the (only) one named

`Sheet1` and store that in `sheet`. We can access individual cells by name or we can iterate through all rows printing out the contents of all cells in those rows.

4.4 Alice in Wonderland

In this section, we write a larger program to do lexical statistics on *Alice's Adventures in Wonderland* by Lewis Carroll.[1]

Our first step is to make sure we can read in the file. Let's just do that and count the lines in the file. Here's one way to do that:

```
#counter for lines
count = 0
#open the file
f = open('alice.txt','r')
#read the file line by line
for line in f:
   count += 1
#close the file
f.close()
#print the number of lines
print('lines:',count)
```

io18.py

Let's now save all the lines in a list:

```
#counter for lines
count = 0
#list for contents of lines
lines = []
#open the file
f = open('alice.txt','r')
#read it line by line
for line in f:
   #add 1 to the counter
```

[1]The full text is available from Project Gutenberg (`http://gutenberg.org`) and is included on the course website.

```
        count += 1
        #add the current line to the list
        lines.append(line)
    #close the file
    f.close()
    #print the number of lines read
    print('lines:',count)
    #print the number of lines saved
    print('saved lines:',len(lines))
```

io19.py

In this latter example, we have created an empty list and then added the lines one by one to the end of that list. At the end of the program we print out the number of lines read and the number of lines in the list. If we've done things correctly, those two numbers should be the same. This is good programming practice generally. Print out the values of things as you proceed so that you can make sure the program is behaving as you intend.

Let's now print out the first few lines:

```
#list to save the lines
lines = []
#open the file
f = open('alice.txt','r')
#read it line by line
for line in f:
    #save each line in the list
    lines.append(line)
#close the file
f.close()
#print the first 100 lines
i = 0
while i < 100:
    print(lines[i])
    i += 1
```

io20.py

The result here is not quite right; each line is printed out with an extra line in between. The problem is that when lines are read in, the're read in with their

final return character. The `print()` function supplies another return and we get each line terminated by two return character. We can get the behavior we want by telling `print()` not to append a return.

```
#list to save lines
lines = []
#open file
f = open('alice.txt','r')
#read line by line
for line in f:
    #save lines to list
    lines.append(line)
#close file
f.close()
#print first 100 lines
i = 0
while i < 100:
    #don't add a return to the line!
    print(lines[i],end='')
    i += 1
```

io21.py

Notice now that the lines we're printing out are not part of the *Alice* story, but are part of a header that Project Gutenberg has added to the file. By playing around with the number of lines we print out, we can see that the header is 255 lines long. Our next version of the program removes this header and then prints out the beginning of the story:

```
#list for lines
lines = []
#open file
f = open('alice.txt','r')
#read lines one by one
for line in f:
    #add lines to list
    lines.append(line)
#close file
f.close()
#strip off first 255 lines
```

```
lines = lines[255:]
#now print the first 50 lines
i = 0
while i < 50:
    #still don't add a return!
    print(lines[i],end='')
    i += 1
```

io22.py

Let's now do some analysis of the lexical content of the file. As a very simple example, let's imagine that we are interested in whether there is a correlation between word length and word frequency. To do this, we must break each line into words and then compute the length of each word. We'll keep track of the number of words we see of each length.

The next version of the program breaks each line into words and then stores all the words in a list.

```
#list of all words
words = []
#list of all lines
lines = []

#open the file
f = open('alice.txt','r')
#save the lines one by one
for line in f:
    lines.append(line)
#close the file
f.close()

#remove Gutenberg header
lines = lines[255:]

#go through the lines one by one
for line in lines:
    #break each line into words
    wds = line.split()
    #add the words to the list
```

```
    words = words + wds

#print the first 100 words
i = 0
while i < 100:
    print(i,words[i])
    i += 1
```

io23.py

This program does indeed get all the words, but it doesn't strip out irrelevant punctuation. Words are returned with adjacent punction like period, question-mark, etc. We need to strip these away before doing our counts if we want an accurate picture of the relationship between word length and frequency.

There are better ways to do this that we'll see in Chapter 6. Our approach here will be to go through each word character by character, counting only alphabetic characters and not counting anything else. To make this easier, we first convert words to lowercase.

To test this idea and make sure it's doing the right thing for us, we'll first write some code that does this for the first 100 words and displays the output for us. If this works, we then scale it up for all the words in the book. Here's a program that shows how to do this:

```
#list of all words
words = []
#list of all lines
lines = []

#open the file
f = open('alice.txt','r')
#save the lines one by one
for line in f:
    lines.append(line)
#close the file
f.close()

#remove Gutenberg header
lines = lines[255:]
```

```
#go through the lines one by one
for line in lines:
   #break each line into words
   wds = line.split()
   #add the words to the list
   words = words + wds

#print the first 100 words
#and their letter counts
i = 0
while i < 100:
   #store the count for the current word
   count = 0
   #convert the current word to lowercase
   word = words[i].lower()
   #go through the word letter by letter
   #if letter is lowercase, add 1 to count
   for l in word:
      if l in "abcdefghijklmnopqrstuvwxyz":
         count += 1
   #print it all out
   print(i,words[i],count)
   i += 1
```

io24.py

If you inspect the output of this program, you'll see that it does get the correct letter count for the first 100 words. Given that that part is doing the right thing, we can now scale up to doing this for all words and saving the results. What we want is to know how many words there are of each length. To do this, we construct a dictionary which we'll use to store the number of words we've seen for each word length. If, for example, we were to call this dictionary `wordlengths`, we would have the number of words that are two letters long in `wordlengths[2]`, etc.

The following program implements this idea:

```
#list of all words
words = []
#list of all lines
```

```
lines = []
#dictionary of all word lengths
wordlengths = {}

#open the file
f = open('alice.txt','r')
#save the lines one by one
for line in f:
   lines.append(line)
#close the file
f.close()

#remove Gutenberg header
lines = lines[255:]

#go through the lines one by one
for line in lines:
   #break each line into words
   wds = line.split()
   #add the words to the list
   words = words + wds

for wd in words:
   #store the count for the current word
   count = 0
   #convert the current word to lowercase
   word = wd.lower()
   #go through the word letter by letter
   #if letter is lowercase, add 1 to count
   for l in word:
      if l in "abcdefghijklmnopqrstuvwxyz":
         count += 1
   #check if we've seen this length already
   if count in wordlengths:
      #if so add 1
      wordlengths[count] += 1
   else:
      #if not, set to 1
```

```
        wordlengths[count] = 1

#print out counts for each word length
for c in wordlengths:
   print(c,wordlengths[c])
```

io25.py

Finally, let's have the program save the results in a file:

```
#list of all words
words = []
#list of all lines
lines = []
#dictionary of all word lengths
wordlengths = {}

#open the file
f = open('alice.txt','r')
#save the lines one by one
for line in f:
   lines.append(line)
#close the file
f.close()

#remove Gutenberg header
lines = lines[255:]

#go through the lines one by one
for line in lines:
   #break each line into words
   wds = line.split()
   #add the words to the list
   words = words + wds

for wd in words:
   #store the count for the current word
   count = 0
   #convert the current word to lowercase
```

```
        word = wd.lower()
        #go through the word letter by letter
        #if letter is lowercase, add 1 to count
        for l in word:
            if l in "abcdefghijklmnopqrstuvwxyz":
                count += 1
        #check if we've seen this length already
        if count in wordlengths:
            #if so add 1
            wordlengths[count] += 1
        else:
            #if not, set to 1
            wordlengths[count] = 1

#open output file
g = open('res27.txt','w')
#print out counts for each word length
for c in wordlengths:
    clen = str(wordlengths[c])
    res = str(c) + ': ' + clen + '\n'
    g.write(res)
#close output file
g.close()
```

io26.py

This program does quite a bit and we have built it up step by step from the building blocks you have learned thus far. Creating the program in this way does two things that we need to keep sight of.

First, it's shown us the contribution of each program element separately. This way we can examine and understand what each is doing.

Second, and more importantly, this stepwise construction of a program is intended to model how *you* should write your own programs. You should build them up step by step, checking at each point that your program is doing what you think it's doing. You check this by printing the value of variables at each point and checking that they are what you want. If they are, you strip out those print statements and go on to the next step printing out the new variables of interest.

This style of building programs is not just something for beginners. I continue to use it myself in my own programming practice and I recommend you get comfortable with it now and make it a part of your continuing programming habits.

4.5 Summary

In this chapter, we've talked about how to input data into our programs. The basic idea is to write programs that can respond to novel data and/or any amount of data. Any number of data items can then be fed into the program.

We considered a number of input forms. First, some number of forms can be entered on the command-line when your program is invoked. Second, programs can be fed into your program via standard input (`stdin`). Third, the user can be prompted for input. Finally, data for your program can come from files of various sorts. We also saw that you can output your data to files.

4.6 Exercises

1. Tweak the `io3.py` program to accommodate uppercase vowels.
2. Tweak the `io3.py` program to count both vowels and consonants. Make sure it can handle both upercase and lowercase letters.
3. Tweak the `io3.py` program to count letters from a list the user supplies. Thus the first command-line argument is a sequence of letters. These are the letters the program will count. The remaining words on the command-line are the words that the counts are performed on.
4. What happens if we feed data into `io6.py` and then *again* into `io6.py`?

   ```
   ... | python io6.py | python io6.py
   ```

5. The programs `io14.py` and `io15.py` produce slightly different output. Why?
6. We've shown how to write to files, but if a file already exists our write operations will obliterate whatever might already be in the file. Python also allows you to *append* to an existing file. Search on the web and in the Python

document to see how to do this and demonstrate how it works. *Make sure to use text files you create just for this purpose.*

7. Write a program that takes input from `stdin` and converts what it gets to lowercase. Show how this program can be used transitively, in between two other programs, i.e. `prog1 | prog2 | prog3`.

8. Write a program that takes a simple mathematical expression on the command-line like `'7 / 45'`, parses it correctly, and prints the result.

Chapter 5

Subroutines & modules

We can now write fairly large programs. As they get larger and longer, they get harder to understand, harder to keep track of what they're doing, and harder to make changes when changes are necessary.

There are several ways you'll see this effect in your actual code. First, code will get repetitive; you'll find yourself repeating whole blocks of code in your programs. This is always a bad idea. The problem is that if you ever need to change one of these blocks, you'll typically need to change all of them, and it's quite easy to either forget to do that, or do be inconsistent about it.

Another way you'll see this in a language like Python is that your indentation for code blocks will become confusing. You'll be working on some line of code at the end of a block that's tabbed/spaced in some number of times and not being sure how many tabs or spaces you need for the next line.

These issues make us want to *factor* our code, break it into more efficient and conceptually more reasonable chunks. In this chapter, we introduce two ways to do this: *functions* and *modules*. We've already been using functions that are provided directly by Python along with functions available in modules we've imported. In this chapter, we show you how to write your own functions.

We've already seen how to make use of modules, either those part of your default Python installation or publically available modules you add to your installation. In this chapter, we show you how to write your own modules.

The chapter is organized as follows:

Simple functions We give the basic syntax for functions and show how they can be used to simplify our code.

Functions that return values We've seen functions that can "do" things like `print()`, but there are also functions that give us back things like `len()`. In this section, we show how to write functions that return values.

Functions that take arguments Functions may or may not take arguments and here we show how to add required or optional arguments to your functions.

Recursive and lambda functions In this section, we go on to recursive and anonymous (lambda) functions. These topics are a bit advanced, but if you've had a fair amount of syntax or semantics, they are quite straightforward.

Modules Finally, we show how to package a set of functions and variables into separate modules that can be used by multiple programs.

5.1 Simple functions

Functions are defined with the `def` keyword, followed by a function name of your choosing, parentheses, and colon. These are followed by a block of statements.

```
def myfunction():
    print('This is a function')
    print("That's all it does")
```

func1.py

We can invoke this function just as we invoke any other function. The invocation must *follow* the function defintion (but need not follow it immediately of course).

```
#the function definition
def myfunction():
    print('This is a function')
    print("That's all it does")

#invoking that function
myfunction()
```

func2.py

Functions allow us to simplify repetitive code. Consider the following simple program:

```
#print a famous sentence over two lines
print('Colorless green ideas...')
print('...sleep furiously')
#get the user to enter a number
num = input('Enter a number: ')
#print the sentence again if it's < 5
if int(num) < 5:
   print('Colorless green ideas...')
   print('...sleep furiously')
else:
   print('Your number was big enough')
```

func3.py

Notice how the first and second lines are completed in the `if` block. We can avoid this repetition by defining our own function:

```
#a function to print that sentence
def myfunc():
   print('Colorless green ideas...')
   print('...sleep furiously')

#invoke the function
myfunc()
#collect the number
num = input('Enter a number: ')
#check if the number is < 5
if int(num) < 5:
   #print the sentence again if so
   myfunc()
else:
   print('Your number was big enough')
```

func4.py

Here we factor out the repeated two-line section as a separate function. We then call that function twice in the following code.

In this case, we have the same number of lines overall, but you can see that as the number of repetitions increases or as the size of factored out code increases, we achieve savings in terms of the number of lines in the overall program.

Savings in terms of number of lines is not the point however. First, the new code in `func4.py` makes clear that those repeated parts are the same. The new code is also easier to maintain in the sense that if we wanted to change one of the repeated lines, we can do so once and the change is applied in both applications of the function.

Functions can be more complex of course. Here's a slightly longer bit of code that takes input from the user.

```
#a function
def myfunc():
    #user supplies a word
    word = input('Word: ')
    #print that word
    print('This is your word:',word)
    #check if > 5
    if len(word) > 5:
        print('Your word was long.')
    else:
        print('Your word was short.')

#invoke the function
myfunc()
```

func5.py

Here the function reads user input, prints it, and then does different things depending on the length of the input.

Notice how the function code creates a variable `word`. It's important to note that that variable is available *only inside the function*. If we try to refer to a variable created and assigned a value inside some function outside that function, we get an error. Here's an example of that:

```
#this doesn't work!

def myfunc():
```

```
    word = input('Word: ')
    print('This is your word:',word)

myfunc()
if len(word) < 5:
    print("Your word wasn't long enough")
```

func6.py

On the other hand, variables outside a function are available inside a function. Here's an example:

```
#user supplies a word
word = input('Word: ')

#function refers to previous value!
def myfunc():
    print('This is your word:',word)

#invoke the function
myfunc()
#check if the word is less than 5 letters
if len(word) < 5:
    print("Your word wasn't long enough")
```

func7.py

Here the value of `word` is set outside the function. When the function is called, it has access to that value.

5.2 Functions that return values

So far, our functions have taken no arguments and have returned no values. In this section, we show how to write functions that return a value. The syntax is very simple, the returned value of a function follows the keyword `return`. Here's a simple example:

```
#function definition
def myfunc():
```

```
    #prints this
    print("This prints.")
    #return the value 6
    return 6
    #gratuitous print command
    print("This doesn't print!")

#invoke the function, assign value to x
x = myfunc()
#print the value of x
print("Here's the function output:",x)
```

func8.py

Notice how the first `print` statement executes, but the second does not. The return statement exits the function, so subsequent statements cannot run.

This does not mean that `return` must always be last in the function. We can, for example, embed `return` in an `if` structure.

```
#function definition
def sillyfunc():
    #user supplies a word
    wd = input('Type a word: ')
    #check the length of the word
    if len(wd) > 4:
        #return length of word...
        #...and exit function
        return len(wd)
    #otherwise...
    else:
        print('The word is too short!')

#save value of function in variable
res = sillyfunc()
#print value of variable
print('The result: ',res)
```

func9.py

Note that this function either returns a value or prints a value. If you use it in a

context where you expect it to return a value, with = for example, we end up with the non-value `None` if it does not, in fact, return a value.

Functions can also return more than one value. This is as simple as putting several values—seperated by commas—after the `return`. Here's a simple example:

```
#function definition
def myfunc():
    #collect two strings
    x = input('First string: ')
    y = input('Second string: ')
    #concatenate the strings
    z = x + ' ' + y
    #return all three
    return len(x),len(y),z

#invoke the function saving all
#3 return values
a,b,c = myfunc()
#print the three values
print('a =',a)
print('b =',b)
print('c =',c)
```

func10.py

Here the function prompts for two strings and then returns three values: the length of the first string, length of the second string, and the concatenation of the two strings. Note incidentally that the returned values need not be of the same type. Here, the first two returned values are integers and the third is a string.

5.3 Functions that take arguments

Functions can take arguments as well. This is superficially simple to do, but can get tricky. Basically, for a function to take an argument, you put some number of variable names in the parentheses in the function definition. Here's a very simple example:

```
#function that takes 2 arguments
def myfunc(a,b):
    #return the concatenation
    #OR addition of those values
    return a + b

#invoke the function with numbers
print(myfunc(3,10))
#invoke the function with strings
print(myfunc('strings ','too'))
```

func11.py

In this example, we give our function two arguments `a` and `b`. The function then applies the + operator to those. If we invoke the function with integer arguments, the result is the addition of the arguments. If we invoke the function with string arguments, we get the concatenation of those arguments. Thus Python does not generally restrict the type of the arguments a function can take.

Ideally, argument names should be novel, not to be confused with other variables. Let's consider this a bit more closely however. Imagine we have a function defined in a context like the following:

```
x = ...

def afunction(y):
    ...
    z = ...
    ...
    return z

w = afunction(x)
```

In this schematic example, `x` and `w` are *global* variables, variables defined outside of any function and available throughout this file and in any functions defined in this file. The variable `z` is defined within the function `afunction` and *not* available outside that function. This, however, does not prevent the *value* of `z` from being returned by the function.

Finally, there is the variable `y`. This variable is available only within the function `afunction` and is *not* available outside of it. The value of `y` is taken from what-

ever element is given as an argument to `afunction` when it is invoked.

Here things get a little tricky and it's important to remember our discussion of mutability in Section 2.3. Consider first the following program:

```
x = 'a value'

def anotherfunc(a):
    a = 'another value!'
    return a

print(x)
print(anotherfunc(x))
print(x)
```

func12.py

Here we assign a string to the variable `x`. We then define a function which takes an argument. We reassign a value to that argument in the function and then return it. After the function definition we print the variable, print the output of the function, and then print the variable again. This has the following output:

```
> python func12.py
a value
another value!
a value
```

Recall that strings are immutable. Hence, when we change the value of `a` in the function, we're not really changing the value of `a` at all; instead, we're assigning a new value to `a` and leaving the old one available for garbage collection. In this case, however, the old value is still attached to `x`, so it isn't garbage collected. Hence, when we print the value of `x` after the function applies, it retains its original value.

Compare this with the following program:

```
x = [4,5,6]

def anotherfunc(a):
    a.append(7)
    return a

print(x)
```

```
print(anotherfunc(x))
print(x)
```

func13.py

Here, we assign a list to `x`. We then define a function which takes an argument and we append `7` to that argument and return the result. After the function definition, we then print the value of `x`, print the output of the function, and print `x` again. This gives us this output:

```
> python func13.py
[4, 5, 6]
[4, 5, 6, 7]
[4, 5, 6, 7]
```

Notice here that the value of `x` changes after the function applies! This is because lists are mutable. Hence when the function applies, it forces `a` to refer to the same list as `x`. We then change that list so that when we print `x` after the function applies, it has changed as well.

The difference between these two programs corresponds to mutability. Mutable objects all work as in the second program; immutable objects work as in the first one.

We've already seen functions with more than one argument. There is more than one way to invoke these. Consider this example:

```
#function definition
def thefunction(x,y):
   return x + ' ' + y

#invoke the function 3 ways
print(thefunction('one','way'))
print(thefunction(x='another',y='way'))
print(thefunction(y='way',x='yet another'))
```

func14.py

Here we define a function with two arguments and invoke it three different ways. One way is to just provide two arguments; these are interpreted as the two arguments in the function in the same order. A second way, is to name the variables. The names tell us which argument gets associated with which variable. Note that

if we take this option, we can give the names in any order, as above.

The = can be used in the function declaration as well to give default values to the function arguments. Here's an example:

```
#function with default value
#for 2nd argument
def f(x,y='oops'):
   return x + ' ' + y

#invoked 3 ways
print(f('hat'))
print(f(x='chair'))
print(f('hat','chair'))
```

func15.py

Here we define a function that takes two arguments and concatenates them. The second argument has the default value `'oops'`. We then invoke the function three times with this output:

```
> python func15.py
hat oops
chair oops
hat chair
```

In the first invocation, we give the function one argument which is take as the value for `x`. The argument `y` takes its default value. The second invocation has the same effect. In the third invocation, we give two arguments, so `x` is associated with the first and `y` with the second.

Note that if you mix arguments with and without default values in your function declaration, all the arguments with default values must follow the arguments without.

You can also write functions with a variable number of arguments. If you want a variable number of unnamed arguments, you put some variable name in the parentheses in your function declaration with a preceding asterisk. This variable can then be used as a list in the function body. If you want a variable number of named arguments, you put some variable name in the parentheses in your function declaration with two preceding asterisks. This variable can be used as a dictionary

in the function body. If you use both, the list variable must precede the dictionary variable. Here is a simple example:

```
#function with an unspecified
#number of unnamed and named arguments
def func(*args,**kwargs):
   #print unnamed args
   for a in args:
      print('\t',a)
   #print named args
   for k in kwargs:
      print('\t',k,'\t',kwargs[k])

#invoked with unnamed FOLLOWED by
#named arguments
func(3,6,8,hat='wow',chair=3.5)
```

func16.py

This function simply prints out all variables given as unnamed variables and then prints out all variables given as named variables. The latter are printed with their names.

5.4 Recursive and lambda functions

This section contains some tricky material. This section is *not* critical to getting started programming, so it can be safely skipped on a first read. If you've had some formal semantics on the other hand, or background in functional programming, then enjoy.

A very nice feature of Python is that functions can be manipulated just like other datatypes. Thus, for example, it's possible to give functions as arguments to other functions. Here's a simple example:

```
#function with 2 args:
#   a function f
#   and something else x
def func(f,x):
   return f(x)
```

```
#invoking the function
print(func(len,'hat'))
```

func17.py

This program defines a function that takes two arguments: a function and something else. It then applies the first argument, the function, to the second argument and returns the result. It then applies this function to the arguments `len` and `'hat'`. Notice here that the argument names are entirely arbitrary. Here we choose `f` and `x`, but we could have just as easily chosen `harry` and `gladys`. Using `f` for the function variable just adds a bit of clarity to what we want this function to do.

Functions can also return other functions. Here is an example:

```
#function that returns a function
def func(x):
    if x == 'L':
        return len
    else:
        return type

#invoking the function returns a
#function which we apply to
#'chair'. This may look confusing....
print(func('L')('chair'))
```

func18.py

This program defines a function that takes a single argument. If that argument is the character `'L'`, then the function returns the function `len()`; otherwise, it returns the function `type()`. We then apply this function to the argument `'L'` and then apply the result of that application to the string `'chair'`.

Functions can, in fact, manipulate *themselves*. A function definition that does this is said to be a *recursive function*. A very typical example of this in many programming languages is a function for calculating factorials. Recall that factorials are defined like this:

$$
\begin{array}{lcll}
1! & = & 1 & = 1 \\
2! & = & 2 \times 1 & = 2 \\
3! & = & 3 \times 2 \times 1 & = 6 \\
4! & = & 4 \times 3 \times 2 \times 1 & = 24 \\
5! & = & 5 \times 4 \times 3 \times 2 \times 1 & = 120
\end{array}
$$

Basically, we define 1! as 1. We then define any higher number n as $n \times (n-1)!$. Here is a function that does this:

```
#function definition
def fac(n):
    #base case of the recursion
    if n == 1:
        return 1
    #recursive clause
    else:
        #invokes the function ITSELF
        return (n * fac(n-1))

#invoked with the base case
print('1! =',fac(1))
#invoked with a recursive case
print('5! =',fac(5))
```

func19.py

Here we define a recursive function `fac()`. If its argument is `1`, then we return `1`. If its argument is anything else (presumably a higher integer), then we return that value times the result of applying `fac()` to the next lower integer. Let's walk through how this works for the invocation `fac(3)` in the table below.

First, we invoke the function with the call `fac(3)` in line a. Since the argument is not `1`, this is converted to line b. Line b includes the call to `fac(2)` which is converted to $2 \times$ `fac(1)` in line c. Finally, `fac(1)` is converted to 1 in line d.

a.	`fac(3)`	=
b.	$3 \times$ `fac(2)`	=
c.	$3 \times 2 \times$ `fac(1)`	=
d.	$3 \times 2 \times 1$	= 6

Finally, Python allows you to create unnamed functions on the fly and manipulate

or apply them. Here's a simple example:

```
print((lambda x: x + x)('hat'))
```

func20.py

Here we define an anonymous function that concatenates a string with itself. We then apply that anonymous function to the string `'hat'`.

Here is another more interesting example:

```
#function definition
def makeAddN(n):
    #returns a new function
    return lambda x: x + n

#invoke twice, making 2 new functions
add2 = makeAddN(2)
add6 = makeAddN(6)
#apply those two new functions
print(add2(17))
print(add6(17))
```

func21.py

In this case, we have defined a function that creates and returns new functions. The function-creating function takes a single integer argument and then returns a new function that adds that adds that integer to its argument. We then create two new functions and apply them to `17`.

5.5 Modules

We've seen that Python has various objects, functions, and methods that are available from the get-go and that it has other objects, functions, and methods that are only available when an appropriate `import` statement has occurred. For example, we saw that the list of command-line arguments `sys.argv` is only available when we have included `import sys` at the beginning of the program. Similarly, we saw that the `random.randint()` function is only available when we have imported the `random` module.

This may seem like a peculiarity, but in fact is deliberate and efficient. The basic idea is that some things are quite frequently needed while others are only needed in specific situations. The module system separates things accordingly. Very general things are available in all cases, but you only make more specific functions and objects available when you are writing specific sorts of programs.

The alternative would have everything available all the time. This would amount to thousands of functions being available at once. It would mean you'd have to be very careful not to overwrite them with your own variables and functions. In addition, we would have to have sufficient names to distinguish everything from each other, which would make for rather long names as well.

In this section, we first show how to find out what modules are available to you and how to get help on any one of them. We then show various ways to import modules. In the next section, we show how to write your own modules.

To find out what modules are installed on your system, go to the interactive system and type:

```
>>> help('modules')
...
```

This will generate a list of every module installed by default and modules you have added. In addition, it will list the names of all Python programs in your current directory. To find out more about any one of these, you first import it and then use the help system. For example:

```
>>> import re
>>> help(re)
...
```

When you import a module, the objects and functions of that module are available with the name of the module prefixed on the left separated by a period. Thus when we make use of `sys.argv` in the `sys` module, this is because the object `argv` is defined within the `sys` module. We saw this in the `io1.py` program, repeated below.

```
import sys

print(sys.argv)
```

io1.py

So far, our `import` statements have imported the entire contents of a module; we can, in fact, import only specific elements of a module. When we do this, we need not specify the full module name in naming the object or function. The following example shows this:

```
from sys import argv

print(argv)
```

func22.py

Here we have access to `argv` from the `sys` module, but we need not give the full name when we use it. In addition, nothing else from that module is available since we have not explicitly imported anything else. Notice that if we do this sort of restricted import, the full name will not work:

```
#this doesn't work
from sys import argv

print(sys.argv)
```

func23.py

We have one more option with `import`. We can create an alias for the module in the `import` statement. We can do this like this:

```
import sys as s

print(s.argv)
```

func24.py

This allows us to use different qualifying module names for any function or object we might import. Altogether, the different import options allow us to keep our program *name space* as uncluttered as possible, both by restricting what elements are available and by letting us control how specific the names of those elements are.

5.6 Writing your own modules

Writing your own modules that can be imported by other programs is as simple as writing programs. Let's create a module with a single function and string variable in it:

```
#our own module

#a variable
myVar = 'hats and lemons'
#a function
def myFunc(s):
   return len(s)
```

func25.py

We can call import and use this variable and this function in all the ways we saw above. First, we can import and use full names:

```
#import the function
import func25

#invoke the variable with its full name
print(func25.myVar)
#invoke both with full names
print(func25.myFunc(func25.myVar))
```

func26.py

We can also import specific elements or all elements. These can then be used without the module prefix:

```
#invoke everything from the module
from func25 import *

#invoke variable without prefix
print(myVar)
#invoke both without prefixes
print(myFunc(myVar))
```

func27.py

Finally, we can, as above, import the module with a different name:

```
#import with abbreviated prefix
import func25 as f

#invoke function with f prefix
print(f.myVar)
#invoke both with f prefix
print(f.myFunc(f.myVar))
```

func28.py

Notice that if we run `func25.py` on its own, we get nothing as that file defines a function and a string variable, but does nothing with them. We can, in fact, write modules that can be imported or be run on their own. When imported, they provide functions and variables that other programs can use. When they're run on their own, they can make use of those functions and variables themselves.

To do this, we take advantage of the `__name__` variable. When a program is loaded in directly, rather than imported from another program, the `__name__` variable is set to `'__main__'`. We can then use this to allow a module to behave differently when it is invoked directly versus when it is imported by another program. Here's a simple example:

```
#module that can run on its own

#a variable
myVar = 'hats and lemons'

#a function
def myFunc(s):
    return len(s)

#if this is loaded on its own...
if __name__ == '__main__':
    #do this
    print(myFunc(myVar))
```

func29.py

This program will print out the length of `myVar` when it is invoked on its own.

On the other hand, when imported by another program, it will behave just like `func25.py`.

At this point we need to revisit the notion of commenting our code. So far, we have used comments in programs as notes to ourselves, or perhaps as notes to other programmers who might inherit our code. When we start writing modules, the need for comments changes slightly. We now want comments that will enable other programmers to use the functions and variables our module provides.

The standard way to document our functions for other programmers is to make use of *docstrings*. When you are in the interactive environment, you can use the `help()` function to find out more about any function. Docstrings are what allow you to do that. Basically, a docstring is a triple-quoted string that occurs within a function right after the `def` line. For example, imagine we write a module like the following:

```
def myLen(s):
    '''This computes the length of a string.

    s -- the string
    '''
    return len(s)
```

func30.py

The triple-quoted string includes two bits of information: an intuitive statement of what the function does and an explantion of what the argument is. We can now get help on this function, either in the interactive environment or in a separate program that imports `func30.py`:

```
import func30

help(func30.myLen)
```

func31.py

A docstring is what you use if you want to make the functions of your modules usable by others. A comment is what you use for you or others to understand or alter your code. Thus the functions in your modules should make use of both, but in different ways.

We've talked about writing modules that make functions and variables available

for other programs. We've also talked about how to document the functions your modules provide. We also want to consider the case where your module includes that you *don't* want to make available.

This may seem odd, but in fact is perfectly reasonable. Imagine you've written a module that is meant to provide some specific functionality, for example, to read in a file and return a list of all words with an even number of letters and how frequent each of those words is. Your module would then optimally make avaiable a function with a name like `evenCount()` that takes a filename as an argument and then returns, for example, a Python dictionary where each key is a word with an even number of letters and each value is the frequency of that word.

However, to make that optimal function work, there may be a number of other "helper" functions that you've written. These would be in the module and called by the `evenCount()` function, but you don't really intend other programmers to have direct access to them. Such private helper functions should always have names that begin with `_`.

Here's a very simple example. In this program we define a function `myF()` that returns the number of words in a string minus one. We've written this somewhat clumsily to take advantage of a helper function `_mySplit()`. This latter function splits a string into words and returns all the words except the first one. We've written this latter function to be private.

```
#this function makes use of _mySplit()
def myF(s):
    '''This calculates the number of
    words in a string minus one.

    s -- the string
    '''
    wds = _mySplit(s)
    return len(wds)

#this function is private!
def _mySplit(s):
    '''This returns all the words in
    a string except the first.

    This docstring is pointless!
```

```
    '''
    ws = s.split()
    return ws[1:]
```

func32.py

When a function is private, it is not available from *certain* calls to `import`. For example, this produces an error:

```
#this doesn't work
from func32 import *

print(_mySplit("This doesn't work"))
```

func33.py

On the other hand, this works:

```
import func32

print(func32._mySplit("Oh, this does work"))
```

func34.py

As does this:

```
from func32 import _mySplit

print(_mySplit("Oh, this works too"))
```

func35.py

Effectively, there is a limited amount of privacy granted by using the underscore prefix. As we've seen, some ways of importing will allow one to reach into a module and make use of something with an underscore prefix. Aside from how the language works, Python programmars operate on the general assumption that functions and variables that begin with underscore are *intended* to be private and *intended* not to be imported. If you use underscore in this way, it will help other programmers understand the logic and intent of your code.

5.7 Analysis of sentences

In this section we incrementally develop a larger program that does some very superficial analysis of sentence structure. We will again make use of the *Alice* text we used in Chapter 4. The program will be modular in that we will break up our code into separate functions and modules.

We first write the framing code to read in the whole text. We print out the number of characters in the text to make sure we're actually reading the whole thing in. Note that we're reading the whole thing in, rather than reading it in line by line, because we will ultimately be interested in sentence-sized units which do not correspond to line breaks.

```
#open the file
f = open('alice.txt','r')
#read it all in
text = f.read()
#close the stream
f.close()
#check that that worked!
print('characters:',len(text))
```

func36.py

Recall that files from Project Gutenberg begin with header information which we want to remove. If we try various options, we'll see that that header comprises 10,840 characters. The following version of the code prints out those first 10,840 characters. We then remove that from the file and print the first 100 characters of the remainder.

```
#open the file
f = open('alice.txt','r')
#read the whole text
text = f.read()
#close the file stream
f.close()
#print the header
print(text[:10840])
#remove the header
text = text[10841:]
```

```
#print something to separate
#the two print statements
print('NEW START OF FILE:\n')
#print the first 100 letters
#of what remains
print(text[:100])
```

func37.py

Let's begin modularizing the program. We'll factor out the file IO part like this:

```
#function to read in file
#and prune header info
def readfile(filename):
    f = open(filename,'r')
    text = f.read()
    f.close()
    text = text[10841:]
    return text

#invoke the function
t = readfile('alice.txt')
#print the number of letters
#to make sure this worked
print('characters:',len(t))
```

func38.py

Let's now start a new function to split the text into sentences. We will see better ways to do this in Chapter 6, but our goal here is to develop a large modular program, so we set aside details of how best to split into sentences. First, we factor that part out with just a shell:

```
#function to read in file
#and prune header info
def readfile(filename):
    f = open(filename,'r')
    text = f.read()
    f.close()
    text = text[10841:]
    return text
```

```
#function to split into sentences
def getsentences(t):
    return t

#read in file and strip header
txt = readfile('alice.txt')
#split into sentences (ultimately)
s = getsentences(txt)
#print first 10 sentences
for i in range(10):
    print(i,s[i])
```

func39.py

The function `getsentences()` does nothing at this point, but our first step in defining the function is to create a function that does nothing so that we can be sure that we're calling the function correctly. We'll now start fleshing it out. The next step is to just split the string on period. To do this, we make use of the `split()` method for strings.

```
#function to read in file
#and prune header info
def readfile(filename):
    f = open(filename,'r')
    text = f.read()
    f.close()
    text = text[10841:]
    return text

#function to split into sentences
def getsentences(t):
    ss = t.split('.')
    return ss

#read in file and strip header
txt = readfile('alice.txt')
#split into sentences
s = getsentences(txt)
```

```
#print first 10 sentences
for i in range(10):
   print(i,s[i])
```

func40.py

This is certainly moving in the right direction, but falls short in two respects. First, it fails to separate sentences that terminate with something other than a period, e.g. question mark and exclamation point. Second, the `split()` method consumes the period, rather than terminating the string with it.

To overcome these, we write our own string-splitting function.

```
#function to read in file
#and prune header info
def readfile(filename):
   f = open(filename,'r')
   text = f.read()
   f.close()
   text = text[10841:]
   return text

#function to split into sentences
def getsentences(t):
   #characters to split on
   splitters = '.?!'
   #where we'll put the sentences
   ss = []
   i = 0
   #go character by character
   while i < len(t):
      #reset the current sentence
      s = ''
      #read until the end of the text or
      #end of a sentence
      while i < len(t) and \
         t[i] not in splitters:
            s = s + t[i]
            i += 1
      #if the text isn't over, the current
```

```
            #character is the splitter and should
            #be appended
            if i < len(t):
               s = s + t[i]
            #go on to the next character
            i += 1
            #add current sentence to list
            ss.append(s)
        return ss

    #read in file and strip header
    txt = readfile('alice.txt')
    #split into sentences
    s = getsentences(txt)
    #print first 10 sentences
    for i in range(10):
        print(i,s[i])
```

func41.py

We've fleshed out the `getsentences()` function quite a bit and the logic is a bit complex, so let's go through it. The basic idea is to step through the text character by character until the end. This is the `while i < len(t)` loop. We also set up two variables. One, `ss`, is the list of sentences we find. As we find sentences, we add them to this list. The other variable is the current sentence `str`. Inside this loop, we examine the current character to test if it is a senence-ending character. If it is not, we add it to the current sentence and go on to the next character. If, on the other hand, it is a sentence-ending character, we add it to the sentence, add the sentence to the list of sentences, reset the current sentence to `''` and go on to the next character.

The logic is tricky, so we've commented the function extensively above. Note that we've had to spread the second `while` loop line over two lines. Python requires that you end the first half of the line with \.

The two functions we've written, `getsentences()` and `readfile()` differ in their generality. The `readfile()` function is specific to the *Alice* text since it trims off a specific number of characters to eliminate the Gutenberg header. The `getsentences()` function, however, is more general. We can well imagine that we might use it again in some other program where we need to break a text into

sentences.

On this reasoning, it's appropriate to put `getsentences()` into its own module, a module we can invoke whenever we need to split a text into sentences. This module is quite simple and merely includes the `getsentences()` function on its own:

```
#function to split into sentences
def getsentences(t):
    #characters to split on
    splitters = '.?!'
    #where we'll put the sentences
    ss = []
    i = 0
    #go character by character
    while i < len(t):
        #reset the current sentence
        s = ''
        #read until the end of the text or
        #end of a sentence
        while i < len(t) and \
            t[i] not in splitters:
                s = s + t[i]
                i += 1
        #if the text isn't over, the current
        #character is the splitter and should
        #be appended
        if i < len(t):
            s = s + t[i]
        #go on to the next character
        i += 1
        #add current sentence to list
        ss.append(s)
    return ss
```

func42.py

We can eliminate the function definition from our main program and import it from `func42.py`:

```
import func42

#function to read in file
#and prune header info
def readfile(filename):
   f = open(filename,'r')
   text = f.read()
   f.close()
   text = text[10841:]
   return text

#read in file and strip header
txt = readfile('alice.txt')
#split into sentences
s = func42.getsentences(txt)
#print first 10 sentences
for i in range(10):
   print(i,s[i])
```

func43.py

Note that if we truly want to make this new module generally useful, we would name it something appropriate, something mnemonic, e.g. `splitter.py` or the like. We've chosen to use the name `func42.py` to keep all the program files organized.

Note now that the sentences we are printing out have odd spaces, tabs, and returns interspersed. In particular, there are returns and tabs in each sentence. In addition, there are instances of multiple spaces. Let's now clean these up. Specifically, we'll convert all returns and tabs to spaces. We'll then take all instances of multiple spaces in a row and convert them to a single space. Finally, we'll eliminate any spaces at the beginning or end of a line. The following program includes a new function `makespaces()` that converts returns and tabs to spaces and then converts any sequence of spaces to a single space.

```
import func42

#function to read in file
#and prune header info
def readfile(filename):
```

```
    f = open(filename,'r')
    text = f.read()
    f.close()
    text = text[10841:]
    return text

#remove non-space breaks and trim spaces
def makespaces(t):
    #characters to convert
    breaks = '\n\t'
    #output of 1st convert
    r1 = ''
    i = 0
    #go through 1 by 1
    while i < len(t):
        #current char should be converted?
        if t[i] in breaks:
            r1 = r1 + ' '
        else:
            r1 = r1 + t[i]
        i += 1
    #eliminate space after another space
    r2 = r1[0]
    #start at second character
    i = 1
    #go through the whole thing
    while i < len(r1):
        #check for two spaces in a row
        if r1[i] == ' ' and \
            r2[len(r2)-1] == ' ':
                #skip if so
                i += 1
                continue
        #otherwise, append current char
        else:
            r2 = r2 + r1[i]
        i += 1
    return r2
```

```
#read in file and strip header
txt = readfile('alice.txt')
#remove non-space breaks and trim spaces
cleanedtext = makespaces(txt)
#split into sentences
s = func42.getsentences(cleanedtext)
#print first 10 sentences
for i in range(10):
   print('\n',i,': ',s[i],sep='')
```

func44.py

The logic of this new function is as follows. First, we set up an empty output string `r1`. The function then goes through the text character by character. If the current character is a return or tab, then it appends a space to `r1`. Otherwise, the current character is appended. We then set up another output string `r2` with just the first character of `r1`. The function then goes through `r1` starting at the second character. If the current character of `r1` is a space and the last character of `r2` is a space, it is skipped; otherwise the current character of `r1` is appended to `r2`. We then return `r2`.

We now need a function to trim extra spaces on the edges of each sentence. The following program adds this:

```
import func42

#function to read in file
#and prune header info
def readfile(filename):
   f = open(filename,'r')
   text = f.read()
   f.close()
   text = text[10841:]
   return text

#remove non-space breaks and trim spaces
def makespaces(t):
   #characters to convert
   breaks = '\n\t'
```

```
    #output of 1st convert
    r1 = ''
    i = 0
    #go through 1 by 1
    while i < len(t):
        #current char should be converted?
        if t[i] in breaks:
            r1 = r1 + ' '
        else:
            r1 = r1 + t[i]
        i += 1
    #eliminate space after another space
    r2 = r1[0]
    #start at second character
    i = 1
    #go through the whole thing
    while i < len(r1):
        #check for two spaces in a row
        if r1[i] == ' ' and \
            r2[len(r2)-1] == ' ':
                #skip if so
                i += 1
                continue
        #otherwise, append current char
        else:
            r2 = r2 + r1[i]
        i += 1
    return r2

#remove spaces at edges of strings
def trimspaces(t):
    #result list
    r1 = []
    #go through one by one
    for s in t:
        #if first char is a space
        if s[0] == ' ':
            s = s[1:]
```

```
            slast = len(s) - 1
            #if last char is a space
            if len(s) > 0 and s[slast] == ' ':
                s = s[:slast]
            r1.append(s)
        #prune empty sentences
        r2 = []
        #go through one by one
        for s in r1:
            #check if sentence is empty
            if len(s) > 0:
                r2.append(s)
        return r2

#read in file and strip header
txt = readfile('alice.txt')
#remove non-space breaks and extra spaces
cleanedtext = makespaces(txt)
#split into sentences
ss = func42.getsentences(cleanedtext)
#trim edges of sentences
ts = trimspaces(ss)
#print first 10 sentences
for i in range(10):
    print('\n',i,': %',ts[i],'%',sep='')
```

func45.py

The new `trimspaces()` function has two loops. The first goes through and eliminates an initial or final space on all strings. This can now result in empty strings, so the second loop eliminates these. In both cases, we do this by creating new lists of strings and only transferring sentences to these new lists if they satisfy the properties we specify. Notice how we've changed the call to `print()` at the end so we can see the effects of our string-trimming function.

The two new functions we've added, `makespaces()` and `trimspaces()`, are both general, so we will move them both to our separate module. Here is the new module:

```
#function to split into sentences
```

```
def getsentences(t):
    #characters to split on
    splitters = '.?!'
    #where we'll put the sentences
    ss = []
    i = 0
    #go character by character
    while i < len(t):
        #reset the current sentence
        s = ''
        #read until the end of the text or
        #end of a sentence
        while i < len(t) and \
            t[i] not in splitters:
                s = s + t[i]
                i += 1
        #if the text isn't over, the current
        #character is the splitter and should
        #be appended
        if i < len(t):
            s = s + t[i]
        #go on to the next character
        i += 1
        #add current sentence to list
        ss.append(s)
    return ss

#remove non-space breaks and trim spaces
def makespaces(t):
    #characters to convert
    breaks = '\n\t'
    #output of 1st convert
    r1 = ''
    i = 0
    #go through 1 by 1
    while i < len(t):
        #current char should be converted?
        if t[i] in breaks:
```

```
            r1 = r1 + ' '
        else:
            r1 = r1 + t[i]
        i += 1
    #eliminate space after another space
    r2 = r1[0]
    #start at second character
    i = 1
    #go through the whole thing
    while i < len(r1):
        #check for two spaces in a row
        if r1[i] == ' ' and \
            r2[len(r2)-1] == ' ':
                #skip if so
                i += 1
                continue
        #otherwise, append current char
        else:
            r2 = r2 + r1[i]
        i += 1
    return r2

#remove spaces at edges of strings
def trimspaces(t):
    #result list
    r1 = []
    #go through one by one
    for s in t:
        #if first char is a space
        if s[0] == ' ':
            s = s[1:]
        slast = len(s) - 1
        #if last char is a space
        if len(s) > 0 and s[slast] == ' ':
            s = s[:slast]
        r1.append(s)
    #prune empty sentences
    r2 = []
```

```
    #go through one by one
    for s in r1:
        #check if sentence is empty
        if len(s) > 0:
            r2.append(s)
    return r2
```

func46.py

And here is the new program that now calls three functions from `func46.py`:

```
import func46

#function to read in file
#and prune header info
def readfile(filename):
    f = open(filename,'r')
    text = f.read()
    f.close()
    text = text[10841:]
    return text

#read in file and strip header
txt = readfile('alice.txt')
#remove non-space breaks and extra spaces
cleanedtext = func46.makespaces(txt)
#split into sentences
ss = func46.getsentences(cleanedtext)
#trim edges of sentences
ts = func46.trimspaces(ss)
#print first 10 sentences
for i in range(10):
    print('\n',i,': %',ts[i],'%',sep='')
```

func47.py

With all this as background, we can now add the functionality we're really interested in. What is the distribution of sentences in terms of average number of words? The code here is actually quite straightforward and very similar to the final bit of code in `io27.py` in Section 4.4.

```
import func46

#function to read in file
#and prune header info
def readfile(filename):
   f = open(filename,'r')
   text = f.read()
   f.close()
   text = text[10841:]
   return text

#read in file and strip header
txt = readfile('alice.txt')
#remove non-space breaks and extra spaces
cleanedtext = func46.makespaces(txt)
#split into sentences
ss = func46.getsentences(cleanedtext)
#trim edges of sentences
ts = func46.trimspaces(ss)
#dictionary to keep track of counts
counts = {}
#go through all sentences
for s in ts:
   #count the words
   slength = len(s.split())
   #add 1 to relevant count in
   #dictionary
   if slength in counts:
      counts[slength] += 1
   else:
      counts[slength] = 1
#print out counts
for c in sorted(counts):
   print(c,counts[c])
```

func48.py

Here we define a dictionary `counts` to keep track of the number of occurrences of sentences of different lengths. We iterate through all the sentences adding to

`counts` as appropriate. Finally, we print out all values of `counts`. We sort the keys of the dictionary so they are in order.

5.8 Exercises

1. What does this function do?

```
def f(x):
    return x
```

2. What happens if we apply the function above like this: `f(f)(f(3))`? Explain.

3. What does the following do? Explain.

```
(lambda f: f(3))(lambda x: x+2)
```

4. Write a function that *composes* two other functions. That is, it takes two functions as as arguments and returns a function that applies the first function to its argument and then the second function. The two functions should each take a single argument.

5. Write a function that has the same effect as * in an expression like `'this' * 3`. You are not allowed to use * in your function definition!

6. Write a function that is helpful to you. It should take at least *three* arguments.

Chapter 6

Regular expressions

In this chapter we treat one of the most important aspects of programming for linguists: pattern matching. You will very often have to assess whether some string matches some pattern, contains some sequence of characters, some number of characters, etc.

We've already seen that we can do this with what we've already learned. For example, if we wanted to know if some string `s` contained the sequence `ab`, we could simply write `'ab' in s` which would return `True` or `False`. If, on the other hand, we wanted to know if a string contained `'a'` and then `'b'` with material potentially intervening, we would have to do more. We might write a function like this:

```
import sys

#a and then b
def mymatch(s):
    i = 0
    #a flag to keep track of
    #whether we see an 'a'
    aFlag = False
    while i < len(s):
        if s[i] == 'a':
            aFlag = True
            break
```

```
        i += 1
    #start looking for 'b'
    #where we left off
    while i < len(s):
        if s[i] == 'b':
            #if we find 'b', return
            #True of False depending
            #on whether we previously
            #saw 'a'
            return aFlag
        i += 1
    #if all that fails, return False
    return False

print(mymatch(sys.argv[1]))
```

re1.py

The function `mymatch()` can be invoked with a command-line argument, so we can test out how it applies to different strings. The logic of the function is that we search the string for the first instance of `'a'` by iterating across the string with the counter `i`. If we find it, we set the value of `aFlag` to `True` and exit the first `while` loop. Then, without resetting `i`, we initiate another `while` loop to look for `'b'`. Not resetting the value of `i` means that the second loop picks up where the first ended. Hence, the `'b'` must follow the (first) `'a'`.

This is fine as it goes, but it doesn't generalize. There are an infinite number of patterns we might want to search for and writing a potentially complex matching function for each one is at best tedious and at worst can lead to programming errors.

Many programming languages, Python included, implement a general pattern matching mechanism that is both flexible and efficient: *regular expressions*. This is not a book about computational linguistics generally, so we don't have time to go into it here, but suffice it to say that the theory behind regular expressions is both fascinating and powerful. We reluctantly set it aside here and focus on how pattern matching with regular expressions is implemented in Python.

The organization of this chapter is as follows. We first outline the basic pattern-patching functions of Python. We then turn to how patterns can be specified using

regular expressions. We then discuss pattern-matching devices that go beyond regular expressions. Finally, we give an extended example showing pattern matching with regular expressions can be used for linguistic purposes.

6.1 Matching

Matching a string against some pattern is done with the `re` module and most typically with the `search()` function in that module. At its very simplest, we can invoke it like this:

```
import re,sys

if re.search('ab',sys.argv[1]):
   print('a match')
else:
   print('no match')
```

re2.py

Here we import from the `sys` module to make use of command-line arguments and from `re` to use the pattern matching function `search()`. This function takes two arguments: a pattern and a string. In this case, the pattern `'ab'` matches any string that contains that letter sequence, e.g. `'abc'`, `'xab'`, `'ab'`, `'xabc'`, etc.[1]

We'll consider the syntax of patterns in depth in the next section, but let's consider one slightly more complex pattern here: `'a.*b'`. This matches a string that contains `'a'` followed anywhere by a `'b'`. You can see this by playing with the following program:

```
import re,sys

if re.search('a.*b',sys.argv[1]):
   print('a match')
```

[1]The `re.search()` function can take an additional argument `flags` which can take a number of values. The only ones you are likely to use are `flags=re.I` which allows case-insensitive matching and `flags=re.S` which allows `.` to match a return in multiline situations. If you use them both, they must have a pipe in between: `flags=re.S|re.I`.

```
else:
   print('no match')
```

re3.py

The `search()` function actually does not return `True` or `False`, but rather a *match* object if the string matches or `None` if it does not. The reason why the code in the two programs above works is that in an `if` statement, a match object will evaluate to `True` and a `None` object will evaluate to `False`. The following code shows this clearly.

```
import re

#do two matches
res1 = re.search('a.*b','hat')
res2 = re.search('a.*b','nab')

#evaluate results of both matches
for s,r in [('hat',res1),('nab',res2)]:
   #simple if test
   if r:
      print(s,"matches 'a.*b'")
      print("r is a match object")
   else:
      print(s,"does not match 'a.*b'")
      print("r is None")
   #does the match simply false?
   if r == False:
      print('r == False')
   else:
      print('r != False')
   #is the match a None object?
   if r == None:
      print('r == None')
   else:
      print('r != None')
```

re4.py

Here we explicitly save the output of `search()` and compare it against `False`

and against `None`.

The interest of this distinction is that a match object does more for us than evaluate to `True`. It is an object with several methods we can make use of: `group()`, `start()`, `end()`, and `span()`.

The `group()` method simply returns the matched part of the string. In the case of a pattern like `'a'`, this will simply return `'a'` in the case of a match. In the case of a more interesting pattern like `'a.*b'`, the `group()` method returns the entire string from `'a'` to `'b'`. The following code exemplifies:

```
import re,sys

#do a match
res = re.search('a.*b',sys.argv[1])
#if the match succeeds...
if res:
   #print out what is matching
   print("match: '",res.group(),"'",sep='')
else:
   print('no match')
```

re5.py

If you try this with different command-line arguments, you'll see that the `group()` method returns the entire string from `'a'` to `'b'`.

The `start()`, `end()`, and `span()` methods return the starting and ending indices of the matched portion. The `span()` method returns both. The following code exemplifies:

```
import re,sys

#do a match
res = re.search('a.*b',sys.argv[1])
#if the match succeeds...
if res:
   #print match and indices
   print("match: '",res.group(),"'",sep='')
   print('starting index:',res.start())
   print('ending index:',res.end())
```

```
    print('both indices:',res.span())
else:
    print('no match')
```

re6.py

Notice that, as with expressions with `:`, the ending index is the index of the character *after* the final character of the pattern.

These methods allow us to see some other aspects of the code. First, the match begins at the earliest possible point in the string. In the case at hand, if there are multiple instances of `'a'`, the match begins with the first one. Second, the match is as greedy as possible. If there are multiple instances of `'b'`, the match uses the rightmost one.

Another useful general matching function is `findall()`. What this does is return all instances of the match in a string. For example, if you match `'a'` against `'abracadabra'`, this will return `['a','a','a','a','a']`. The following code exemplifies:

```
import re,sys

#find all matches
res = re.findall('a',sys.argv[1])
#if it succeeds, if there is at least 1
if res:
    #print the list
    print('match:',res)
else:
    #print the empty list
    print('no match:',res)
```

re7.py

Note that in the event of no match, `findall()` returns an empty list rather than `None`.

6.2 Patterns

In this section, we go over the general structure and specific syntax of the kinds of patterns we can specify for the functions covered in the previous section and those to follow in the next chapter.

Patterns to be matched are defined in terms of *regular expressions* (REs). These have a very simple syntax that we can specify recursively, like a phrase-structure grammar.[2]

1. A single symbol is a RE. For example: `'a'`, `'3'`, `'k'`, etc. These will match a string which consists of just the symbol indicated.

2. A *concatenation* or sequence of REs is a RE. For example: `'ab'`, `'3g'`, `'kk'`, etc. Such an expression matches if the expressions it is composed of match in sequence. Thus `'ab'` matches if `'a'` matches and then `'b'` matches.

   Note that the definition is recursive, so if `'ab'` is legal and `'cd'` is legal, then so are `'abcd'` and `'cdab'`.

3. The *union* of disjunction of two REs is a regular expression. Union can be indicated with a tiebar, e.g. in `'a|b'`, `'a|d'`, etc. An expression like this is matched if either one or the other of the component expressions matches. Thus, for example, `'a|b'` matches if either `'a'` or `'b'` matches.

   This definition is recursive as well so we can build up expressions with both union and concatenation repeatedly. This can result in ambiguity and we can use parentheses to disambiguate. For example, in principle, something like `'a|bc'` is ambiguous can can be rewritten as `'(a|b)c'` or `'a|(bc)'`.

4. Finally, we have *Kleene star*. This allows a RE to be matched zero or more times. It is indicated with a following asterisk and is recursive as well. We have, for example: `a*`, `a(b*)`, `(ab)*`, `(a|b)*`, etc.

Virtually everything else about REs can be reduced to these simple operations, so let's take some time to understand them in more depth.

A RE is a string defined in terms of the recursive operations above: concatenation, union, and Kleene star. A RE itself is a finite sequence of symbols, but it defines a potentially infinite set of strings. For example, the RE `ab*c` is a finite sequence of

[2] Formally, one can show that these are more restricted than a phrase-structure grammar.

symbols, but defines the infinite set of strings {`ac`, `abc`, `abbc`, `abbbc`, ...}. Similarly, the regular expression `(ab)|(c*)` defines the set {`ab`, ϵ, `c`, `cc`, `ccc`, ...}.[3]

The general idea in pattern matching is that if the string we are matching against contains any of the strings that the relevant RE defines then there is a match. For example, if we try to match the RE `a|b` against the string `pancake`, we have a match because the RE defines the stringset {`a`, `b`} and `pancake` contains the substring `a`. Similarly, the RE `a*` will match any string because the set of strings it defines includes ϵ and every string definitionally includes the empty string.

The following chart gives examples of simple REs (along the left) and whether they match various strings (along the top).

	`a`	`b`	`ab`	`acb`	`ba`
`a`	✓		✓	✓	✓
`ab`			✓		
`a|b`	✓	✓	✓	✓	✓
`a*`	✓	✓	✓	✓	✓
`a|(bc)`	✓		✓	✓	✓
`(a|b)c`				✓	
`a*|b`	✓	✓	✓	✓	✓
`a|(b*)`	✓	✓	✓	✓	✓
`(a|b)*`	✓	✓	✓	✓	✓
`a(b*)`	✓		✓	✓	✓
`(ab)*`	✓	✓	✓	✓	✓

The reason why most programming languages use REs to do pattern matching is that it is possible to be extremely efficient checking whether some string matches some pattern. If we were to enrich our pattern matching system significantly beyond the three operations listed above, we would lose this efficiency.

There is a tradeoff however. With this very efficient system, there are patterns we cannot specify. Most programming languages, Python included, thus go slightly beyond REs in what they allow in pattern-matching syntax. The resulting system is still limited in what it allows, but for most purposes is more than enough for the kinds of pattern matching and string manipulation linguists need.

In the remainder of this section, we will go through some additional notational

[3] We use ϵ to indicate the empty string.

conventions available in REs. In most cases, these are for convenience and do not extend the power of REs in any significant way.

To play with these, we'll make use of the following program. This program takes one command-line argument that specifies a pattern. That pattern is then matched against the words in the *Alice* text and printed to the screen.

```
import sys,re
#read in 'Alice' and
#break into words
f = open('alice.txt','r')
words = f.read().split()
f.close()
#match RE against each word
for w in words:
   m = re.search(sys.argv[1],w)
   if m:
      print(w)
```

re8.py

For example, we might invoke it like this:

```
> python re8.py ab*c
...
```

We will see below that some of the special characters we use in REs also have an interpretation in some operating systems. We must therefore enter the pattern in quotes or use other special conventions to make sure the pattern is passed through the operating system to Python. We note this where relevant below.

We've already seen the notations for concatenation, union, and Kleene star. We've also seen that parentheses can be used to disambiguate.

A very simple addition to these is `'.'` which matches any single character. Thus an expression like `'a.b'` will match any string where `'b'` follows `'a'` with a single character intervening. Keep in mind that that single character can be alphabetic, numeric, space, tab, return, etc. For example, `'...'` matches any string with at least three letters.

We can add `'^'` and `'$'` as well. The former matches the beginning of the string and the latter matches the end of the string. Thus `'ab'` matches any string

that contains that substring, but `'^ab'` matches only strings that begin with that substring. Similarly, `'ab$'` will match any string that ends with that substring. A pattern like `'^ab$'` will only match that exact string. The RE `'^...$'` will match any string that has exactly three characters.

We've already seen that tiebar can be used to indicate disjunction or union. For example, something like `'(a|b|cd|ef)g'` will match a string that contains any of these as substrings: `'ag'`, `'bg'`, `'cdg'`, or `'efg'`. If the elements in the union are single characters, then Python offers an alternative notation using square brackets instead of the tiebar. For example, something like `'a(b|c|d)e'` can also be written `'a[bcd]e'`. This is *not* possible if any of the elements in the union is more than a single character, like the first example in this paragraph.

Interestingly, the square bracket syntax—but not the tiebar—can be used to specify the inverse set of characters. The syntax is to put the caret symbol first inside the square brackets to denote the opposite set of characters. Thus `'[^abc]'` will match a single character other than `'a'`, `'b'`, or `'c'`. As with simple square brackets, this only works with single individual characters.

Either square bracket expression can be used with a naturally ordered character sequence denoted with hyphen. Thus `[a-e]` is the same as `[abcde]` and `[0-5]` is the same as `[012345]`. Multiple sequences can be used in the same square brackets. For example, `[a-zA-Z]` denotes a single upper- or lowercase letter. Finally, sequences can be used in inverse character classes. Hence `[^a-z]` denotes a single character that is not a lowercase letter.

We've already discussed Kleene star which lets an expression be matched zero or more times. Thus `(b|c)*` matches zero or more instances of `b` or `c`. There are two related notations: `(b|c)+` indicates one or more instances of `b` or `c`, and `(b|c)?` indicates zero or one instance of `b` or `c`.

There is a whole set of character classes that are pre-defined. The most useful of these include: `\w` "word" characters, `\W` "nonword" characters, `\s` whitespace, `\S` nonwhitespace, `\d` digits (equivalent to `[0-9]`), `\D` nondigits (equivalent to `[^0-9]`). (Note that all of these must occur within quotes when used on the command-line.)

6.3 Backreferences

Backreferences technically move pattern matching beyond regular expressions. While they allow a lot of power and convenience, they should be used reluctantly as they can significantly affect how efficiently your programs run.

The simplest characterization is that every time you use parentheses in a pattern, you can refer back to them later. These can be parentheses you've used to disambiguate a pattern, e.g. `a|(bc)` vs. `(a|b)c`, but it can also be parentheses you've simply added with no such effect, e.g. `.*a` vs. `(.*)a`.

One way you can refer back to them is with a match object. If you've matched a pattern with parentheses, then you can extract that portion from the match object with the `group()`, `start()`, `end()`, or `span()` methods. The following program exemplifies:

```
import sys,re

#do a match
m = re.search('(.*)b(.*)',sys.argv[1])
#if it succeeds, print...
if m:
    #the whole match
    print('all: "',m.group(),'"',sep='')
    #the first part
    print('group 1: "',m.group(1),'"',sep='')
    #the second part
    print('group 2: "',m.group(2),'"',sep='')
```

re9.py

In this program, we invoke the `group()` method with an integer argument. The integer refers back to parentheses in the pattern. For example, in an expression with three sets of parentheses, we can refer back to `group(1)`, `group(2)`, or `group(3)`. In fact, `group()` is the same as `group(0)`. The first set of parentheses in `re9.py` are of this gratuitous sort.

Note, incidentally, that the parentheses don't have to be justified to disambiguate. Gratuitous parentheses, ones that don't disambiguate the pattern, can also be used and referred back to with `group()`.

The other match object methods can also be used with backreferences. The following code shows how this works.

```
import sys,re

m = re.search('(.*)b(.*)',sys.argv[1])
if m:
    print('all: "',m.group(),'"',sep='')
    print('group 1: "',m.group(1),'"',sep='')
    print('group 1 start:',m.start(1))
    print('group 1 end:',m.end(1))
    print('group 2: "',m.group(2),'"',sep='')
    print('group 2 start:',m.start(2))
    print('group 2 end:',m.end(2))
```

re10.py

Here, we print out the start and end indices for groups 1 and 2.

Interestingly, there is a notation that allows us to use backreferences in the same pattern: `\1`, `\2`, `\3`, etc. For example, `'(..)\1'` will match any two-letter sequence that is repeated, e.g. `abab`, `bcbc`, `bbbb`, etc. This is an extremely powerful notation and moves pattern matching beyond simple regular expressions. Use this one with caution.

6.4 Initial consonant clusters

Let's now exemplify how to use pattern matching to investigate the distribution of word-initial consonant clusters in *Alice*. The basic question is how frequent different kinds of initial consonant clusters are.

A challenge here is that English orthography only indirectly reflects the phonology. We will therefore set aside some issues about which precise cluster different letter sequences represent. There are several sorts of problems to deal with. First, we must deal with silent letters. These include cases like *know* or *gnostic* where *k* and *g* are silent. Another issue to wrestle with is that sometimes a single consonant is written with several letters, e.g. [θ] as in *thimble* or [ʃ] as in *show*, etc. Finally, there are cases where the same letter (sequence) has multiple pronunciations. For example, *c* is pronounced [s] in *city*, but [k] in *coat*. Similarly, *ch* is pronounced [tʃ]

in *church*, but [k] in *chord*. Note that sometimes the difference is predictable, as in the case of *c*, but sometimes it is not, as in the case of *ch*. We will therefore set aside the mapping of orthography to precise phonological forms, except insofar as we need to decide what a cluster is.

We will, as always, build our code up incrementally. Let's first write the framing code to read in the *Alice* text.

```
#open the file
f = open('alice.txt','r')
#read it all in
text = f.read()
#close the file stream
f.close()
#print the first 100 letters
#to make sure this works
print(text[:100])
```

re11.py

We print out the first 100 characters to make sure everything is working.

Anticipating our task, we strip the Gutenberg header, convert the whole text to lowercase, and then split it into words.

```
#open the file
f = open('alice.txt','r')
#read it all in
text = f.read()
#close file stream
f.close()
#remove header
text = text[10841:]
#convert to lowercase and split into words
words = text.lower().split()
#print first 50 words
for w in words[:50]:
   print(w)
```

re12.py

Again, we print out the first 50 words to make sure things are working right.

Our first challenge is non-alphabetic characters. To examine this more closely, we can make use of the `re8.py` program we wrote above to see what kinds of non-alphabetic things we're getting. We do this with the following command:

```
> python re8.py '\W'
```

We see immediately that a great many of these are cases where some punctuation like comma or period is on the right end of the word. Let's exclude these cases and see what's left. We therefore try this:

```
> python re8.py '\W\w'
```

Now what we see are mostly apostrophe, hyphen and single and double quotation marks. We must clearly exclude initial quotation marks; we don't want these to confuse what we take to be an initial consonant cluster.

Hyphens are another matter. It looks like a double hyphen is essentially a word break; the most reasonable thing would be to convert those to a single space. Single hyphens as in *jury-box* are more complex. Do we want to consider *box* here in our calculation of initial clusters? This is effectively a theoretical decision. We'll therefore simply choose to include cases like box as items that have initial clusters. On this assumption, a single hyphen needs to be converted to a space as well.

The simplest thing is to simply convert all of these to spaces before we break the text into words. The following code handles this:

```
import re

#read in Alice
f = open('alice.txt','r')
text = f.read()
f.close()
#strip header
text = text[10841:]
#convert to lower case
lowertext = text.lower()
#punctuation to convert
punc = '[\.\?\-!\?\*,"\():\'\[\];_/~]'
#convert punctuation to space
newtext = ''
for c in lowertext:
```

```
    if re.search(punc,c):
        newtext = newtext + ' '
    else:
        newtext = newtext + c
#split into words
words = newtext.split()
#print the first 50 words
for w in words[:50]:
    print(w)
```

re13.py

There's now apostrophe and single quotes to deal with: these we delete. The following revision does this:

```
import re

#read in Alice
f = open('alice.txt','r')
text = f.read()
f.close()
#strip header
text = text[10841:]
#convert to lower case
lowertext = text.lower()
#punctuation to convert
punc = '[\.\?\-!\?\*,"\(\):\'\[\];_/~]'
#convert punctuation to space
newtext = ''
for c in lowertext:
    if re.search(punc,c):
        newtext = newtext + ' '
    else:
        newtext = newtext + c
#split into words
words = newtext.split()
#eliminate single quotes
newwords = []
for w in words:
```

```
    word = ''
    for c in w:
        if c != "'":
            word = word + c
    newwords.append(word)
#print the first 50 words
for w in newwords[:50]:
    print(w)
```

re14.py

This last version is a little complex as we're constructing a new list `newwords` by going through the old list word by word and for each word we're constructing a new word `word` by going through the old word letter by letter.

Finally, we can see that there are a number of words that either are numbers or contain numbers. We'll just eliminate these altogether.

```
import re

#read in Alice
f = open('alice.txt','r')
text = f.read()
f.close()
#strip header
text = text[10841:]
#convert to lower case
lowertext = text.lower()
#punctuation to convert
punc = '[\.\?\-!\?\*,"\():\'\[\];_/~]'
#convert punctuation to space
newtext = ''
for c in lowertext:
    if re.search(punc,c):
        newtext = newtext + ' '
    else:
        newtext = newtext + c
#split into words
words = newtext.split()
#eliminate single quotes
```

```
newwords = []
for w in words:
   word = ''
   for c in w:
      if c != "'":
         word = word + c
   newwords.append(word)
#eliminate words with numbers
finalwords = []
for w in newwords:
   if re.search('[0-9]',w):
      continue
   else:
      finalwords.append(w)
#print the first 50 words
for w in finalwords[:50]:
   print(w)
```

re15.py

Our next step is to identify what consonant clusters occur. We've already seen that the identification of certain consonants is lexical, that the identification of what a letter stands for sometimes is based on what word it occurs in. For example, *g* is [g] in *get*, but [ʤ] in *gem*.

We will therefore aggregate by words before doing counts for individual clusters. The following code does this:

```
import re

#read in Alice
f = open('alice.txt','r')
text = f.read()
f.close()
#strip header
text = text[10841:]
#convert to lower case
lowertext = text.lower()
#punctuation to convert
punc = '[\.\?\-!\?\*,"\():\'\[\];_/~]'
```

```
#convert punctuation to space
newtext = ''
for c in lowertext:
   if re.search(punc,c):
      newtext = newtext + ' '
   else:
      newtext = newtext + c
#split into words
words = newtext.split()
#eliminate single quotes
newwords = []
for w in words:
   word = ''
   for c in w:
      if c != "'":
         word = word + c
   newwords.append(word)
#eliminate words with numbers
finalwords = []
for w in newwords:
   if re.search('[0-9]',w):
      continue
   else:
      finalwords.append(w)
#do counts for words
wordlist = {}
for w in finalwords:
   if len(w) > 0:
      if w in wordlist:
         wordlist[w] = wordlist[w] + 1
      else:
         wordlist[w] = 1
#sort the words
keys = sorted(wordlist.keys())
#print out the first 100 words
for i in range(100):
   print(keys[i],wordlist[keys[i]])
#print out the number of distinct words
```

```
print('Keys:',len(keys))
```

re16.py

This code makes use of a new function `sorted()` which sorts a list of strings (or numbers).

Let's now begin to modularize our code. First, we convert `re16.py` into a module `re17.py` that we can call.

```
import re

def preprocess():
    #read in Alice
    f = open('alice.txt','r')
    text = f.read()
    f.close()
    #strip header
    text = text[10841:]
    #convert to lower case
    lowertext = text.lower()
    #punctuation to convert
    punc = '[\.\?\-!\?\*,"\(\):\`\[\];_/~]'
    #convert punctuation to space
    newtext = ''
    for c in lowertext:
        if re.search(punc,c):
            newtext = newtext + ' '
        else:
            newtext = newtext + c
    #split into words
    words = newtext.split()
    #eliminate single quotes
    newwords = []
    for w in words:
        word = ''
        for c in w:
            if c != "'":
                word = word + c
        newwords.append(word)
```

```
    #eliminate words with numbers
    finalwords = []
    for w in newwords:
       if re.search('[0-9]',w):
          continue
       else:
          finalwords.append(w)
    #do counts for words
    wordlist = {}
    for w in finalwords:
       if len(w) > 0:
          if w in wordlist:
             wordlist[w] = wordlist[w] + 1
          else:
             wordlist[w] = 1
    return wordlist
```

re17.py

That module contains a single function `preprocess()` that we can call from other programs like this:

```
import re17

wordlist = re17.preprocess()
#sort the words
keys = sorted(wordlist.keys())
#print out the first 100 words
for i in range(100):
   print(keys[i],wordlist[keys[i]])
#print out the number of distinct words
print('Keys:',len(keys))
```

re18.py

The first order of business is to find all possible word-initial consonant clusters. Here's a first pass just at getting this list:

```
import re,re17

#get the word counts
```

```
wordlist = re17.preprocess()
#just get the words
words = wordlist.keys()
#strip off onsets
clusters = []
for w in words:
   m = re.search('^[^aeiou]*',w)
   if m:
      onset = w[0:m.end()]
      clusters.append(onset)
#eliminate duplicate onsets
clusters = sorted(set(clusters))
#print all onsets
for c in clusters:
   print("'",c,"'",sep='')
#print number of onsets
print(len(clusters))
```

re19.py

This program makes use of the `set()` function which converts a list to a set, the effect of which is to remove duplicates from the list. We then use `sorted()` to sort it alphabetically. This results in the following 76 hypothetical onset clusters.

null	b	bl	br	by	c	ch	chr	chrys	cl
cr	cry	d	dr	dry	f	fl	fly	fr	fry
g	gl	gr	gryph	h	hjckrrh	hm	j	k	kn
l	ly	m	my	mys	myst	n	p	pl	pr
q	r	s	sc	sch	scr	sh	shr	shy	shyly
sk	sky	sl	sm	sn	sp	spl	spr	sq	st
str	sw	t	th	thr	tr	try	tw	v	w
wh	why	wr	x	y	z				

There's a fair amount of noise in here that we need to clean up. We can track down some of it by using our `re8.py` program above (remembering that we converted to lowercase and removed a fair amount of punctuation).

A big source of noise is the treatment of *y* and other vowels. Specifically, if we require words to contain a vowel and allow *y* to count as a vowel when it is not word-initial, we can eliminate many of these. The following revision does this:

```
import re,re17

#get the word counts
wordlist = re17.preprocess()
#just get the words
words = wordlist.keys()
#strip off onsets
clusters = []
for w in words:
   m = re.search('^([^aeiouy]*)[aeiouy]',w)
   if m:
      if m.end(1) == 0 and w[0] == 'y':
         onset = 'y'
      else:
         onset = w[0:m.end(1)]
      clusters.append(onset)
#eliminate duplicate onsets
clusters = sorted(set(clusters))
#print all onsets
for c in clusters:
   print("'",c,"'",sep='')
#print number of onsets
print(len(clusters))
```

re20.py

This now produces a very reasonable list of 58 hypothetical word onsets.

Our last step is to do counts for all clusters. The following code does this:

```
import re,re17

#get the word counts
wordlist = re17.preprocess()
#just get the words
words = wordlist.keys()
#strip off onsets and do counts
clusters = {}
for w in words:
   m = re.search('^([^aeiouy]*)[aeiouy]',w)
```

```
    if m:
        if m.end(1) == 0 and w[0] == 'y':
            onset = 'y'
        else:
            onset = w[0:m.end(1)]
        if onset in clusters:
            clusters[onset] = clusters[onset] + 1
        else:
            clusters[onset] = 1
#print onset counts
keys = sorted(clusters.keys())
for c in keys:
    print("'",c,"': ",clusters[c],sep='')
```

re21.py

6.5 Exercises

1. Write a function that will match a string that contains `a.*b.*c.*d` *without* using regular expressions.
2. What will the pattern `'..^'` match? Explain why.
3. What's the difference between `(a*)|(b*)` and `(a|b)*`? Explain the difference and give examples of strings that both will match, only the first will match, and only the second will match.
4. Describe in words what each of the following patterns will match:
   (a) `(Tom)|(Dick)|(Harry)`
   (b) `(.*)\1`
   (c) `(a[^a])+`
   (d) `^[^0-9]+$`
   (e) `(a|b)*c(d*|e*)`
5. Write a program that collects the *final* consonant clusters of English.
6. Write a regular expression that finds reduplicated words.

7. Write a program that uses regular expressions to find palindromes.

Chapter 7

Text manipulation

The previous chapter covered regular expressions and pattern matching in response to the fact that language researchers are very often interesting in sifting through texts and finding words or phrases with particular properties.

In this chapter, we focus on manipulating text, converting one string of letters into another. This is another task that comes up quite often when writing programs that deal with natural language.

We have, in fact, already done some of this in previous chapters. For example, in Section 6.4, we developed a program that calculated how often different consonant clusters occurred as word onsets in the *Alice* text. This program effectively translated from words to onsets using pattern matching and backreferences via the match object methods `start()` and `end()`.

In this chapter, we'll explain more general and powerful ways to do this using the functions `re.sub()`, `str.translate()`, `re.split()`, and the string method `join()`. We conclude the chapter implementing a large example program that does a bit of English morphology.

7.1 Manipulating text

The simplest function for manipulating text is `sub()` in the `re` module. This function converts one string into another by pattern matching: whatever part of

the string matches the specified pattern is replaced with the specified replacement. The function takes those three arguments plus two more: a pattern, a replacement, the string, and the maximum number of replacements `count` plus additional flags `flags`. Here is a simple example:

```
import re

#define a string
s1 = 'This is a rather long string'
#replace '.s' with 'WOW'
s2 = re.sub('.s','WOW',s1)
#print old and new strings
print(s1,'\n',s2)
```

manip1.py

We can see the `count` variable at work in the next example:

```
import re

#a test string
s1 = 'This is a rather long string'
#a pattern
pat = '.s'
#find how many instances of the pattern
countmax = len(re.findall(pat,s1))
#print the string
print(s1)
#make that many substitutions 1 by 1
i = 1
while i < countmax+1:
    #make a change
    s2 = re.sub(pat,'WOW',s1,count=i)
    #print that one change
    print('\t',i,':',s2)
    #increment counter
    i += 1
```

manip2.py

Here, we identify how many instances of the pattern there are with `findall()`

and we then iterate through making different numbers of substitutions. Note that when `count = 0`, we make all the substitutions, rather than none of them.

Finally, the `flags` argument allows for a number of options. The only one you're liable to use is case-insensitive matching when `flags=RE.i`. Here's an example:

```
import re

#a test string
s1 = 'This is a rather long string'
#do a replacement
s2 = re.sub('t','WOW',s1)
#do a case-insensitive replacement
s3 = re.sub('t','WOW',s1,flags=re.I)
#incorporate case directly in the pattern
s4 = re.sub('t|T','WOW',s1)
#show all three results
print(s1,'\n',s2,'\n',s3,'\n',s4,sep='')
```

manip3.py

Notice here how the effect of case-insensitive matching can be achieved by adjusting the pattern instead.

If your substitutions are all converting single letters to other single letters you can make use of the efficient `translate()` string method. You first make use of the `str.maketrans()` method to make a *translation table*; you then use that table to make the translation. Here's an example:

```
#make a translation table
mytab = str.maketrans('aeiou','happy')
#a test string
s = 'This is my sample string'
#print that string
print(s)
#print the translation
print(s.translate(mytab))
```

manip4.py

A translation table is implemented as a Python dictionary. Note that the two string arguments to `str.maketrans()` must be the same length.

Another function that is quite useful is `re.split()`. Recall the string method `split()` which splits a string up based on some specific delimiter string. The `re.split()` function allows you to split a string based on a regular expression instead. Here's an example:

```
import re

#a test string
s = 'First sentence. Second sentence.'
#do a regular split
ss1 = s.split('e.')
#do re.split
ss2 = re.split('e.',s)
#print the sentence
print(s)
#print split() results
print('s.split()')
for ss in ss1:
   print('\t"',ss,'"',sep='')
#print re.split() results
print('re.split()')
for ss in ss2:
   print('\t"',ss,'"',sep='')
```

manip5.py

Here we invoke the string method `split()` and `re.split()` with the string `'e.'`. The string method `split()` interprets this literally and splits the string into three strings; `re.split()` interprets this as a regular expression and splits the string into eight strings. Note too that the syntax for these is different. The `re.split()` function takes two arguments where the string to split is the second argument. The `split()` method is instead suffixed to the string it operates on and takes a single argument.

Finally, we have the string method `join()` which joins a set of strings together with string infix. The syntax is a bit unintuitive. The string it is suffixed to is the infix. It takes a single argument which is a list of strings. Here's a simple example:

```
#a test sentence
s = 'This is a sentence.'
```

```
#split it into words
wds = s.split()
#define hyphen
hyphen = '-'
#join bits with hyphen
hyphenated = hyphen.join(wds)
#print original sentence
print(s)
#print hyphenated sentence
print(hyphenated)
```

manip6.py

7.2 Morphology

In this section, we build a stemming program for English. In particular, the program will remove suffixes so that words like *running*, *obfuscation*, *looks*, etc. become *run*, *obfuscate*, *look*, etc. The particular algorithm we will implement is not at all perfect, but it is a classic one: Porter (1980).[1]

Why do this? A stemming program like this can be viewed in a number of ways. One is to think of it as a theory of morphological decomposition: a model of how speakers break words up into meaningful units. Another way to think of a stemmer is simply as a practical tool so that we can find words that are morphologically related. For example, if we were searching for documents having to do with horses, it stands to reason that we would be interested in documents that contained the word *horses* or *horse*.

With Porter's algorithm, suffixes are removed from words in rule blocks. In the first block, one set of suffixes is removed. In the next block a different set of suffixes is removed. And so on. Each block is a set of rules that are organized disjunctively. Each rule in the block generally removes or rewrites one suffix. If, more than one rule in a block is applicable, then the rule that is most specific applies and the others do not. For example, a block might contain these rules:

[1] Porter, M. F. (1980) "An algorithm for suffix stripping", *Program* 14, 130–137.

sses	$\rightarrow$	ss
ies	$\rightarrow$	i
ss	$\rightarrow$	ss
s	$\rightarrow$	$\emptyset$

This would map *caresses* to *caress*, *carries* to *cari*, *looks* to *look*, etc. Note that the disjunctive requirement entails that *caresses* is not mapped to *caresse*, but to *carress*, because the first rule is more specific than the last.

Finally, rules are subject to conditions. Most often this is a condition on the size of the stem, but it can include other information as well, e.g. whether the final consonant is doubled, the identity of the final consonant, etc.

We will take our task to be to write a function that takes a word and stems it. Once we've gotten this function in order, we can then apply it to words in *Alice* or, indeed, to anything else. Let's write some framing code that we can use to test our stemming function on a command-line argument:

```
import sys

#frame for stemming function
def stem(w):
   return w

#get a word from the command-line
word = sys.argv[1]
#stem it!
root = stem(word)
#print the word and its stem
print(word,':\t',root,sep='')
```

manip7.py

This code takes a command-line argument, applies the function `stem()` to it, and returns the output. To get a sense of what we're after, we might enrich `stem()` like this:

```
import re,sys

#stemming function for words in -ed
def stem(w):
```

```
    #does the word end in ed?
    m = re.search('(^.*)ed$',w)
    #if it does...
    if m:
        #return the stem
        return m.group(1)
    #if it doesn't...
    else:
        #just return the word
        return w

#get the word from the command-line
word = sys.argv[1]
#stem it
root = stem(word)
#print word and stem
print(word,':\t',root,sep='')
```

manip8.py

This simply examines a word to see if it ends in *-ed* and, if so, removes it. Other words are unaffected. This is not a general solution to the stemming problem, but shows the general logic of what we want to do.

The first step in our implementation is to code up Porter's *measure* function. Many of his rules are contingent on the size of the remaining stem when some putative suffix is removed. The measure of a stem is defined in terms of consonants and vowels. Specifically a consonant is defined as a letter other than *a*, *e*, *i*, *o*, *u*, or *y*. In the case of *y*, it is a consonant if it is not preceded by a consonant. We therefore start with a function to determine whether some specific letter in a string is a consonant.

```
import re,sys

#test if some letter is a consonant
#with respect to a word!
def consonant(s,i):
    #get the relevant letter
    letter = s[i]
    #it's not a consonant if it's aeiou
    if letter in 'aeiou':
```

```
        return False
    #word-initial y is a consonant
    elif letter == 'y' and i == 0:
        return True
    #it's a vowel if it follows a consonant
    elif letter == 'y' and consonant(s,i-1):
        return False
    #otherwise it's a consonant
    else:
        return True

#the frame for the stemming function again
def stem(w):
    return w

#get the command-line argument
word = sys.argv[1]
#print it
print(word)
#code to test the consonant() function
for i in range(len(word)):
    if consonant(word,i):
        print('C',end='')
    else:
        print('V',end='')
print()
```

manip9.py

We've added this to the program with the `stem()` function shell with framing code so we can test the function on strings given as a command-line argument.

If we take C to be a consonant and V to be a vowel, Porter treats all stems as matching this regular expression: `C*(V+C+)*V*`. The measure of a stem is defined as the number of times the `(V+C+)*` part matches. Another simpler way to look at this is that the measure of a stem is the number of times the sequence `VC` occurs. Porter gives these examples:

$m = 0$ tr, ee, tree, y, by
$m = 1$ trouble, oats, trees, ivy
$m = 2$ troubles, private, oaten, orrery

Our implementation of the measure function converts a stem to Cs and Vs and then returns the number of times the sequence VC occurs.

```
import re,sys

#checks if some element in
#a string is a consonant
def consonant(s,i):
    letter = s[i]
    if letter in 'aeiou':
        return False
    elif letter == 'y' and i == 0:
        return True
    elif letter == 'y' and consonant(s,i-1):
        return False
    else:
        return True

#converts a string to Cs and Vs
def cv(w):
    res = ''
    for i in range(len(w)):
        if consonant(w,i):
            res += 'C'
        else:
            res += 'V'
    return res

#returns the measure of a string
def measure(w):
    cvword = cv(w)
    vcs = re.findall('VC',cvword)
    return len(vcs)

#frame for stemming code
```

```
def stem(w):
    return w

word = sys.argv[1]
print(word)
print(cv(word))
print(measure(word))
```

manip10.py

The `measure()` function uses another function `cv()` which converts a string into `C`s and `V`s. We also use this function to display that intermediate output in the framing code in the program.

We're now ready to consider the rules of the system. Rules have three main components. First, there is a test to see if the form ends in some particular string. Second, there are a number of tests on the stem that precedes the string that is tested for. If those tests are true, the string on the right is mapped to a different string. For example:

$(m > 1)$ ement $\rightarrow \emptyset$

Here, we first ask if the word ends in the string *ement*. Second, we ask if the measure of the remaining material is greater than 1. If both of those hold, we map *ement* to null. This rule would fail to apply to *happiness* because it does not end in the relevant string. This rule would fail to apply to *cement* because the measure of *c* is 0. Finally, this rule would apply to *requirement* because the measure of *requir* is 2.

Porter's conditions also include things like the following:

$*$s	—	the stem ends with *s* (and similarly for the other letters).
$*$V$*$	—	the stem contains a vowel.
$*$D	—	the stem ends with a double consonant (e.g. *tt*, *ss*).
$*$O	—	the stem ends `CVC`, where the second `C` is not *w*, *x*, or *y* (e.g. *-wil*, *-hop*).

These are expressed in a version of Porter's notation; we will convert these to regular expressions. The conditions on a rule can be more complex: multiple separate conditions joined together with *and* or *or*. For example:

(m $>$ 1 and ($*$s or $*$t))

This condition tests for a stem where $m > 1$ and that ends in *s* or *t*. Here's another:

(∗d and not (∗L or ∗S or ∗Z))

This tests for a stem ending with a double consonant other than *l*, *s*, or *z*.

Let's now add code for handling such conditions to our system. Here is a first pass:

```
import re,sys

#is some element in string a consonant?
def consonant(s,i):
    letter = s[i]
    if letter in 'aeiou':
        return False
    elif letter == 'y' and i == 0:
        return True
    elif letter == 'y' and consonant(s,i-1):
        return False
    else:
        return True

#converts a string to Cs and Vs
def cv(w):
    res = ''
    for i in range(len(w)):
        if consonant(w,i):
            res += 'C'
        else:
            res += 'V'
    return res

#returns the measure of a string
def measure(w):
    cvword = cv(w)
    vcs = re.findall('VC',cvword)
    return len(vcs)

#general rule framework
def rule(c,e,r,w):
```

```
    m = re.search('^(.*)'+e+'$',w)
    if m:
        s = m.group(1)
        if c(s):
            return s+r
    return None

#condition: m > 0
def m1cond(x):
    if measure(x) > 0:
        return True
    return False

#specific sample rule for -ed
def edrule(w):
    x = rule(m1cond, 'ed', '', w)
    return x

#stemming with -ed rule
def stem(w):
    res = edrule(w)
    if res:
        return res
    return w

word = sys.argv[1]
print(word)
print(stem(word))
```

manip11.py

There are four basic changes here. First, we've added a general form for rules called `rule()`. This function takes four arguments: `c`: a condition, `e`: the suffix, `r`: what the suffix is replaced with, and `w`: the word we are applying the rule to. The idea is that any specific rule we want can be defined in terms of `rule()`.

We then define a sample rule using this that we call `edrule()`. This is a simple example of what a rule might look like. This rule rewrites *-ed* as null just in case the measure of the remaining stem is greater than 0. The condition on the rule is

formalized as `m1cond()`.

Finally, we add the function `edrule()` to our `stem()` function. If the word satisfies `edrule()`, we return that result. If not, we just return the word.

All of this is called with a command-line argument so we can play around with different word types.

We've got a fair amount of code now, so let's separate the general code off into a callable module. The idea would be that we could build different stemmers that could draw on this code. Here's the module:

```
import re,sys

#is some element in string a consonant?
def consonant(s,i):
    letter = s[i]
    if letter in 'aeiou':
        return False
    elif letter == 'y' and i == 0:
        return True
    elif letter == 'y' and consonant(s,i-1):
        return False
    else:
        return True

#converts a string to Cs and Vs
def cv(w):
    res = ''
    for i in range(len(w)):
        if consonant(w,i):
            res += 'C'
        else:
            res += 'V'
    return res

#returns the measure of a string
def measure(w):
    cvword = cv(w)
    vcs = re.findall('VC',cvword)
```

```
    return len(vcs)

#general rule framework
def rule(c,e,r,w):
    m = re.search('^(.*)'+e+'$',w)
    if m:
        s = m.group(1)
        if c(s):
            return s+r
    return None
```

manip12.py

We then call it with something like this:

```
import re,sys,manip12

#condition: m > 0
def m1cond(x):
    if manip12.measure(x) > 0:
        return True
    return False

#specific sample rule for -ed
def edrule(w):
    x = manip12.rule(m1cond, 'ed', '', w)
    return x

#stemming with -ed rule
def stem(w):
    res = edrule(w)
    if res:
        return res
    return w

word = sys.argv[1]
print(word)
print(stem(word))
```

manip13.py

As discussed, the algorithm divides rules up into eight blocks:

Step 1 a
b
c
Step 2
Step 3
Step 4
Step 5 a
b

Let's elaborate our system a bit to anticipate this:

```
import re,sys,manip12

#condition: m > 0
def m1cond(x):
   if manip12.measure(x) > 0:
      return True
   return False

def step1a(w):
   return w

def step1b(w):
   return w

def step1c(w):
   return w

def step2(w):
   return w

def step3(w):
   return w

def step4(w):
   return w
```

```
def step5a(w):
    return w

def step5b(w):
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
print(word)
print(stem(word))
```

manip14.py

Here we've simply indicated that the function `stem()` is a set of blocks that apply in sequence. We've then added placeholders for each of those blocks.

Porter's first block—step 1a—is the one we gave above on page 156. We implement this in the function `step1a()`.

```
import re,sys
from manip12 import *

#condition: m > 0
def m1cond(x):
    if measure(x) > 0:
        return True
    return False

#a vacuous condition
```

```
def nullcond(x):
    return True

def step1a(w):
    a = rule(nullcond,'sses','ss',w)
    if a: return a
    b = rule(nullcond,'ies','i',w)
    if b: return b
    c = rule(nullcond,'ss','ss',w)
    if c: return c
    d = rule(nullcond,'s','',w)
    if d: return d
    return w

def step1b(w):
    return w

def step1c(w):
    return w

def step2(w):
    return w

def step3(w):
    return w

def step4(w):
    return w

def step5a(w):
    return w

def step5b(w):
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
```

```
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
print(word)
print(stem(word))
```

manip15.py

There are a couple of things to note here. First, we import from `manip12.py` a little differently so we can use its functions without the `manip12.` prefix. Second, our rule format requires a condition, so we've implemented a vacuous condition `nullcond()` to accommodate cases where Porter's rules have no condition. Finally, we've implemented the disjunctive property of Porter's rules by checking if a rule has applied. If it does, we immediately exit the block with a `return`.

Let's now go on to the next block Step 1b:

Step 1b

Condition	Change	Example
m > 0	eed → ee	feed → feed
		agreed → agree
∗V∗	ed → ∅	plastered → plaster
		bled → bled
∗V∗	ing → ∅	motoring → motor
		sing → sing

Here is a first pass at implementing this block:

```
import re,sys
from manip12 import *

#condition: m > 0
def m1cond(x):
    if measure(x) > 0:
```

```
            return True
        return False

    #a vacuous condition
    def nullcond(x):
        return True

    #condition: contains a vowel
    def vcond(x):
        cvform = cv(x)
        if re.search('V',cvform):
            return True
        return False

    def step1a(w):
        a = rule(nullcond,'sses','ss',w)
        if a: return a
        b = rule(nullcond,'ies','i',w)
        if b: return b
        c = rule(nullcond,'ss','ss',w)
        if c: return c
        d = rule(nullcond,'s','',w)
        if d: return d
        return w

    def step1b(w):
        a = rule(m1cond,'eed','ee',w)
        if a: return a
        b = rule(vcond,'ed','',w)
        if b: return b
        c = rule(vcond,'ing','',w)
        if c: return c
        return w

    def step1c(w):
        return w

    def step2(w):
```

```
    return w

def step3(w):
    return w

def step4(w):
    return w

def step5a(w):
    return w

def step5b(w):
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
print(word)
print(stem(word))
```

manip16.py

The `step1b()` function makes use of the `m1cond()` condition and a new condition `vcond()`. There is another wrinkle however. If either of the *-ed* or *-ing* rules applies, the following special block applies:

Special Condition	Change	Example
	at → ate	conflat(ed) → conflate
	bl → ble	troubl(ed) → trouble
	iz → ize	siz(ed) → size
(*D and not (*l or *s or *z))	. . . → single letter	hopp(ing) → hop
		tann(ed) → tan
		fall(ing) → fall
		hiss(ing) → hiss
		fizz(ed) -> fizz
(m = 1 and *O)	∅ → E	fail(ing) → fail
		fil(ing) → file

The fourth rule here is rather complex both in terms of the condition on its application and in terms of what it does, so we will write a special rule for this.

First, we add a new special block and have it apply just in case the *-ed* or *-ing* rules apply.

```
import re,sys
from manip12 import *

#condition: m > 0
def m1cond(x):
   if measure(x) > 0:
      return True
   return False

#a vacuous condition
def nullcond(x):
   return True

#condition: contains a vowel
def vcond(x):
   cvform = cv(x)
   if re.search('V',cvform):
      return True
   return False
```

```
def step1a(w):
    a = rule(nullcond,'sses','ss',w)
    if a: return a
    b = rule(nullcond,'ies','i',w)
    if b: return b
    c = rule(nullcond,'ss','ss',w)
    if c: return c
    d = rule(nullcond,'s','',w)
    if d: return d
    return w

#special block for ed/ing
def special(w):
    return w

def step1b(w):
    a = rule(m1cond,'eed','ee',w)
    if a: return a
    b = rule(vcond,'ed','',w)
    if b: return special(b)
    c = rule(vcond,'ing','',w)
    if c: return special(c)
    return w

def step1c(w):
    return w

def step2(w):
    return w

def step3(w):
    return w

def step4(w):
    return w

def step5a(w):
```

```
    return w

def step5b(w):
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
print(word)
print(stem(word))
```

manip17.py

We now flesh out the contents of the `special()` block.

```
import re,sys
from manip12 import *

#condition: m > 0
def m1cond(x):
    if measure(x) > 0:
        return True
    return False

#a vacuous condition
def nullcond(x):
    return True

#condition: contains a vowel
```

```
def vcond(x):
    cvform = cv(x)
    if re.search('V',cvform):
        return True
    return False

def step1a(w):
    a = rule(nullcond,'sses','ss',w)
    if a: return a
    b = rule(nullcond,'ies','i',w)
    if b: return b
    c = rule(nullcond,'ss','ss',w)
    if c: return c
    d = rule(nullcond,'s','',w)
    if d: return d
    return w

#specialrule
def specialrule(w):
    cvform = cv(w)
    m = re.search('CC$',cvform)
    if m:
        m2 = re.search('^(.*)([^szl])\\2',w)
        if m2:
            return m2.group(1)+m2.group(2)
    return None

#m1ocond
def m1ocond(w):
    cvform = cv(w)
    if measure(cvform) == 1:
        m = re.search('CVC$',cvform)
        if m:
            m2 = re.search('[^xyw]$',w)
            if m2:
                return True
    return False
```

```
#special block for ed/ing
def special(w):
   a = rule(nullcond,'at','ate',w)
   if a: return a
   b = rule(nullcond,'bl','ble',w)
   if b: return b
   c = rule(nullcond,'iz','ize',w)
   if c: return c
   d = specialrule(w)
   if d: return d
   e = rule(m1ocond,'','e',w)
   if e: return e
   return w

def step1b(w):
   a = rule(m1cond,'eed','ee',w)
   if a: return a
   b = rule(vcond,'ed','',w)
   if b: return special(b)
   c = rule(vcond,'ing','',w)
   if c: return special(c)
   return w

def step1c(w):
   return w

def step2(w):
   return w

def step3(w):
   return w

def step4(w):
   return w

def step5a(w):
   return w
```

```
def step5b(w):
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
print(word)
print(stem(word))
```

manip18.py

There are a couple of complications in the `special()` block. First, we must implement a new condition `m1ocond()`. Second, the rule that eliminates final double letters doesn't really follow our `rule()` format, so we craft a special rule for it with the unimaginative name `specialrule()`. That rule is interesting because of the complexity of the regular expression it uses. We need to identify stems where the final letter is doubled and then we need to be able to return everything but the final letter. We use a backreference in the pattern to do this. Note that when used in a pattern like this, we must use an extra backslash: `\\2`.

There are a number of remaining steps to implement, but they are straightforward given what we have done so far. The next version of the code is the complete stemming algorithm with all these additional steps filled in.

```
import re,sys
from manip12 import *

#condition: m > 0
def m1cond(x):
    if measure(x) > 0:
```

```
            return True
        return False

    #condition: m > 1
    def m2cond(x):
        if measure(x) > 1:
            return True
        return False

    #a vacuous condition
    def nullcond(x):
        return True

    #condition: contains a vowel
    def vcond(x):
        cvform = cv(x)
        if re.search('V',cvform):
            return True
        return False

    def step1a(w):
        a = rule(nullcond,'sses','ss',w)
        if a: return a
        b = rule(nullcond,'ies','i',w)
        if b: return b
        c = rule(nullcond,'ss','ss',w)
        if c: return c
        d = rule(nullcond,'s','',w)
        if d: return d
        return w

    #specialrule
    def specialrule(w):
        cvform = cv(w)
        m = re.search('CC$',cvform)
        if m:
            m2 = re.search('^(.*)([^szl])\\2',w)
            if m2:
```

```
            return m2.group(1)+m2.group(2)
    return None

#m=1 and ends in CV[^xyw]
def m1ocond(w):
    cvform = cv(w)
    if measure(cvform) == 1:
        m = re.search('CVC$',cvform)
        if m:
            m2 = re.search('[^xyw]$',w)
            if m2:
                return True
    return False

#special block for ed/ing
def special(w):
    a = rule(nullcond,'at','ate',w)
    if a: return a
    b = rule(nullcond,'bl','ble',w)
    if b: return b
    c = rule(nullcond,'iz','ize',w)
    if c: return c
    d = specialrule(w)
    if d: return d
    e = rule(m1ocond,'','e',w)
    if e: return e
    return w

def step1b(w):
    a = rule(m1cond,'eed','ee',w)
    if a: return a
    b = rule(vcond,'ed','',w)
    if b: return special(b)
    c = rule(vcond,'ing','',w)
    if c: return special(c)
    return w

def step1c(w):
```

```
    a = rule(vcond,'y','i',w)
    if a: return a
    return w

def step2(w):
    a = rule(m1cond,'ational','ate',w)
    if a: return a
    b = rule(m1cond,'tional','tion',w)
    if b: return b
    c = rule(m1cond,'enci','ence',w)
    if c: return c
    d = rule(m1cond,'anci','ance',w)
    if d: return d
    e = rule(m1cond,'izer','ize',w)
    if e: return e
    f = rule(m1cond,'abli','able',w)
    if f: return f
    g = rule(m1cond,'alli','al',w)
    if g: return g
    h = rule(m1cond,'entli','ent',w)
    if h: return h
    i = rule(m1cond,'eli','e',w)
    if i: return i
    j = rule(m1cond,'ousli','ous',w)
    if j: return j
    k = rule(m1cond,'ization','ize',w)
    if k: return k
    l = rule(m1cond,'ation','ate',w)
    if l: return l
    m = rule(m1cond,'ator','ate',w)
    if m: return m
    n = rule(m1cond,'alism','al',w)
    if n: return n
    o = rule(m1cond,'iveness','ive',w)
    if o: return o
    p = rule(m1cond,'fulness','ful',w)
    if p: return p
    q = rule(m1cond,'ousness','ous',w)
```

```
    if q: return q
    r = rule(m1cond,'aliti','al',w)
    if r: return r
    s = rule(m1cond,'iviti','ive',w)
    if s: return s
    t = rule(m1cond,'biliti','ble',w)
    if t: return t
    return w

def step3(w):
    a = rule(m1cond,'icate','ic',w)
    if a: return a
    b = rule(m1cond,'ative','',w)
    if b: return b
    c = rule(m1cond,'alize','al',w)
    if c: return c
    d = rule(m1cond,'iciti','ic',w)
    if d: return d
    e = rule(m1cond,'ical','ic',w)
    if e: return e
    f = rule(m1cond,'ful','',w)
    if f: return f
    g = rule(m1cond,'ness','',w)
    if g: return g
    return w

#m > 1 and ends in [st]
def m2stcond(w):
    if m2cond(w):
        m = re.search('[st]$',w)
        if m:
            return True
    return False

def step4(w):
    a = rule(m2cond,'al','',w)
    if a: return a
    b = rule(m2cond,'ance','',w)
```

```
    if b: return b
    c = rule(m2cond,'ence','',w)
    if c: return c
    d = rule(m2cond,'er','',w)
    if d: return d
    e = rule(m2cond,'ic','',w)
    if e: return e
    f = rule(m2cond,'able','',w)
    if f: return f
    g = rule(m2cond,'ible','',w)
    if g: return g
    h = rule(m2cond,'ant','',w)
    if h: return h
    i = rule(m2cond,'ement','',w)
    if i: return i
    j = rule(m2cond,'ment','',w)
    if j: return j
    k = rule(m2cond,'ent','',w)
    if k: return k
    l = rule(m2stcond,'tion','',w)
    if l: return l
    m = rule(m2cond,'ou','',w)
    if m: return m
    n = rule(m2cond,'ism','',w)
    if n: return n
    o = rule(m2cond,'ate','',w)
    if o: return o
    p = rule(m2cond,'iti','',w)
    if p: return p
    q = rule(m2cond,'ous','',w)
    if q: return q
    r = rule(m2cond,'ive','',w)
    if r: return r
    s = rule(m2cond,'ize','',w)
    if s: return s
    return w

#m = 1 and not *O
```

```
def m1notocond(w):
    if measure(w) != 1:
        return False
    cvform = cv(w)
    m = re.search('CVC$',cvform)
    if m:
        m2 = re.search('[wxy]$',w)
        if m2:
            return False
    return True

def step5a(w):
    a = rule(m2cond,'e','',w)
    if a: return a
    b = rule(m1notocond,'e','',w)
    if b: return b
    return w

def step5b(w):
    if m2cond(w):
        m = re.search('(^.*l)(l)$',w)
        if m:
            return m.group(1)
    return w

#stemming with blocks
def stem(w):
    s1a = step1a(w)
    s1b = step1b(s1a)
    s1c = step1c(s1b)
    s2 = step2(s1c)
    s3 = step3(s2)
    s4 = step4(s3)
    s5a = step5a(s4)
    s5b = step5b(s5a)
    return s5b

word = sys.argv[1]
```

```
print(word)
print(stem(word))
```

manip19.py

This is a fairly large piece of code, but we have tried to modularize it in several ways. First, we have factored out generic code and put it into a separate module `manip12.py`. Second, we have posited a general rule format and put that in `manip12.py` as well. Finally, following Porter's own description of the algorithm, we have broken it into steps and made each of these its own function.

7.3 Exercises

1. Imagine you have some sentence `s` and you do this:

   ```
   ' '.join(s.split())
   ```

   Will that have any effect? If so, when?

2. The stemming algorithm suffers from the absence of a general technique for disjunction: we have to keep repeating `if ...: return ...`. Can you think of a way to avoid this?

3. Why would the `sub()` function be harder to use in our stemmer?

4. Write a program that strips off English prefixes.

5. Write a program that plays Pig Latin.

6. Use the `translate()` method to create a function that does the work of `upper()`.

7. Write your own function that will do the work of `translate()`.

Chapter 8

Internet data

In this chapter, we discuss how to get data from the internet. This is a huge topic, so we can only scratch the surface though.

Specifically, we talk about how to retrieve webpages and extract text or other information from them. This entails a discussion of the structure of HTML documents and methods for getting various sorts of information out of them.

Working with web data very quickly leads to issues of efficiency. Retrieving any web page requires interacting with other computers over the web. This means that your program can have to wait for other systems to respond. We therefore introduce some simple methods for parallelizing your code so that these interactions can be as efficient as possible.

Finally, we conclude the chapter with a program for a simple webcrawler, a program that follows and retrieves and links with particular properties.

8.1 Retrieving webpages

Retrieving webpages is extremely simple. The `urllib.request` module includes a function `urlopen()` which creates a stream that can be read from. The following program exemplifies:

```
import urllib.request
```

```
#a url to read from
link = "http://www.u.arizona.edu/~hammond/"
#open a link to the url
f = urllib.request.urlopen(link)
#read the page
myfile = f.read()
#print the decoded page
print(myfile.decode('UTF-8'))
```

web1.py

Here we import the relevant module. We open a connection with `urlopen()`, and then read from it with `read()`. We convert that to a readable text format with the string method `decode('UTF-8')`; we cover this in depth in the next chapter. We can then print out what is read.

Note that a simple webpage, like the one we read here, is actually text intermixed with various sorts of formatting commands. If we want to make sense of what we read in, we need to know a bit about that formatting.

8.2 HTML

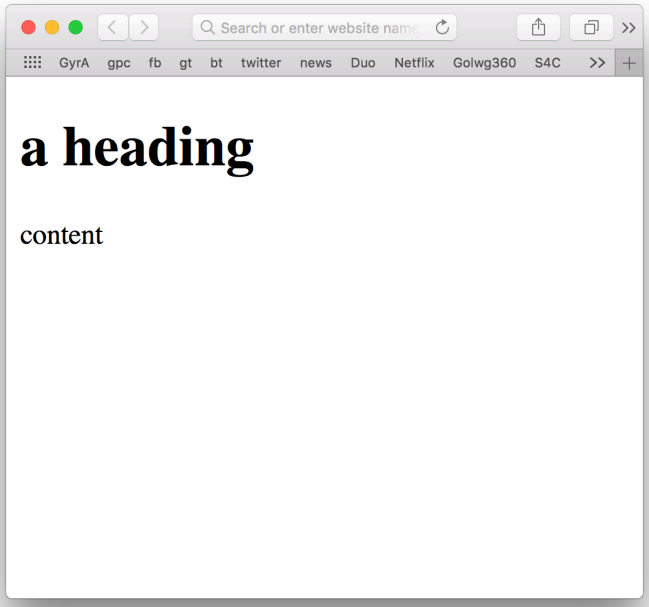
When you surf the web, you are using your browser to retrieve data from other computers. That data can be in a variety of formats. For example, you can retrieve pictures, music, movies, pdf documents, etc.

You most commonly see text documents formatted using HTML or *hypertext markup language*. Following is a very very simple example of what such a document might look like:

```
<!DOCTYPE html>
<html>
   <head>
      <title>a title</title>
   </head>
   <body>
      <h1>a heading</h1>
      <p>content</p>
```

```
    </body>
</html>
```

Of course, such a document doesn't display like that in your web browser. Rather, all the things in angled brackets are invisible instructions for how your browser should display what. The page above might display like this:



HTML is built around the notion of *tags*, instructions to your web browser that are marked with angled brackets. For example, `<p>` marks a paragraph, `</em>` marks the end of a span of emphasized text, etc.

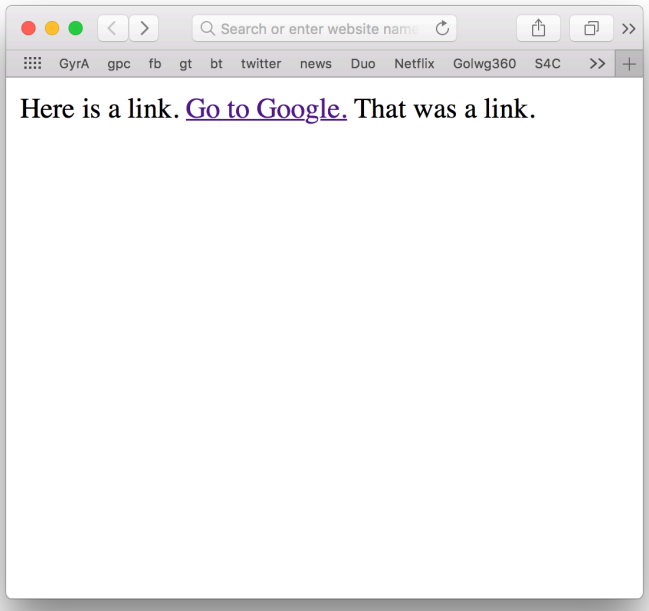
Those tags may or may not come in pairs. For example, in the example above, the document declaration at the very beginning which declares that the document is written in HTML (version 5) is unpaired. On the other hand, the tags marking the *head* of the document `<head>` and `</head>` are paired. When tags are paired, they typically have that structure; the opening tag is marked simply with angled brackets and the closing tag has angled brackets and a slash after the left bracket.

Tags can also have attributes, additional information specified in the tag. For example, a hyperlink, text that you can click to take you to a different web page, has

this structure:

```
Here is a link.
<a href="http://www.google.com">Go
to Google.</a>
That was a link.
```

Here there is a paired tag `a` with an opening and closing tag. The opening tag has an attribute `href` which is specified for a web address. This might display like this:



Clicking on the highlighted text would open the specified page.

The general structure of a page marked up with HTML is otherwise a little underdetermined…a little wild west. There are two reasons for this. First, there are a number of versions of HTML in use on the web and they do not all have the same requirements. Second, individual web browsers sometimes allow for browser-specific tags, or their own special interpretation of tags in general use. Our remarks here then should be taken as strongly qualified.

As exemplified above, an HTML document can begin with a document declara-

tion. It may mark the entire remaining document with `<html>...</html>`. The document is typically broken up into two parts: the head and the body which are marked with `<head>...</head>` and `<body>...</body>` respectively. The head of the document includes metadata about the document, the title, javascript code, color and formatting information, etc. The body of the document includes the text with various sorts of markup to structure the text or format spans of text.

We can't cover all the formatting possibilities, but here are some of the main ones.

Headings Documents can include section headings, e.g. `<h1>`, `<h2>`, `<h3>`, etc. These occur paired: `<h1>...</h1>`.

Paragraphs Paragraphs are marked with `<p>...</p>`. Here the closing tag is *not* required. Line breaks can be marked with the unpaired tag `<br>`.

Lists There are various sorts of lists, ordered lists `<ol>...</ol>` and unordered lists `<ul>...</ul>`. List items are marked with `<li>...</li>`. The list item tag need not be paired.

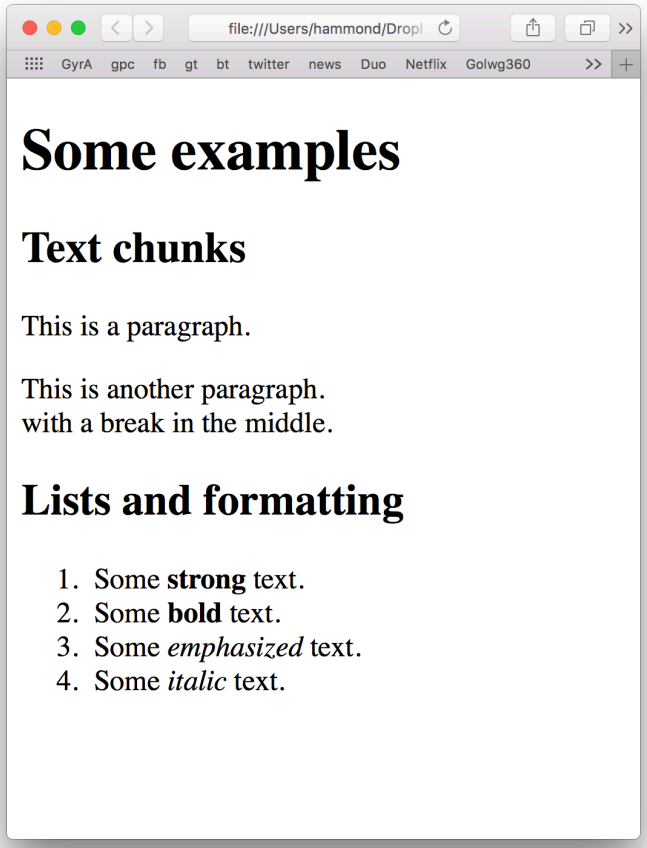
Formatting Text can be formatted in several ways. There is specific formatting which says precisely how the text is to be formatted, e.g. italic `<i>...</i>` or boldface `<b>...</b>`. There is also logical formatting where the code leaves it up to the browser how to display the text, e.g. strong `<strong>...</strong>` or emphatic `<em>...</em>`.

Here is a very simple HTML document that includes many of these:

```
<!DOCTYPE html>
<html>
 <head>
  <title>Here's a title</title>
 </head>
 <body>
  <h1>Some examples</h1>
  <h2>Text chunks</h2>
  <p>This is a paragraph.</p>
  <p>This is another paragraph.<br>
     with a break in the middle.</p>
  <h2>Lists and formatting</h2>
  <ol>
   <li>Some <strong>strong</strong> text.</li>
```

```
    <li>Some <b>bold</b> text.</li>
    <li>Some <em>emphasized</em> text.</li>
    <li>Some <i>italic</i> text.</li>
   </ol>
  </body>
 </html>
```

In my own browser, this displays like this:



Notice how the default settings for my browser render strong text as bold and emphasized text as italic.

Finally, web pages can be *dynamic*, rendered differently depending on day, time, lo-

cation or browser of the user etc. On the host side, this is often done with languages like `php`, but since this is handled on the hosting machine, you won't see this code. On the other hand, dynamic content can be rendered with `javascript` on the client side, which means that you can often find javascript code in webpages you download.

8.3 Parsing HTML

If you collect data via the web, you will most often be collecting data from text pages marked up with HTML. It is then necessary to remove or translate some or all of the markup.

How you do that depends tremendously on your goals. If all you want is the words on the page and you don't care about formatting or discourse or syntactic breaks, simply stripping the HTML may suffice. On the other hand, if you are interested in the larger structure of the webpage, where the section breaks are, the difference between line breaks, sentence breaks, paragraph breaks, then you can't simply remove the HTML.

There are several ways to do this. A priori, the simplest is to write code yourself to remove the HTML. The code files for the text include my own webpage downloaded as `hammond.html`. For convenience, we will operate with this local file.

First, we make sure we can actually open and read the file:

```
f = open('hammond.html','r')
t = f.read()
f.close()
print(t)
```

web5.py

If you run this program, you'll see that my own webpage is not exactly in orthodox format. For example, it does not begin with a document declaration. In addition, the head of the document does not terminate with `</head>`. There are many other issues here as well. For example, notice that some of the tags are capitalized and some are not. Our code for stripping and translating HTML must accommodate these.

Let's first remove everything up to the body of the page.

```
import re

#open the local file
f = open('hammond.html','r')
#read the whole thing in
t = f.read()
#close the stream
f.close()
#do a multi-line substitution, deleting
#everything up to the body of the page
t = re.sub('^.*<body>','',t,flags=re.I|re.S)
#print the result
print(t)
```

web6.py

Here we are matching `.` against any character including a line return, so we must use the flag `re.S`. We are also anticipating that some tags are capitalized and some not, so we use `re.I` for that. As already noted, when we use both flags, they must be joined with `|`.

To remove all remaining tags, we again use `re.sub()`.

```
import re

#open local page
f = open('hammond.html','r')
#read it all in
t = f.read()
#close file stream
f.close()
#eliminate header up to body of page
t = re.sub('^.*<body>','',t,flags=re.I|re.S)
#remove all tags
t = re.sub('<[^>]*>',' ',t,flags=re.I|re.S)
#print what's left
print(t)
```

web7.py

Here we replace tags with spaces which generally works, but running the program

shows that this sometimes puts spaces between text and punctuation where there shouldn't be. If we were removing punctuation later, this is not a problem of course.

Another issue with this code is that it seems to leave the string `-->` scattered about the page. This is the right side of an HTML comment. Comments in HTML are of the form `<!--...-->` and it looks like the page source includes things like `<!--</a>-->` which our code above parses incorrectly. The following code gets some of these.

```
import re

#open local webpage
f = open('hammond.html','r')
#read it all in
t = f.read()
#close file stream
f.close()
#get rid of header
t = re.sub('^.*<body>','',t,flags=re.I|re.S)
#get rid of (at least some) html comments
t = re.sub('<!--[^-]*-->',' ',t,flags=re.I|re.S)
#get rid of at least some tags
t = re.sub('<[^>]*>',' ',t,flags=re.I|re.S)
#print what remains
print(t)
```

web8.py

This works better, but still doesn't get all cases.

We can keep tweaking this code to do better, but the lesson should be clear: it is very hard to accurately and exactly translate or strip HTML code. If you want to write the code to do that yourself, you must pay special attention to why you are stripping HTML, so that you can focus your efforts on removing or translating what really needs to be removed or translated. You must also ultimately be prepared for a certain amount of noise in your data.

There is another way to go here though. There are existing modules for parsing HTML. These are also not perfect, but they can often be a lot more perfect that you or I might have patience for!

One very common solution in Python is *Beautiful Soup*[1], a free open-source module for Python for parsing and manipulating HTML. You have to install it yourself, but once installed, it can be called like any other module. The module is called `bs4` and the relevant function is `BeautifulSoup()`. What that does is parse the HTML and build a *document model*. This is a treelike representation of the HTML document and you can extract elements from it easily. The following code exemplifies:

```
#import for reading urls
import urllib.request
#import for parsing html
from bs4 import BeautifulSoup

#non-local page this time
link = "http://www.u.arizona.edu/~hammond/"
#connect to that page
f = urllib.request.urlopen(link)
#read it all in
myfile = f.read()
#build a document model
soup = BeautifulSoup(myfile,'html.parser')
#print the page verbatim
print(myfile)
#pretty-print the html
print(soup.prettify())
#extract the text
print(soup.get_text())
#got through all the hyperlinks...
for link in soup.find_all('a'):
   #...and print them
   print(link.get('href'))
```

web9.py

Here we read in a web page and then parse it with `BeautifulSoup()`. We can then print a pretty version of it with `prettify()`, extract the text with `get_text()`, or find all instances of a tag with `find_all()`. Each tag found is its own treelike representation, so we can continue to call methods on them. In

[1] `https://www.crummy.com/software/BeautifulSoup/`

the example at hand, we call the `get()` method to extract the text of the `href` attribute for the `a` tags.

Notice incidentally that the `get_text()` method does a better job of dealing with HTML comments in this sample.

8.4 Parallelism

Once you start using web data as input in your program, you very quickly run into a problem. When your program requests a web page, it relies on the speed of the network and the speed of the other computer you are requesting the page from. If you are getting a lot of web pages, this can really slow down your program. Here's an example of a program that shows this effect:

```
#import for timing your code
import time
#import for reading webpages
from urllib.request import urlopen

#return the time in milliseconds
def mytime():
    return round(time.time() * 1000)

#function to read a url and time that read
def myget(url):
    start = mytime()
    data = urlopen(url,timeout=5).read()[:50]
    result = {"url": url, "data": data}
    now = str(mytime() - start)
    print(url + ": " + now + "ms")
    return result

#a random list of urls
urls = ['http://www.google.com/',
'http://www.yahoo.com/',
'http://golwg360.cymru/newyddion',
'https://news.google.com/news',
```

```
'https://tartarus.org/martin/PorterStemmer/',
'https://en.wikipedia.org/wiki/Main_Page',
'http://www.u.arizona.edu']

#start overall timing
start = mytime()
#list to collect results
results = []
#go through urls 1 by 1
for i in range(len(urls)):
    #get url and text read
    result = myget(urls[i])
    #append those to results
    results.append(result)
#get end time
now = str(mytime() - start)
#print overall time
print("Total = " + now + " ms\n")
```

web10.py

This program imports from the `urllib.request` module for the `urlopen()` function. It also reads from the `time` module for the `time()` function which returns the current time (from a specific and irrelevant time of origin). We can use the `time()` function to determine how long it takes our code to run. First, we define a function `mytime()` which gets the current time in milliseconds. We also define a function `myget()` which takes a url as an argument and reads the first 50 characters of that file and then prints out how long it took to get that done. Note how the `urlopen()` function takes an additional argument which specifies how long it will wait for a webpage before moving on. We then define a fairly random list of urls and run through them with `myget()`. We also return the total amount of time for the whole program to run.

If you run this, you'll see that the total run time for the program is roughly the sum of the time it takes to retrieve each page. This is perhaps unsurprising. Notice though that most of the time your computer is simply waiting for the webpages to be delivered. That is, for each request, your program sends the request and then sits idle while it waits for the other machine to send its response.

A more efficient system would have your computer do something else while waiting

for the other computer to respond.

A related issue is that most modern computers have a multi-processor architecture, which mean that at the processing level, setting aside hardware bottlenecks, they can do more than one thing at once.

We don't want to get into the nitty gritty of processes, threads, parallelism, etc., but we can do substantially better if we take advantage of these ideas. The basic logic is that, with `multiprocessing` module, you can do more than one thing at once, contingent on your own computer hardware.

The following bit of code shows this:

```
#for timing info
import time
#to read webpages
from urllib.request import urlopen
#to do more than one thing at once
from multiprocessing import Pool

#current time in milliseconds
def mytime():
    return round(time.time() * 1000)

#50 characters of a webpage
def myget(url):
    start = mytime()
    data = urlopen(url,timeout=5).read()[:50]
    result = {"url": url, "data": data}
    now = str(mytime() - start)
    print(url + ": " + now + "ms")
    return result

#some random urls
urls = ['http://www.google.com/',
'http://www.yahoo.com/',
'http://golwg360.cymru/newyddion',
'https://news.google.com/news',
'https://tartarus.org/martin/PorterStemmer/',
'https://en.wikipedia.org/wiki/Main_Page',
```

```
'http://www.u.arizona.edu']

#print urls in order accessed
for i in range(len(urls)):
   print(i+1,': ',urls[i],sep='')
print()

#multiple processes
mypool = Pool()
#start the clock
start = mytime()
#separate process for each url
results = mypool.map(myget, urls)
#print total elapsed
now = str(mytime() - start)
print("Total = " + now + " ms\n")
```

web11.py

We import from the `time` module so we can keep track of how long the code takes to run. We import from `urllib.request` to open and read web pages. Finally, we import from `multiprocessing` so we can do more than one thing at a time.

We define the same functions `mytime()` and `myget()` as in `web10.py`. We also use the same urls. We now print out the urls in order.

The next part of the code handles the parallelism. First, we create a `Pool` that keeps track of how many things we can do at once. This will vary depending on what kind of machine you run this on. The key bit of code is `mypool.map()` which applies `myget()` to all the urls. Each of these applications of `myget()` proceeds in parallel, so if any page is slow to load, the other requests proceed unaffected. Since `myget()` prints out its run time as it finishes, you can see each process terminate. Finally, the program prints out the total run time.

If you run the code several times, you'll see that the total run time varies as a function of the speed of the internet, your connection, and the other machines you are interacting with.

You should see immediately that this program runs much more quickly than the `web10.py` program. You should also see that the run time for this code is *not* the sum of the length of the individual calls to `myget()`. How much faster than that

depends on your own computational resources, but the best case scenario is that total run time is roughly equivalent to the slowest call to `myget()`.

Finally, you should also see that the order that each call to `myget()` terminates is *not* necessarily the same order as in the initial list. Rather, assuming they all run in parallel, the order they finish is based on how long each takes to load. If your resources are limited then you won't be able to sustain as many parallel processes and this may not be quite true.

8.5 A webcrawler

In this section we program a simple webcrawler: a program that searches the web for webpages of interest and collects relevant data. In our case, we will search for webpages in Welsh and save the text.

As usual, we build our program up slowly to model good programming habits. Let's start by reading in one page from a Welsh news site.

```
from urllib.request import urlopen

#a welsh news site
url = 'http://golwg360.cymru'
#open the connection
w = urlopen(url,timeout=5)
#read in the whole page
t = w.read()
#print number of words
print(len(t.split()))
```

web12.py

What we will ultimately want is a program that iterates through a list of urls. If a webpage satisfies some criterion—in this case, say, that it's in Welsh—then we save the text and add the links from that page to our list of links. We then continue on. Let's add this general logic to our program.

```
from urllib.request import urlopen

#seed for list of urls
```

```
urls = ['http://golwg360.cymru',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
    #open/read url
    u = urls.pop(0)
    w = urlopen(u,timeout=5)
    t = w.read()
    #placeholder: count words
    print(i,': ',len(t.split()),sep='')
    i += 1
    #check if the page is in Welsh
    if True:
        res.append([u,t])
        #extract links and append
```

web13.py

We converted our url to a list of urls. I've deliberately put one clearly Welsh url in the list and one that is clearly not Welsh. We've also created a list to store the results of our crawling. We then iterate through the list as long as there are urls on the list and our counter doesn't reach 100. We will ultimately be adding links to the list and then removing them as we work through them. We need to check at each iteration that there are actually items still on the list. We add the counter so that the program stops at some point.

We then go through and read each page on our list. In this version of the program we print the length of the page, but that's just a placeholder. We will ultimately be checking each page to see if it's in Welsh. If it is, we save it and add its links to the list or urls.

Next, let's use Beautiful Soup to extract the text and the links.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re
```

```
#seed for list of urls
urls = ['http://golwg360.cymru',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
    #open/read url
    u = urls.pop(0)
    w = urlopen(u,timeout=5)
    h = w.read()
    #parse html
    s = BeautifulSoup(h,'html.parser')
    t = s.body.get_text()
    i += 1
    #check if the page is in Welsh
    if True:
        res.append([u,t])
        print(u,': ',len(t.split()),sep='')
        #extract links
        links = s.find_all('a')
        for l in links:
            print('\t',l.get('href'))
```

web14.py

We will ultimately want to follow links, so we need to be mindful of what kind of links we see here. There are two distinctions of interest. First, we have relative and absolute links. Absolute links begin with `http://` or `https://` and relative links do not. Relative links are, as you might expect, urls relative to the current page. For example, if we are on a page `http://www.where.edu` and we find the relative link `/wales.html`, we would need to convert it to `http://www.where.edu/wales.html`. Thus, if we want to follow relative links, we will need to convert them to absolute links.

Another kind of link is a local link, which can occur in either an absolute or relative link. These include the # symbol and might look like this: `wales.html#yma` or `http://www.where.edu#lle`. These link to the same pages as the two

preceding links, but position the browser window in specific locations. If we are just interested in the content of web pages, we should prune the local link information.

The next version of the code strips out local links and converts relative links to absolute links.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
   m = re.search('^http',res)
   if m:
      return res
   res = u + '/' + res
   res = re.sub('([^:]/)/+','\\1',res)
   return res

#seed for list of urls
urls = ['http://golwg360.cymru',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
   #open/read url
   u = urls.pop(0)
   w = urlopen(u,timeout=5)
   h = w.read()
   #parse html
   s = BeautifulSoup(h,'html.parser')
   t = s.body.get_text()
   i += 1
   #check if the page is in Welsh
   if True:
      res.append([u,t])
```

```
        print(u,': ',len(t.split()),sep='')
        #extract links
        links = s.find_all('a')
        for l in links:
            link = l.get('href')
            if link:
                print('\t',link)
                fixedlink = fixlinks(u,link)
                print('\t\t',fixedlink)
```

web15.py

The next issue to sort out is what happens if a link doesn't work or times out. The code as currently written simply stops if that occurs. What would be better is if the code simply skips over bad links. We address this with a new control structure `try`/`except`. Here commands in the `try` block are executed. If no error occurs, the program continues. If an error does occur, the commands in the `except` block apply. Here's a simple example:

```
print('Before the first try block:')
try:
    print('\tthree' + 3)
except:
    print("\tThat math doesn't work.")
print('Before the second try block:')
try:
    print('\tthree' + ' + 3.')
except:
    print("That math doesn't work.")
print('All done.')
```

web16.py

Here the first `try` block fails because + is not defined for strings and numbers together and its `except` block applies. The second `try` block does succeed so its `except` block does not apply.

Let's now use this in our webcrawler code:

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
```

```
import re

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
   m = re.search('^http',res)
   if m:
      return res
   res = u + '/' + res
   res = re.sub('([^:]/)/+','\\1',res)
   return res

#seed for list of urls
urls = ['http://golwg360.cymru',
'http://bad',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
   #open/read url
   u = urls.pop(0)
   i += 1
   try:
      w = urlopen(u,timeout=5)
      h = w.read()
   except:
      print('bad url:',u)
      continue
   #parse html
   s = BeautifulSoup(h,'html.parser')
   t = s.body.get_text()
   #check if the page is in Welsh
   if True:
      res.append([u,t])
      print(u,': ',len(t.split()),sep='')
      #extract links
```

```
links = s.find_all('a')
for l in links:
   link = l.get('href')
   if link:
      print('\t',link)
      fixedlink = fixlinks(u,link)
      print('\t\t',fixedlink)
```

web17.py

Here if the url fails to open or we can't read from it, we print out the name of the url and go on to the next one.

Another issue we have to face is that we may encounter non-textual data. Sometimes it will be apparent from the url, i.e. it ends in `.au`, `.zip`, etc. Sometimes, however, it will not. To accommodate this, we use the same conversion string conversion utility as above: `decode('UTF-8')`. This will succeed if the webpage is appropriate text. The following version of the code adds this.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
   m = re.search('^http',res)
   if m:
      return res
   res = u + '/' + res
   res = re.sub('([^:]/)/+','\\1',res)
   return res

#seed for list of urls
urls = ['http://golwg360.cymru',
'http://bad',
'http://www.u.arizona.edu/~hammond/greeting.au',
'http://www.u.arizona.edu/~hammond']
#results
res = []
```

```
#iterate through list
i = 1
while urls and i < 100:
    #open/read url
    u = urls.pop(0)
    i += 1
    try:
        w = urlopen(u,timeout=5)
        h = w.read()
        h = h.decode('UTF-8')
    except:
        print('bad url:',u)
        continue
    #parse html
    s = BeautifulSoup(h,'html.parser')
    t = s.body.get_text()
    #check if the page is in Welsh
    if True:
        res.append([u,t])
        print(u,': ',len(t.split()),sep='')
print('Stored pages:',len(res))
```

web18.py

Our next step is to implement the check for whether the page is in Welsh. There are sophisticated ways to do this, but we will use an intuitive simple strategy. First, we calculate what are the most common words of Welsh. We then score documents by what percentage of the document are potentially instances of these words.

First, we use the CEG corpus[2] to find the 20 most common wordforms of Welsh. We set aside forms marked with apostrophes and forms with accents.

yn	y	i	a	o
ei	ar	yr	bod	ac
am	wedi	hi	ond	eu
fel	na	un	ni	mewn

We now write a function that computes what percentage of a webpage's words are

[2]Ellis, N. C., C. O'Dochartaigh, W. Hicks, M. Morgan, and N. Laporte. 2001. *Cronfa Electroneg o Gymraeg (CEG)*, http://www.bangor.ac.uk/canolfanbedwyr/ceg.php.en

on this list. Our goal is to find a separation point between pages in Welsh and pages in other languages.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

welshwords = ['yn','y','i','a','o',
'ei','ar','yr','bod','ac',
'am','wedi','hi','ond','eu',
'fel','na','un','ni','mewn']

def welsh(u,t):
    n = t.lower()
    n = re.sub('[^a-z]',' ',n)
    n = re.sub('  +',' ',n)
    wds = n.split()
    total = len(wds)
    wcount = 0
    for w in wds:
        if w in welshwords:
            wcount += 1
    percent = wcount/total
    print(u,'\n\t',wcount,'/',total, \
        ' (',percent,')',sep='')
    return True

#fix relative and local links
def fixlinks(u,l):
    res = re.sub('#.*$','',l)
    m = re.search('^http',res)
    if m:
        return res
    res = u + '/' + res
    res = re.sub('([^:]/)/+','\\1',res)
    return res

#seed for list of urls
```

```
urls = ['http://golwg360.cymru',
'https://cy.wikisource.org/wiki/Hafan',
'http://haciaith.com',
'http://techiaith.cymru',
'https://www.bbc.co.uk/cymru',
'https://www.yahoo.com',
'https://news.google.com/news/',
'https://en.wikipedia.org/wiki/Main_Page',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
   #open/read url
   u = urls.pop(0)
   i += 1
   try:
      w = urlopen(u,timeout=5)
      h = w.read()
      h = h.decode('UTF-8')
   except:
      print('bad url:',u)
      continue
   #parse html
   s = BeautifulSoup(h,'html.parser')
   t = s.body.get_text()
   #check if the page is in Welsh
   if welsh(u,t):
      res.append([u,t])
      print('\t',len(t.split()),sep='')
print('Stored pages:',len(res))
```

web19.py

We've changed our list of urls here so that we have pages we know are in Welsh and others that we know are in English. What we see when we run this is that when the the words above comprise 10% or more of the words on the page, we can be pretty sure the page is in Welsh. This misses some pages, but it's a reasonable starting

point. The following code alters the `welsh()` function to do this.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#most frequent Welsh words
welshwords = ['yn','y','i','a','o',
'ei','ar','yr','bod','ac',
'am','wedi','hi','ond','eu',
'fel','na','un','ni','mewn']

#function to test for Welsh
def welsh(u,t):
   n = t.lower()
   n = re.sub('[^a-z]',' ',n)
   n = re.sub('  +',' ',n)
   wds = n.split()
   total = len(wds)
   wcount = 0
   for w in wds:
      if w in welshwords:
         wcount += 1
   percent = wcount/total
   if percent > .09:
      return True
   else:
      return False

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
   m = re.search('^http',res)
   if m:
      return res
   res = u + '/' + res
   res = re.sub('([^:]/)/+','\\1',res)
   return res
```

```
#seed for list of urls
urls = ['http://golwg360.cymru',
'https://cy.wikisource.org/wiki/Hafan',
'http://haciaith.com',
'http://techiaith.cymru',
'https://www.bbc.co.uk/cymru',
'https://www.yahoo.com',
'https://news.google.com/news/',
'https://en.wikipedia.org/wiki/Main_Page',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 100:
   #open/read url
   u = urls.pop(0)
   i += 1
   try:
      w = urlopen(u,timeout=5)
      h = w.read()
      h = h.decode('UTF-8')
   except:
      print('bad url:',u)
      continue
   #parse html
   s = BeautifulSoup(h,'html.parser')
   t = s.body.get_text()
   #check if the page is in Welsh
   if welsh(u,t):
      res.append([u,t])
      print(u,': ',len(t.split()),sep='')
print('Stored pages:',len(res))
```

web20.py

The next step is to add urls to our list if the page they are on is in Welsh. The following code does this:

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#most frequent Welsh words
welshwords = ['yn','y','i','a','o',
'ei','ar','yr','bod','ac',
'am','wedi','hi','ond','eu',
'fel','na','un','ni','mewn']

#function to test for Welsh
def welsh(u,t):
   n = t.lower()
   n = re.sub('[^a-z]',' ',n)
   n = re.sub('  +',' ',n)
   wds = n.split()
   total = len(wds)
   wcount = 0
   for w in wds:
      if w in welshwords:
         wcount += 1
   percent = wcount/total
   if percent > .09:
      return True
   else:
      return False

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
   m = re.search('^http',res)
   if m:
      return res
   res = u + '/' + res
   res = re.sub('([^:]/)/+','\\1',res)
   return res

#seed for list of urls
```

```
urls = ['http://golwg360.cymru',
'https://cy.wikisource.org/wiki/Hafan',
'http://haciaith.com',
'http://techiaith.cymru',
'https://www.bbc.co.uk/cymru',
'https://www.yahoo.com',
'https://news.google.com/news/',
'https://en.wikipedia.org/wiki/Main_Page',
'http://www.u.arizona.edu/~hammond']
#results
res = []
#iterate through list
i = 1
while urls and i < 20:
   #open/read url
   u = urls.pop(0)
   i += 1
   try:
      w = urlopen(u,timeout=5)
      h = w.read()
      h = h.decode('UTF-8')
   except:
      print('bad url:',u)
      continue
   #parse html
   s = BeautifulSoup(h,'html.parser')
   t = s.body.get_text()
   #check if the page is in Welsh
   if welsh(u,t):
      res.append([u,t])
      print(u,': ',len(t.split()),sep='')
      links = s.find_all('a')
      for l in links:
         lu = l.get('href')
         if lu:
            urls.append(fixlinks(u,lu))
print('Stored pages:',len(res))
```

web21.py

Notice that we must test if we were actually able to extract the `href` attribute from the `a` tag before trying to append it to our list.

This works fine, but fails in an important respect. The program so far adds links regardless of whether they are already in the list or whether we have already looked at them and popped them off the list. The following code implements these checks.

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#most frequent Welsh words
welshwords = ['yn','y','i','a','o',
'ei','ar','yr','bod','ac',
'am','wedi','hi','ond','eu',
'fel','na','un','ni','mewn']

#function to test for Welsh
def welsh(u,t):
   n = t.lower()
   n = re.sub('[^a-z]',' ',n)
   n = re.sub('  +',' ',n)
   wds = n.split()
   total = len(wds)
   wcount = 0
   for w in wds:
      if w in welshwords:
         wcount += 1
   percent = wcount/total
   if percent > .09:
      return True
   else:
      return False

#fix relative and local links
def fixlinks(u,l):
   res = re.sub('#.*$','',l)
```

```
        m = re.search('^http',res)
        if m:
            return res
        res = u + '/' + res
        res = re.sub('([^:]/)/+','\\1',res)
        return res

    #seed for list of urls
    urls = ['http://golwg360.cymru',
    'https://cy.wikisource.org/wiki/Hafan',
    'http://haciaith.com',
    'http://techiaith.cymru',
    'https://www.bbc.co.uk/cymru',
    'https://www.yahoo.com',
    'https://news.google.com/news/',
    'https://en.wikipedia.org/wiki/Main_Page',
    'http://www.u.arizona.edu/~hammond']
    #results
    res = []
    #urls already checked
    already = []
    #iterate through list
    i = 1
    while urls and i < 20:
        #open/read url
        u = urls.pop(0)
        already.append(u)
        i += 1
        try:
            w = urlopen(u,timeout=5)
            h = w.read()
            h = h.decode('UTF-8')
        except:
            print('bad url:',u)
            continue
        #parse html
        s = BeautifulSoup(h,'html.parser')
        t = s.body.get_text()
```

```
        #check if the page is in Welsh
        if welsh(u,t):
            res.append([u,t])
            print(u,': ',len(t.split()),sep='')
            links = s.find_all('a')
            for l in links:
                lu = l.get('href')
                if lu:
                    lufixed = fixlinks(u,lu)
                    if lu not in already \
                        and lu not in urls:
                            urls.append(lufixed)
print('Stored pages:',len(res))
```

web22.py

Finally, the program must save results when it's done. The following code adds this:

```
from urllib.request import urlopen
from bs4 import BeautifulSoup
import re

#most frequent Welsh words
welshwords = ['yn','y','i','a','o',
'ei','ar','yr','bod','ac',
'am','wedi','hi','ond','eu',
'fel','na','un','ni','mewn']

#function to test for Welsh
def welsh(u,t):
    n = t.lower()
    n = re.sub('[^a-z]',' ',n)
    n = re.sub('  +',' ',n)
    wds = n.split()
    total = len(wds)
    wcount = 0
    for w in wds:
        if w in welshwords:
```

```
            wcount += 1
      percent = wcount/total
      if percent > .09:
         return True
      else:
         return False

   #fix relative and local links
   def fixlinks(u,l):
      res = re.sub('#.*$','',l)
      m = re.search('^http',res)
      if m:
         return res
      res = u + '/' + res
      res = re.sub('([^:]/)/+','\\1',res)
      return res

   #seed for list of urls
   urls = ['http://golwg360.cymru',
   'https://cy.wikisource.org/wiki/Hafan',
   'http://haciaith.com',
   'http://techiaith.cymru',
   'https://www.bbc.co.uk/cymru',
   'https://www.yahoo.com',
   'https://news.google.com/news/',
   'https://en.wikipedia.org/wiki/Main_Page',
   'http://www.u.arizona.edu/~hammond']
   #results
   res = []
   #urls already checked
   already = []
   #iterate through list
   i = 1
   while urls and i < 20:
      #open/read url
      u = urls.pop(0)
      already.append(u)
      i += 1
```

```
        try:
            w = urlopen(u,timeout=5)
            h = w.read()
            h = h.decode('UTF-8')
        except:
            print('bad url:',u)
            continue
        #parse html
        s = BeautifulSoup(h,'html.parser')
        t = s.body.get_text()
        #check if the page is in Welsh
        if welsh(u,t):
            res.append([u,t])
            print(u,': ',len(t.split()),sep='')
            links = s.find_all('a')
            for l in links:
                lu = l.get('href')
                if lu:
                    lufixed = fixlinks(u,lu)
                    if lu not in already \
                        and lu not in urls:
                            urls.append(lufixed)
print('Stored pages:',len(res))
#save results
#already
f = open('already.txt','w')
for u in already:
    f.write(u+'\n')
f.close()
#urls
f = open('urls.txt','w')
for u in urls:
    f.write(u+'\n')
f.close()
#results
f = open('resuts.txt','w')
f.write('<results>\n')
for r in res:
```

```
        f.write('<record>\n')
        u = r[0]
        t = r[1]
        f.write('<url>\n')
        f.write(u+'\n')
        f.write('</url>\n')
        f.write('<text>\n')
        f.write(t+'\n')
        f.write('</text>\n')
        f.write('</record>\n')
    f.write('</results>\n')
    f.close()
```

web23.py

The code simply writes the three data structures to files: `urls` to `urls.txt`, `already` to `already.txt` and `res` to `results.txt`. The only complication is that the `res` list is a list of lists and we want to make easy use of.

To allow for this we've written the `results.txt` file as an *XML* file. The basic idea is that we have tags, much like in HTML, but the tags can be whatever we want. In our case, we have tags for `<results>`: the whole file, `<record>`: a url-text pair, `<url>`: the url, and `<text>`: the text of that url. Here is a schematic view:

```
<results>
  <record>
     <url>
   ...
   </url>
   <text>
   ...
   </text>
  </record>
  ...
</results>
```

In fact, the BeautifulSoup module has simple functions for dealing with XML data, which we leave as an exercise. There are, in fact, a number of other things that can be done to improve this program, but all of them are left as exercises.

8.6 Exercises

1. Augment the webcrawler code so that you can restart the system with existing files. The basic idea is that you might want to add urls and add additional data.
2. The webcrawler is slow. Rewrite it so it uses parallel techniques and runs faster. This is hard!
3. The webcrawler is designed to search for Welsh webpages. Convert it to a different language.
4. The `welsh()` function in the webcrawler program can be revised in many ways. Can you come up with another approach? design a test program so your new function can be compared against the one in the text.
5. Write a function that takes a url as an argument and returns any items on the page marked with the `<strong>` tag.
6. Write a function that takes a url as an argument and extracts and prints any ordered lists marked with `<ol>`. Note that individual items in such a list are marked with `<li>`. Also, make sure each item in the list is clearly separated *and numbered appropriately*. Use *BeautifulSoup* to do this.
7. Do the same thing without *BeautifulSoup*.

Chapter 9

Unicode and text encoding

As linguists, we are very often concerned with textual representations of language. The problem is that computers don't really process text directly. Rather, for computers, text is represented internally as numbers. This has consequences for us as programmers and we deal with them in this chapter.

In this chapter, we discuss generally how characters are represented internally and the major character encodings you may run across. We then discuss methods for reading, writing, and converting different encodings. Finally, we discuss methods for deducing the encoding of some document or resource.

9.1 Representing characters

As above, the computer represents characters internally as numbers. In turn, numbers are represented as binary numbers or base-2.

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010

Thus, we might imagine a system like the following for representing letters:

Decimal	Binary	Letters
0	0	a
1	1	b
2	10	c
3	11	d
4	100	e
5	101	f
6	110	g
7	111	h
8	1000	i
9	1001	j
10	1010	k
…	…	…

This is fine for individual letters, but presents a problem when we get to letter sequences. Using the hypothetical encoding above, a sequence like 101 is multiply ambiguous:

101	f
1+0+1	bab
10+1	cb

The solution is to pad the numbers so they are of the same width, say, like this:

Decimal	Binary	Padded	Letters
0	0	0000	a
1	1	0001	b
2	10	0010	c
3	11	0011	d
4	100	0100	e
5	101	0101	f
6	110	0110	g
7	111	0111	h
8	1000	1000	i
9	1001	1001	j
10	1010	1010	k
…	…	…	

Doing this, the three interpretations for 101 above would be disambiguated like this:

101	f	0101
1+0+1	bab	000100000001
10+1	cb	00100001

The trick here is that we know every character has exactly four digits. This solution requires that we know how much padding needs to be added. In other words, we need to calculate from a finite set of characters what the "widest" binary number we will need is. From that, we can calculate how much padding to add. If we only needed to represent the letters above, we know that the biggest binary number we will need is 1010: four digits wide. Smaller numbers are padded accordingly. We refer to each of these digit slots as a *bit*.

When transmitting data encoded like this it is possible for errors to occur. One strategy to detect errors is to suffix one more slot on each letter that helps detect errors: a *parity bit*.

One of the earliest approaches to character encoding is ASCII and it has essentially this structure. It used 7 bits to encode each letter (plus an additional parity bit). An 8-bit unit of this sort is referred to as a *byte*.

If you do the math, you will see that with only seven binary bits to encode letters, this allows for a maximum of $2^7 = 128$ distinct characters. While this may suffice for a language like English, it doesn't do for all the characters of all the languages of the world. It certainly doesn't accommodate documents with multiple character

sets.

Historically, at this point, we enter the wild west of character encoding. A huge variety of different approaches were adopted to deal with character sets beyond the 128 that ASCII could accommodate. Eventually, the *Unicode* standard was proposed, a uniform numerical value for every character in virtually every language. The growing majority of web resources that you will encounter make use of this standard.

There is an obvious issue, however. There are well over a million distinct characters in the Unicode standard. This means that if you want distinct bitwise representations of a constant width, each character will have to be substantially "wider" than 8 bits (1 byte).

There are two broad solutions to this that you will encounter. The first is *UTF-16* (Unicode Transformation Format), an encoding that bites the bullet and encodes every character with 16 bits (2 bytes).

The other more common solution is *UTF-8*. This approach encodes each character with a variable number of bytes: 1 to 4. The trick is that each byte is marked so that you can tell whether it is the start of some new multi-byte character or a continuation of the multi-byte sequence. The basic idea is as follows, where *x* indicates a bit that can be used for character values:

	Byte 1	Byte 2	Byte 3	Byte 4
1	0xxxxxxx			
2	110xxxxx	10xxxxxx		
3	1110xxxx	10xxxxxx	10xxxxxx	
4	11110xxx	10xxxxxx	10xxxxxx	10xxxxxx

The really interesting part of UTF-8, however is that the one-byte case is identical to ASCII. That is any ASCII-encoded text is a legal subcase of UTF-8. The most frequent encoding seen on the web today is UTF-8.

9.2 Bytes and strings

Python is natively UTF-8. What this means is that file IO and the interactive environment handle UTF-8 characters directly. For example, we might enter the following in the interactive environment:

```
>>> x = 'русский язык'
>>> y = '中文'
>>> len(x)
12
>>> len(y)
2
```

Note that the Russian and Chinese characters are displayed properly and their lengths are calculated correctly. This also works from a program file:

```
x = 'русский язык'
y = '中文'
print(x,': ',len(x),sep='')
print(y,': ',len(y),sep='')
```

uni1.py

Similarly, if a file is encoded as UTF-8, it can be read from directly. The following program exemplifies:

```
f = open('enc/russian.txt','r')
r = f.read()
f.close()
print('Some Russian:',r,end='')

f = open('enc/chinese.txt','r')
c = f.read()
f.close()
print('Some Chinese:',c,end='')
```

uni2.py

In this case, the two files read from contain Russian and Chinese characters and are both encoded as UTF-8.

On the other hand, if a file is encoded in some other way this will fail. Here we try to read Chinese from a file encoded in the *Big5* encoding and it fails.

```
f = open('enc/cb5.txt','r')
f.read()
...
UnicodeDecodeError ...
```

A similar problem occurs if we try to read Russian from a file encoded in *Windows-1251* encoding:

```
f = open('enc/r1251.txt','r')
f.read()
...
UnicodeDecodeError ...
```

To read files in other encodings like this, we must first read in the raw bytes and then explicitly convert the encodings using the bytes method `decode()`. The following program exemplifies:

```
#open a file to read bytes
f = open('enc/cb5.txt','rb')
#read the bytes
c = f.read()
#convert from big5 to utf8 characters
c = c.decode('big5')
#print characters
print('Chinese:',c)

#open a file to read bytes
f = open('enc/r1251.txt','rb')
#read the bytes
r = f.read()
#convdert from windows-1251 to utf8
r = r.decode('1251')
#print characters
print('Russian:',r)
```

uni3.py

In both cases, we invoke the `open()` function with the argument `'rb'` so that we read raw bytes. The `read()` command is then executed without arguments. To display these strings we must then convert from bytes to UTF-8 and to do that we must explicitly convert from the relevant encodings with the `decode()` method.

If you want to write to a file in an encoding other than UTF-8, you must also use raw bytes. The following program writes out strings in UTF-8 converted to Windows-1251 and Big5 encodings using the bytes method `encode()`.

```
#a string in Russian
r = 'русский язык'
#open a connection to write bytes
f = open('enc/rout1251.txt','wb')
#write bytes in windows-1251
f.write(r.encode('1251'))
#close connection
f.close()
#a string in chinese
c = '中文'
#open a connection to write bytes
f = open('enc/coutb5.txt','wb')
#write bytes in big5
f.write(c.encode('big5'))
#close connection
f.close()
```

uni4.py

9.3 What is the encoding?

The biggest challenge to working with character encodings is that you may have a document and simply not know what the encoding is. In this section, we discuss ways to deal with this.

The first "solution" to the encoding problem is to make sure that it's really a problem for you! Recall the webcrawler program in Section 8.5. That program crawled the web looking for webpages in Welsh. It included a function to do language identification that *assumes the page is encoded in UTF-8*. A side effect of this is that web pages in other encodings are assumed to be not in Welsh. This probably misses some pages that are in Welsh, but it also simplifies the language identification problem. Pages in other encodings are taken to be not in Welsh *and that's generally true*.

The moral is that—for that application—we don't need to figure out what encoding a page is in.

Another option for web pages specifically is that the encoding is specified in the document itself. In more recent versions of HTML this occurs in the `<meta>` tag.

For example, the following in the head of an HTML document indicates that the document is encoded in UTF-8.

```
<head>
   <meta charset="UTF-8">
</head>
```

Unfortunately, this is not a required part of every HTML page. In addition, this doesn't help with determining the encoding of a document that is not in HTML.

Another solution is to attempt to figure out what the encoding is. The basic logic is that there are only a finite number of encodings out there and they have specific structures in terms of what kinds of bytes and byte sequences occur. In addition, certain encodings are tailored to specific languages. Thus we can examine some document to see what encodings are possible and whether the text produced is consistent with the languages we expect to see.

One module that does this is `chardet` (not part of the default Python distribution). If we run this on our Russian file, it succeeds:

```
>>> import chardet
>>> f = open('enc/r1251.txt','rb')
>>> r = f.read()
>>> chardet.detect(r)
{'language': 'Russian',
  'encoding': 'windows-1251',
  'confidence': 0.99}
```

Here we import the `chardet` module and invoke its `detect()` function on bytes read from the short Russian file. That function returns a dictionary with three records indicating language, encoding, and its confidence in determining those.

This technique fails with our Chinese file:

```
>>> import chardet
>>> f = open('enc/cb5.txt','rb')
>>> c = f.read()
>>> chardet.detect(c)
{'language': '',
  'encoding': 'ISO-8859-1',
  'confidence': 0.73}
```

Presumably this is because the Chinese file is only two characters long and does not provide enough information for the `detect()` function. If we do this with longer downloaded web pages in the same languages and encodings, the function is successful in both cases:

```
>>> f = open('enc/rnd.html','rb')
>>> r = f.read()
>>> chardet.detect(r)
{'language': 'Russian',
  'encoding': 'windows-1251',
  'confidence': 0.9596062000298741}

>>> f = open('enc/dh.html','rb')
>>> c = f.read()
>>> chardet.detect(c)
{'language': 'Chinese',
  'encoding': 'Big5',
  'confidence': 0.99}
```

The `BeautifulSoup` module also includes a method for guessing the encoding of a document. This method works in conjunction with `chardet` and filters away HTML markup to make it more effective. Using the same downloaded HTML pages as above, we get:

```
>>> from bs4 import UnicodeDammit
>>> dr = UnicodeDammit(r)
>>> dr.original_encoding
'windows-1251'
>>> dc = UnicodeDammit(c)
>>> dc.original_encoding
'big5'
```

9.4 Exercises

1. Write a function that takes some webpage in some encoding as an argument. Your function should incrementally apply the `chardet.detect()` function to the page and report back how much of the page in bytes had to be

read to reach a certain confidence level (that you specify) to identify the encoding.

2. Do the same thing with `UnicodeDammit`. Which does better?
3. Choose a language and do some research on what encodings are typically used for it on the web. Then find examples of each on the web.
4. Tweak the webcrawler program from the preceding chapter so that it reports whether it finds the `<meta charset=...>` tag and what value it returns. Your code should save this as a separate field in the XML results file.
5. What special challenges occur with respect to text encoding when a language is written right to left? Explain the problem and show how it can be treated with Python.

Chapter 10

Objects

In this topic we introduce the general logic and structure of *object-oriented (OO) programming*. So far, we have treated programs as sequences or groups of commands. In this section, we will instead treat programs as a network of objects or things.

Some tasks really lend themselves to this sort of approach, others less so. Regardless, OO programming forces the programmer to think about their program differently and allows for separating the different parts of a program in a very different way as well.

We first introduce the general logic of classes and objects. We then treat the basic syntax of classes, focusing on the difference between classes and instances of classes. We then treat the mechanism of inheritance. Finally, we conclude with an extended example: syllabificaiton.

10.1 General logic

How do we go about treating some programming problem as a network of objects, rather than a sequence of commands? Let's take a concrete example. Imagine we want to read in some text file and parse it into sentences. Up to now, we might do it like this:

```
import re
```

```
#open and read file
f = open('alice.txt','r')
t = f.read()
f.close()
#strip header
t = t[10841:]
#split into sentences
ss = re.split('([\.?!])',t)
#show first 10
i = 0
while i < 20:
   s = ss[i] + ss[i+1] + '\n'
   print(s)
   i += 2
```

obj1.py

Here we take advantage of the fact that when we use `re.split()` and mark the match with parentheses, the splitting string is returned as well.

We might instead conceptualize this differently. We want to take a `File` object, create a `Text` object from that, and then extract `Sentence` objects from it. At the highest level, this might look like this:

```
#This is only schematic!

f = File('alice.txt')

t = Text(f)

ss = t.getSentences()

for s in ss[:10]:
   print(s)
```

obj2.py

Ultimately, the same work has to be done in both cases. The difference is in how we organize the code.

In general, we'll see that OO code tends to be longer. On the other hand, it can

often have a clearer logic. This means that when choosing whether to program in OO style, you are often choosing between writing less code that is less clear or more code that is more clear.

10.2 Classes and instances

When we create objects, we must distinguish the general from the specific. Thus, if we were to create word objects, we would want a general characterization of what a word is and then specific instances of that. The terminology used is that we create a general *class* which we can have *instances* of. At the simplest level, we might define a word class like this:

```
#a class definition
class Word:
   #this class has a variable
   info = "I'm a word."

#create an instance of that class
w = Word()
#access the variable from the instance
print('w:',w.info)
#access the variable from the class
print('Word:',Word.info)
```

obj3.py

We define a class with the keyword `class` followed by the class name and a colon. Properties of that class occur in the following indented block. Class names are customarily capitalized. In our `Word` class, we have only the variable `info`. A class is instantiated by invoking its name with parentheses. We can then extract the variable in the class body by suffixing that variable name to the instance `w` or to the class name `Word` itself. A variable like this that can be accessed from the class name or from any specific instance is referred to as a *class variable*.

Class definitions can include function definitions. A function defined in a class definition is a *method*. Here's a simple example:

```
#a class definition
class Word:
```

```
    #a method definition
    def whatami():
        #the body of that method
        return "I'm a word."

#invoke the method from class name
print('Word:',Word.whatami())
```

obj4.py

This does *not* work with an instance of the `Word` class. Thus an expression like `w.whatami()` generates an error. The problem is that `w.whatami()` is actually equivalent to something we might think of as `w.whatami(w)`. When you invoke a method from an instance of the class, it's as if the first argument to the method is the instance itself. Here's a version of the same program that uses this.

```
#a class definition
class Word:
    #an instance method
    def whatami(self):
        return "I'm a word."

#create an instance of the class
w = Word()
#call instance method
print('w:',w.whatami())
```

obj5.py

Here we define the `whatami()` method to take an argument, an argument that is never used. Now, when we call that method on the `w` instance of the class `Word`, everything works fine. It is customary to use the variable name `self` in just this case to indicate a variable that is bound to the instance of the class. In this case then, `self` is effectively a reference to `w`. In this case, we say that `whatami()` is an *instance method* because it refers to the particular instantiation of `Word` indirectly through the variable `self`.

We have seen class methods, instance methods, and class variables. There are then, of course, *instance variables* too. These are created and accessed in similar fashion to instance methods: by invoking the particular instance. The trick is that instance variables are only created and accessed through instance methods. Here's

an example:

```
#class definition
class Word:
    #instance method
    def whatami(self):
        #creating an instance variable
        self.x = "I'm a noun!"

#create an instance of the class
w = Word()
#call the instance method
w.whatami()
#print the instance variable
print(w.x)
```

obj6.py

Here we define the class `Word` to include the instance method `whatami()`. We know it's an instance method because it is defined with the customary instance variable `self`. When that method is invoked, it creates an instance variable `self.x` and assigns it a string value. We know that that's an instance variable because it is defined in an instance method and has the prefix `self`. We instantiate our class in the usual way and call the instance method `whatami()`. Since it is an instance method, it must be invoked with the instantiated variable as a prefix. Finally, we print out the value of the instance variable, again using the instantiated variable as a prefix.

This is a fair bit of terminology, so let's review and make sure we understand the terms and concepts.

Class definition. A class definition specifies a type of object. When specified, it has the word `class` followed by a (capitalized) word, followed by a colon, and then an indented block.

```
class MyClass:
    ...
```

Object or instance of a class. An object is an instance of some class. It is created by invoking the class name followed by parentheses.

```
x = MyClass()
```

Class method. A class method is a method specific to some class, but not specific to any instance of that class. It is defined in the body of a class definition and it does *not* refer to `self`. It is invoked with the class names as a prefix. For example:

```
class MyClass:
   def myMethod():
      print('wow')

MyClass.myMethod()
```

Instance method. An instance method is specific to some instance of a class. It is defined in a class definition body and includes `self` as its first argument. It is invoked with an instance of the class as a prefix. For example:

```
class MyClass:
   def myMethod(self):
      print('wow')

x = MyClass()
x.myMethod()
```

Class variable. A class variable is information relevant for an entire class. It is defined in the body of the class definition. It is invoked with the class name as a prefix. For example:

```
class MyClass:
   myVariable = 'wow'

print(MyClass.myVariable)
```

Instance variable. Finally, an instance variable is information relevant for some particular instance of a class. It is always created and manipulated through instance methods. It will always have `self` as a prefix in an instance method. If it is accessed directly from outside the class, it will have a class instance as a prefix. For example:

```
class MyClass:
   def setVal(self,x):
      self.n = x
   def getVal(self):
      return self.n
```

```
x = MyClass()
x.setVal(3)
print(x.getVal())
```

obj7.py

This last example shows an additional not unexpected feature we haven't seen yet: instance methods may take other arguments as well. Here we define two instance methods `setVal()` and `getVal()`. The `setVal()` method takes two arguments: `self` and one other and creates an instance variable `n` with the value of its second argument. The other method `getVal()` retrieves the value of that instance variable.

Let's now make sense of the distinction between instance and class variables. Imagine we want to extend our `Word` class to distinguish parts of speech and to keep track of how many words we have. We might do that like this:

```
#a class definition
class Word:
    #a class variable
    count = 0
    #an instance method
    def setPOS(self,x):
        #create an instance variable and
        #set it to x
        self.pos = x
        #increment the class variable count
        Word.count += 1

#make an instance of the class
a = Word()
#set its instance variable to 'noun'
a.setPOS('noun')
#make another instance
b = Word()
#set its instance variable to 'verb'
b.setPOS('verb')
#print the value of count associated with a
print('a count:',a.count)
```

```
#print the value of count associated with b
print('b count:',b.count)
#print the value of count associated with the class
print('Word count:',Word.count)
#print pos of a
print('a POS:',a.pos)
#print pos of b
print('b POS:',b.pos)
```

obj8.py

Here we define a class `Word` with a class variable `count` and an instance method `setPOS()`. The latter creates an instance variable `pos` and increments the value of `count`. We then instantiate the class twice for a noun and a verb. We then print the value of `count` associated with each instance and the class and the value of `pos` associated with each instance. As we expect, the values for `pos` are different, but the values for `count` are not; it is 2 in both cases.

Here, `count` keeps track of information relevant to the entire class: how many instances of it are there. On the other hand, `pos` keeps track of information relevant to a specific instance of a class: its own part of speech. This is a fairly typical structure and logic.

There is a more customary way to implement something like the above. You can define your class so that when you instantiate it, it does some sort of setting up. When a class is instantiated, Python automatically invokes a specific instance method if it exists: `__init__()`. If you include a definition for that method in your class definition, then that function will be run when the class is instantiated. Here's a very simple example:

```
class MyClass:
   def __init__(self):
      print('Instantiating MyClass!')

x = MyClass()
y = MyClass()
```

obj9.py

We can do more interesting work with this however. The following is a revision of `obj8.py`:

```
#class definition
class Word:
   #class variable
   count = 0
   #initializer takes an extra arg
   def __init__(self,x):
      #create instance variable, set to x
      self.pos = x
      #increment class count variable
      Word.count += 1

#instantiate with 'noun'
a = Word('noun')
#instantiate with 'verb'
b = Word('verb')
#continue as before
print('a count:',a.count)
print('b count:',b.count)
print('a POS:',a.pos)
print('b POS:',b.pos)
```

obj10.py

Here we've defined the `__init__()` method to take an extra argument which we use to set a value for the instance variable `pos`. We also increment the class variable `count`. Now we instantiate the class twice with different arguments. We get the same results when we print the contents of the variables associated with the two objects.

Let's now return to our example `obj2.py` on page 230. We can now flesh that out. We start by setting up preliminary class definitions so the code at least runs:

```
#class def for File
class File:
   #initialize with arg
   def __init__(self,s):
      #instance variable for filename from arg
      self.filename = s
   #method that will eventually extract text
   def getText(self):
```

```
        return 'some text'

#class def for Text
class Text:
    #initialize by getting text from File arg
    def __init__(self,f):
        self.strings = f.getText()
    #method that will eventually
    #return a list of sentences
    def getSentences(self):
        return ['1','2','3','4','5']

#instantiate File with filename
f = File('alice.txt')
#instantiate Text with file instance
t = Text(f)
#extract sentences from Text
ss = t.getSentences()
#print the first 3
for s in ss[:3]:
    print(s)
```

obj11.py

We start with a `File` class. We know that it has to be created with a string argument that represents the name of the file to be read. We therefore set up an `__init__()` method that takes a string argument and saves it as an instance variable `filename`.

The `File` object will be an argument to the `Text` object, so we create a function `getText()` that `Text` will call to extract the text from the `File` object.

We next create a `Text` object. It has to be instantiated with the `File` object as an argument, so we define an `__init__()` method that takes a `File` object as an argument. It then invokes that `File` object's `getText()` method to extract the text of the file and assigns that to an instance variable `strings`.

Finally, we know that we want to extract sentences from the `Text` object with a method `getSentences()`, so we create an instance method with that name that returns a list of dummy sentences.

This code runs, but does nothing interesting yet. It is the frame that we will build our code on. Note that the code that invokes these classes is fairly simple and that the real work of reading files, extracting text, etc., will be done "behind the scenes" in the definition of the classes.

Let's now flesh out the `File` class to actually open the file, read in the text, and remove the header.

```
#File class def
class File:
    #initialize with string argument
    def __init__(self,s):
        #open connection to fil
        f = open(s,'r')
        #read it all in and assign to
        #instance variable
        self.text = f.read()
        #close connection
        f.close()
        #stripo header
        self.text = self.text[10841:]
        #temp message to let us know this happened!
        print('<file read in>')
    #instance method to return the text
    def getText(self):
        return self.text

#Text class def
class Text:
    #initialize with File arg
    def __init__(self,f):
        #set instance variable
        self.strings = f.getText()
    #return sentences
    def getSentences(self):
        return ['1','2','3','4','5']

#create an instance of File
f = File('alice.txt')
```

```
#create an instance of Text
#from the File instance
t = Text(f)
#get the sentences
ss = t.getSentences()
#print the first 3
for s in ss[:3]:
   print(s)
```

obj12.py

Here we've fleshed out the `__init__()` method for `File` to read the file and strip the header. We've also added some temporary code to print out that this initialization has happened. We will of course delete this when we're done.

Let's now flesh out `Text`:

```
import re

#File def
class File:
   #initialize with file name
   def __init__(self,s):
      #read in file
      f = open(s,'r')
      self.text = f.read()
      f.close()
      #strip header
      self.text = self.text[10841:]
   #return the text of the file
   def getText(self):
      return self.text

#Text class def
class Text:
   #initialize with File instance arg
   def __init__(self,f):
      #get the text from File instance
      text = f.getText()
      #split on sentence breaks
```

```
        #saving split letter with parens!
        bits = re.split('([\.!?])',text)
        #instance variable list to save sentences
        self.sentences = []
        #assemble each sentence and add to list
        i = 0
        while i < len(bits)-1:
            self.sentences.append(bits[i]+bits[i+1])
            i += 2
    #return the sentences
    def getSentences(self):
        return self.sentences

#instance of File
f = File('alice.txt')
#instance of Text
t = Text(f)
#get sentences
ss = t.getSentences()
#print the first 10
for s in ss[:10]:
    print(s)
```

obj13.py

We first transfer the text from the `File` object via its `getText()` method to a variable `text`. This variable has no prefix, so it is entirely local to this function. We then split the text into sentence-sized units with `re.split()`. Since we've marked the splitting elements with parentheses, they are also in the resulting list, so we then concatenate sentences and their final punctuation in pairs and put them in an instance variable `sentences`. Since this is prefixed with `self`, it is preserved in the instance outside the `__init__()` function and available to the `getSentences()` instance method.

10.3 Inheritance

When you start writing fairly large programs in OO style, you end up with classes that are related. Python allows for you to express and simplify these relationships with *inheritance*. The basic idea is that if some class is specified to inherit from some other class, then the methods and variables of that latter class are available to the former. The syntax for this is for the inheriting class to specify the classes it inherits from in parentheses after the class name in the class definition. For example:

```
class MyParent:
    ...

class MyChild(MyParent):
    ...
```

Here the methods and variables of `MyParent` are available from `MyChild`. Here's a working example:

```
#parent class def
class MyParent:
    #class method
    def wow():
        print('wow!')
    #instance method with arg
    def printthis(self,x):
        print(x)

#child class def inherits from MyParent
class MyChild(MyParent):
    #nothing in the body
    pass

#make an instance of the child
a = MyChild()
#inherits parent class method
MyChild.wow()
#insherits parent instance method
a.printthis('oh?')
```

obj14.py

Here we define a class `MyParent` with a class method `wow()` and an instance method `printthis()`. We then define a class `MyChild` that inherits from `MyParent` and has no methods or variables itself; we indicate an empty class body with `pass`. We can call the methods of `MyParent` from `MyChild` as if they were part of `MyChild`.

The same is true of variables:

```
#parent class def
class MyParent:
    #class variable
    info = 'wow!'
    #instance method
    def oh(self):
        #creates an instance variable
        self.oh = 'yippee!'

#child class def
class MyChild(MyParent):
    #nothing in the body
    pass

#create an instance of child
a = MyChild()
#inherits parent class variable
print(MyChild.info)
#inherits parent instance method
a.oh()
#inherits parent instance variable
print(a.oh)
```

obj15.py

Here we've defined a class variable `info` for `MyParent`. We've also created an instance variable for it created via the instance method `oh()`. These are all available to the inheriting class `MyChild`. First we instantiate that class as `a`. We then print out the value of `info`, inherited from `MyParent`. We then run the `oh()` instance method, also inherited from `MyParent`. That creates an instance

variable `oh` in `a` which we access in the usual way.

Inheritance is transitive as well. The methods and variables of classes more than one "generation" back are also available. For example:

```
#grandparent class def
class MyGrandparent:
   #class variable
   info = 'wow'
   #instance method
   def hm(self,x):
      #instance variable
      self.oh = x

#parent class inherits from MyGrantparent
class MyParent(MyGrandparent):
   #nothing in body
   pass

#child class inherits from MyParent
class MyChild(MyParent):
   #nothing in body
   pass

#an instance of the child class
a = MyChild()
#inherits grandparent class variable
print(a.info)
#inherits grandparent instance method
a.hm('bummer')
#inherits grandparent instance variable
print(a.oh)
```

obj16.py

Here we define a class `MyGrandparent`. The class `MyParent` inherits from that and the class `MyChild` inherits from `MyParent`. Methods and variables of `MyGrandparent` are then available to `MyChild`.

You can override inherited methods and variables by defining them locally. Here's

a simple example:

```
#parent class def
class MyParent:
    #class variable
    info = 'wow'
    #instance method
    def mySet(self,x):
        #instance variable
        self.oh = x
    #initializing method
    def __init__(self,x):
        #another instance variable
        self.var = x

#child class def
class MyChild(MyParent):
    #instance method overrides parent method!
    def mySet(self,x):
        #instance variable
        self.oh = x+x

#create child instance
a = MyChild('ok')
#invoke child instance method (overriding parent)
a.mySet('hm')
#invoke parent class variable
print(MyChild.info)
#parent instance variable
print(a.var)
#child instance variable
print(a.oh)
```

obj17.py

Here we define `MyParent` with a class variable `info`. We also have an instance method `mySet` which sets a value for the instance variable `oh`. Finally, we have the `__init__()` method which sets a value for `var`.

These are all inherited by `MyChild`, but the `mySet()` method is overridden by

a new definition in `MyChild`. We now instantiate `MyChild` with the argument `'ok'`. Since the `__init__()` method is inherited and not overridden, this sets the value of the instance variable `var`. We then invoke the `mySet()` method, but since there is a local version in `MyChild`, that is the version that is used. This means that there is now an instance variable with the value `'hmhm'`. We then print out these values.

Finally, Python allows for multiple inheritance. You can specify multiple classes to inherit from. Here's a simple example:

```
#parent class def
class MyMom:
    #class variable
    info = 'wow'
    #instance method
    def mySet(self,x):
        #instance variable
        self.oh = x

#other parent class def
class MyDad:
    #initializer method
    def __init__(self,x):
        #instance variable
        self.var = x

#child class def multiply inherits
class MyChild(MyMom,MyDad):
    #nothing in body
    pass

#make an instance of the child
#uses initializer from MyDad
a = MyChild('ok')
#instance method from MyMom
a.mySet('hm')
#class variable from MyMom
print(MyChild.info)
#instance variable from MyDad
```

```
print(a.var)
#instance variable from MyMom
print(a.oh)
```

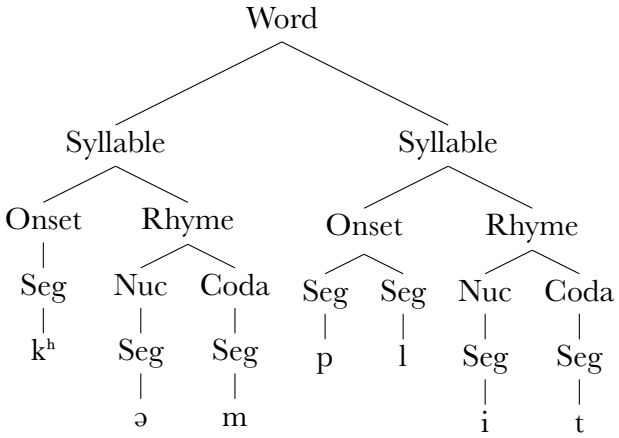
obj18.py

Here we define a class `MyMom` with a class variable, an instance method, and a consequent instance variable. We define another class `MyDad` with an `__init__()` method that creates an instance variable. The class `MyChild` is specified to inherit from both of these, so all of those variables and methods are available to it.

10.4 Syllabification

We illustrate OO in more detail with syllabification. We're going to build up a set of types that we can use to represent syllable structure. We might use these in a model of syllabification, a program that hyphenates, etc.

Let's assume our model of syllabification includes syllables, onsets, nuclei, codas, rhymes, and segments. We might think of a word like *complete* [kʰəmplit] as being parsed like this:



Let's begin with the idea that all of these elements are classes.

```
class Syllable:
   pass
class Onset:
   pass
```

```
class Nucleus:
   pass
class Coda:
   pass
class Rhyme:
   pass
class Segment:
   pass
```

obj19.py

It would be reasonable to assume that any element in this hierarchy can be pronounced and spelled. Rather than encode this in each, let's put this into a single class that all of these inherit from:

```
#parent class def
class Speech:
   #initialize with spelling, pronunciation
   def __init__(self,s,p):
      self.spelling = s
      self.pronunciation = p
   #return the spelling
   def spell(self):
      return self.spelling
   #return the pronunciation
   def pronounce(self):
      return self.pronunciation

#all classes inherit from Speech
class Syllable(Speech):
   pass
class Onset(Speech):
   pass
class Nucleus(Speech):
   pass
class Coda(Speech):
   pass
class Rhyme(Speech):
   pass
```

```
class Segment(Speech):
   pass
```

obj20.py

For `Segment`, the lowest level of the hierarchy, this suffices. We treat `obj20.py` as a module and instantiate it like this:

```
from obj20 import *

a = Segment('ng','ŋ')
print(a.spell())
print(a.pronounce())
```

obj21.py

For higher levels, there are two problems. First, some elements of the hierarchy allow more than one element in a row. For example, an onset can be comprised of zero or more consonants. Another issue is that there is a hierarchy. While onsets are comprised of segments, syllables, etc. are not directly made up of segments.

Let's address the first issue and revise the arguments to the `__init__()` method. First, we remove it from `Speech`. We then implement it in `Segment` to specify two string arguments.

```
#Speech class def
class Speech:
   #return spelling
   def spell(self):
      return self.spelling
   #return pronunciation
   def pronounce(self):
      return self.pronunciation

#everybody inherits from Speech
class Syllable(Speech):
   pass
class Onset(Speech):
   pass
class Nucleus(Speech):
   pass
```

```
class Coda(Speech):
   pass
class Rhyme(Speech):
   pass
class Segment(Speech):
   #initializer from spelling,pronunciation
   def __init__(self,s,p):
      #check that args are strings!
      if type(s) != str or type(p) != str:
         raise Exception('Usage: Segment(str,str)')
      #set instance variables
      self.spelling = s
      self.pronunciation = p
```

obj22.py

We use the `type()` function to check the type of the arguments to `__init__()`. We use the `raise` statement to generate an exception, an error, just in case either of the arguments is not a string.

We now turn to the elements that are built on top of segments: onsets, nuclei, codas. These all have the same general structure in that they are built on segments. Rather than repeat this in each of these classes, we create a new class `Subsyl` that specifies this. The `Subsyl` class will inherit from `Speech` and then `Onset`, `Nucleus`, and `Coda` will inherit from it.

```
#Speech class def
class Speech:
   #return spelling
   def spell(self):
      return self.spelling
   #return pronunciation
   def pronounce(self):
      return self.pronunciation

#Segment class def
class Segment(Speech):
   #initialize from spelling and pronunciation
   def __init__(self,s,p):
      #those have to be strings!
```

```
        if type(s) != str or type(p) != str:
            raise Exception('Usage: Segment(str,str)')
        #set instance variables
        self.spelling = s
        self.pronunciation = p

#general class for elements above segments
class Subsyl(Speech):
    #daughter elements are segments
    daughters = Segment
    #initializer from a list of segments
    def __init__(self,xs):
        #set instance variables
        self.spelling = ''
        self.pronunciation = ''
        #got through the argument list 1 by 1
        for x in xs:
            #check that they are segments
            if type(x) != self.daughters:
                raise Exception('Type error!')
            #concatenate spellings
            self.spelling += x.spelling
            #concatenate pronunciations
            self.pronunciation += x.pronunciation

#now inheriting from Subsyl
class Onset(Subsyl):
    pass
class Nucleus(Subsyl):
    pass
class Coda(Subsyl):
    pass
#still inheriting from Speech
class Rhyme(Speech):
    pass
class Syllable(Speech):
    pass
```

obj23.py

Here the `Subsyl` class defines what its daughters must look like: they must be of the class `Segment`. Its `__init__()` method takes a list as an argument. It then checks the type of each element in the list. If they are segments, then it extracts their spelling and pronunciation and adds them to its own spelling and pronunciation.

We can import this and test it out like this:

```
from obj23 import *

c = Segment('c','k')
l = Segment('l','l')
o = Onset([c,l])
print(o.spelling)
print(o.pronunciation)
```

obj24.py

We see that `Onset` functions correctly, inheriting from `Subsyl` directly and indirectly from `Speech`.

Nothing more need be done for `Onset`, `Nucleus`, and `Coda`. We turn then to rhymes and syllables. Rhymes require a nucleus and an optional coda. We capture this with a new `__init__()` method for `Rhyme` that takes an optional argument.

```
#speech class def
class Speech:
   #return spelling and pronunciation
   def spell(self):
      return self.spelling
   def pronounce(self):
      return self.pronunciation

#segment class def
class Segment(Speech):
   #initialize from strings
   def __init__(self,s,p):
      if type(s) != str or type(p) != str:
         raise Exception('Usage: Segment(str,str)')
```

```
        self.spelling = s
        self.pronunciation = p

#Subsyl class def
class Subsyl(Speech):
    #daughters are segments
    daughters = Segment
    #initialize from list of segments
    def __init__(self,xs):
        self.spelling = ''
        self.pronunciation = ''
        #check each element in list
        for x in xs:
            if type(x) != self.daughters:
                raise Exception('Type error for Subsyl!')
            #concatenate instance variables
            self.spelling += x.spelling
            self.pronunciation += x.pronunciation

#inherit from Subsyl
class Onset(Subsyl):
    pass
class Nucleus(Subsyl):
    pass
class Coda(Subsyl):
    pass

#Rhyme class def
class Rhyme(Speech):
    #initialize from Nucleus and optional Coda
    def __init__(self,n,c=''):
        #check type of Nucleus
        if type(n) != Nucleus:
            raise Exception('Type error for Rhyme!')
        #set instance variables
        self.spelling = n.spelling
        self.pronunciation = n.pronunciation
        #check if a coda argument is present
```

```
        if c != '':
            #check that it's the right type
            if type(c) != Coda:
                raise Exception('Type error for Rhyme!')
            #set instance variables
            self.spelling += c.spelling
            self.pronunciation += c.pronunciation

#still inherits from Speech
class Syllable(Speech):
    pass
```

obj25.py

Again, for caution's sake, we test this immediately:

```
from obj25 import *

a = Segment('a','a')
r = Segment('r','r')
t = Segment('t','t')
n = Nucleus([a])
c = Coda([r,t])
r = Rhyme(n,c)
print(r.spelling)
print(r.pronunciation)
```

obj26.py

We create three segments and then build a nucleus and a coda from them. We then assemble them into a rhyme and extract the spelling and pronunciation to make sure everything worked.

We now turn to `Syllable` which is straightforwardly similar to `Rhyme`:

```
#Speech class def
class Speech:
    #return spelling and pronunciation
    def spell(self):
        return self.spelling
    def pronounce(self):
```

```
        return self.pronunciation

#Segment class def
class Segment(Speech):
    #initialize from strings
    def __init__(self,s,p):
        if type(s) != str or type(p) != str:
            raise Exception('Usage: Segment(str,str)')
        #set instance variables
        self.spelling = s
        self.pronunciation = p

#Subsyl class def
class Subsyl(Speech):
    #daughters are Segment type
    daughters = Segment
    #initialize from list of Segments
    def __init__(self,xs):
        self.spelling = ''
        self.pronunciation = ''
        for x in xs:
            if type(x) != self.daughters:
                raise Exception('Type error for Subsyl!')
            #set instance variables by concatenating
            self.spelling += x.spelling
            self.pronunciation += x.pronunciation

#all inherit from Subsyl
class Onset(Subsyl):
    pass
class Nucleus(Subsyl):
    pass
class Coda(Subsyl):
    pass

#Rhyme class def
class Rhyme(Speech):
    #initialize from Nucleus and optional Coda
```

```
    def __init__(self,n,c=''):
        if type(n) != Nucleus:
            raise Exception('Type error for Rhyme!')
        self.spelling = n.spelling
        self.pronunciation = n.pronunciation
        if c != '':
            if type(c) != Coda:
                raise Exception('Type error for Rhyme!')
            self.spelling += c.spelling
            self.pronunciation += c.pronunciation

#Syllable class def
class Syllable(Speech):
    #initialize from Rhyme and optional Onset
    def __init__(self,r,o=''):
        #check Rhyme type
        if type(r) != Rhyme:
            raise Exception('Type error for Syllable!')
        #set instance variables
        self.spelling = r.spelling
        self.pronunciation = r.pronunciation
        #if onset arg is present
        if o != '':
            #check that it's an onset
            if type(o) != Onset:
                raise Exception('Type error for Syllable!')
            #concatenate with existing instance variables
            self.spelling = o.spelling + \
                self.spelling
            self.pronunciation = o.pronunciation + \
                self.pronunciation
```

obj27.py

The only odd part is that we must order the arguments to `__init__()` counterintuitively. This is because the onset is optional and optional arguments must occur on the right.) Again, we test this immediately:

```
from obj27 import *
```

```
k = Segment('c','kʰ')
a = Segment('a','a')
r = Segment('r','r')
t = Segment('t','t')
o = Onset([k])
n = Nucleus([a])
c = Coda([r,t])
r = Rhyme(n,c)
s = Syllable(r,o)
print(s.spelling)
print(s.pronunciation)
```

obj28.py

10.5 Exercises

1. Rewrite `obj13.py` using functions instead of classes.
2. What happens if a method with the same name appears in two classes and some other class inherits from both?
3. Give an example showing how multiple inheritence interacts with multi-generation inheritance. Explain how it works.
4. In our syllabification example above, the code for `Syllable` and `Rhyme` is redundant. This could be addressed by enriching the class hierarchy and factoring out the common parts here. Do this.
5. Write a class system to handle simple morphology in some language. You will want classes for `Stem`, `Prefix`, `Suffix`, `Morpheme`, and the like.
6. Use a class system and inheritance to model historical change. The idea is that languages inherit from other languages, but can innovate as well. Build a toy system with the right properties.

Chapter 11

GUIs

So far, all of our programs have been text-based. This means you run them from the terminal window and the output is either some text in that window or text in some file.

In this chapter we very briefly describe how to write Python programs with a *graphical user interface* (GUI). These are programs where your interaction with the program occurs through other input modes than simply typing text, e.g. buttons, menus, dialogs, and other mouse- or trackpad-based operations.

There are a host of systems you can use to do this with Python, but we will use *tkinter*. There are a number of reasons for this choice.

1. Tkinter is the oldest GUI for Python and quite stable, so code using it works and is not subject to version dependencies.
2. Tkinter is included in any Python distribution, so it is available regardless of what version of Python you're working with or what your operating system is.
3. Tkinter works "out of the box". There are no additional packages required to make it work.
4. Tkinter is relatively easy. While it may not have every GUI bell and whistle we might want, it's a good entry point for GUI programming generally.
5. Finally, there are a number of other languages that have essentially the same system for GUIs, e.g. Perl, Ruby, Tcl, etc.

There are some limitations of tkinter.

1. Some versions of tkinter only run if you also have the X11 windowing system installed. (This is available for all operating systems and you should see a warning if this is the case.)
2. Tkinter programs may not have a local "look and feel". That is, while you can have windows, labels, and buttons, they may not look quite like the normal elements of those sorts on your computer.
3. Tkinter is limited. Not all GUI widgets are available.
4. Finally, tkinter applications are interpreted programs just like other Python programs, so they will usually not be as fast as other GUI applications.

In this chapter we will outline the general logic of GUI programming and how it is done with tkinter. We will cover some of the more usual GUI elements, widgets, and how to make your program make use of those. We conclude with a GUI-version of our stemmer program from Section 7.2.

11.1 The general logic

We have seen two general models for programming so far. The first is *procedural*. We see programs as a sequence of commands executed in sequence, with control structures to govern that sequence.

The second model, introduced in the preceding chapter, is *object-oriented*. Here we see programs as a network of objects. A program is a set of class definitions and then, as much as possible, instantiation of those classes makes the program work.

In this chapter, we consider a third model: *event-driven* programming. On this view, we create a set of GUI elements or *widgets*. Those elements are then laid out and "wait" for user input.

The best way to understand this perhaps is to run an example. If you run the following program, it will generate the window below. (This is on a mac, using X11.)

```
from tkinter import *

#start tkinter
```

```
r = Tk()
#make a window
f = Frame(r)
f.pack()
#make a button
b = Button(f,
   padx=20,pady=10,
   text="Quit",command=quit)
b.pack(side=LEFT,
   padx=20,pady=20)
#wait for something to happen
mainloop()
```

gui1.py

The program does nothing until you click/press the button. When you do, the program ends.

The general structure of the code is as follows. First, we import from the `tkinter` module so we can use GUI elements. We then start the GUI with the `Tk()` command. We then create several GUI elements a `Frame` and a `Button`. We position them with the `pack()` method. In the case of the button, there are a number of variables that control its size, shape, and what it does. In addition, when we invoke `pack()` on it, there are additional variables that govern where it goes. The important point is that one of the variables we specify when we create the button is what it does, in this case `command=quit`.

Once those elements are specified and located on the screen we tell the program to wait for something to happen `mainloop()`. The program simply sits and waits

for the user to do something. Any activity of the user is noticed by `mainloop()`, but our program is written so that only a button click is attended to. In this case, a button click invokes the `quit()` function, which quits the program.

This then is the standard structure for a GUI-based program:

1. You create a set of GUI elements (widgets).
2. The widgets are specified for what functions apply if the user interacts with them.
3. You lay your widgets out in some fashion. This includes where they are in the window, whether they are "active" and available for user input, whether they are visible at all, etc.
4. Finally, you initiate the event loop, instructing the program to wait for user input.

There are complications that can occur, but this general view will suffice for our purposes.

One other issue is worth mentioning at this point. Tkinter is an interesting system because it actually uses another programming language. The Tcl programming language (Tool Command Language) includes a set of extensions for creating graphical user interfaces called Tk (widget toolkit). Tkinter makes the Tk widgets usable from Python. As we noted above, there are a number of other programming languages that do this as well. The important consequence of this is that GUI commands thus don't always look like other Python commands. Tkinter tries to minimize this, but it's still a fundamental reality of this system.

11.2 Some simple examples

In this section we describe a set of basic widgets, their properties, and options for how they can be placed in a window.

The simplest thing you can do with tkinter is nothing. You simply start the GUI system and wait for something to happen. If you do that, you'll get a blank window. The program ends when you close that window.

```
from tkinter import *
Tk()
```

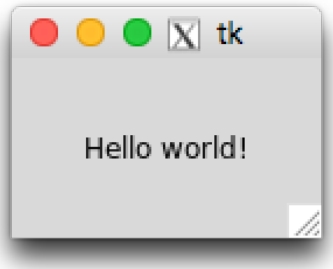
```
mainloop()
```

gui2.py

A very simple widget that you can add to your window is a label. It simply allows you to display some text in a window. Here's a simple example:

```
from tkinter import *

w = Tk()
l = Label(w,
   text='Hello world!',
   padx=30,pady=30)
l.pack()

mainloop()
```

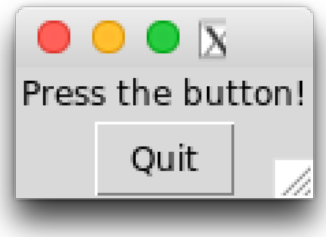
gui3.py



You can, of course, have both labels and buttons:

```
from tkinter import *

w = Tk()
l = Label(w,
   text='Press the button!')
l.pack()
b = Button(w,
   text='Quit',
   command=quit)
b.pack()

mainloop()
```

gui4.py



Notice how, in the absence of further specification, buttons and labels are just big enough to hold the text you specify. Similarly, the window is just big enough to hold them. Also note that, unless you specify otherwise, the widgets are laid out top to bottom in the window.

So far, we've only seen buttons that can quit the program, but if you can write a function for it, your button can initiate it. Here's a simple example where pressing a button prints something.

```
from tkinter import *

#function to print something
def wow(): print('wow!')

#start GUI
w = Tk()
#make a label
```

```
l = Label(w,
   text='Press either button!')
#place the label
l.pack()
#make a button
b1 = Button(w,
   text='Wow',
   command=wow)
#place the button
b1.pack()
#make another button
b2 = Button(w,
   text='Quit',
   command=quit)
#place the other button
b2.pack()

#go...
mainloop()
```

gui5.py

In fact, you can alter the content of your GUI with a button press by using the `configure()` method:

```
from tkinter import *

#variable to store number of button presses
count = 0
```

```
#function to update button presses
def wow():
   #we're updating the variable above, so
   #we have to specify that
   global count
   #upate the variable
   count += 1
   #reset the label below
   l.configure(text=count)

#start the GUI
w = Tk()
#make and place a label
l = Label(w,text=count)
l.pack()
#make and place a button
b1 = Button(w,
   text='Wow',
   command=wow)
b1.pack()
#make and place another button
b2 = Button(w,
   text='Quit',
   command=quit)
b2.pack()

#go...
mainloop()
```

gui6.py

Here the upper button changes the value of the label every time you press it. To do this, we first declare a variable `count` and assign it the value 0. We then define a function `wow()` that changes the value of that variable and then assigns the new value as the text of the label. There is an interesting quirk of Python here. If you try to change the value of a variable from outside of a function you must declare that it is an external variable with the `global` keyword. Interestingly, even though you are changing the value of the text of the label as well, you need not declare it as global. The rest of the program is as in the previous example.

11.3 Widget options

Widgets like buttons and labels have a number of shared options that can be set. We won't go through them all here, but they include:

background (bg) The background color.

foreground (fg) The foreground color, in the case of buttons and labels, this is the color of the text.

font What font to display the text in. The font is specified as a triple of name, size, and (optionally) style, e.g. `('times', 14, 'italic')`.

anchor What edge of the widget to align the text to. This only has a visible effect if you force the widget to be bigger than the text. It takes the values: `N`, `NE`, `E`, `SE`, `S`, `SW`, `W`, `NW`. The default is `CENTER`.

command What command to execute, only relevant for buttons so far.

padx How much extra space to leave on the x-axis.

pady How much extra space to leave on the y-axis.

textvariable This can be specified as a particular variable. If the value of the variable changes, the text will change without having to invoke `configure()`.

To see some of these in action, the following program dynamically manipulates foreground, background, and font of a label.

```
from tkinter import *

#list of colors
cs = ['red','blue','green']
#list of fonts
fs = [('times',14,'italic'),
('monaco',24),
('Comic Sans MS',30)]

#current foreground, background, and color
fgval = 0
bgval = 0
fontval = 0

#change the *val variables to next leval value
def switch(x):
   if x < 2: x += 1
   else: x = 0
   return x

#change the font
def fval():
   global fontval
   fontval = switch(fontval)
   l.configure(font=fs[fontval])

#change the foreground
def fgcol():
```

```
    global fgval
    fgval = switch(fgval)
    l.configure(fg=cs[fgval])

#change the background
def bgcol():
    global bgval
    bgval = switch(bgval)
    l.configure(bg=cs[bgval])

#start the GUI
w = Tk()
#make and place a label
l = Label(w,
    text='I am a label',
    fg=cs[fgval],
    bg=cs[bgval],
    font=fs[fontval],
    padx=30,pady=30)
l.pack()
#button to change foreground
b1 = Button(w,
    text='Foreground',
    command=fgcol)
b1.pack()
#button to change background
b2 = Button(w,
    text='Background',
    command=bgcol)
b2.pack()
#button to change font
b3 = Button(w,
    text='Font',
    command=fval)
b3.pack()
b4 = Button(w,
    text='Quit',
    command=quit)
```

```
b4.pack()

#go...
mainloop()
```

gui7.py

First we define a set of three colors and a set of three fonts. (Note that the fonts available may vary from system to system.) We then define three variables to keep track of the current colors for foreground and background and the current font. If you look down at the values for the label, you'll see we use these variables as indices into the lists of colors and fonts. For example, `cs[fgval]` gives the current value of the foreground color. The first three buttons rotate through those values every time you click the button. Thus the three buttons together allow you to see all combinations of these values for foreground, background, and font.

The three buttons call the functions `fval()`, `fgcol()`, and `bgcol()` which all work the same way, so we'll just talk about `fval()`. When the relevant button is pressed, this function collects the current value of `fontval` which, tells us what the current font is. We then use the `switch()` function to increment the value of `fontval`. If `fontval` is already at its maximum of 2, the `switch()` function sets it to 0. We then use `configure()` to update the font of the label. The other two functions, `fgcol()`, and `bgcol()`, work the same way.

Let's now look at the `textvariable` property. This allows us to dynamically alter the content of a widget without using `configure()`. To use it you must set up a special tkinter variable. When that variable is associated with some widget's `textvariable` and that variable changes, the widget will automatically update.

The trick is that this has to be a special tkinter variable, e.g. an integer `IntVar`, a string `StringVar`, etc. To use one of these, it must be declared in advance, but

after the GUI has started. For example, `x = IntVar()`. In addition, to access the value of one of these you must use a special method, i.e. `x.get()`. Similarly, to set the value, you must use another special method, i.e. `x.set(...)`. The following program exemplifies:

```
from tkinter import *

#start gui
w = Tk()

#create a tkinter integer variable
count = IntVar(w)
#set it to 0
count.set(0)

#function to increment count variable
def wow():
    #get the current value + 1
    c = count.get() + 1
    #re-set the count variable
    count.set(c)

#a label that's tagged for the count variable
l = Label(w,textvariable=count)
l.pack()
#a button
b1 = Button(w,
    text='Wow',
    command=wow)
b1.pack()
#another button
b2 = Button(w,
    text='Quit',
    command=quit)
b2.pack()

#go...
mainloop()
```

gui8.py

Here we declare `count` as an `IntVar` and then set its value with `set()`. The relevant button calls the function `wow()`. That function simply increments the value of `count` which automatically updates the displayed value of the label.

11.4 Packing options

We've discussed some simple widgets and their basic attributes. We now turn to laying widgets out in a window or other container.

There are three basic ways to lay things out. The `place()` method allows you to specify precise pixel locations in a window. The `grid()` method splits a window into a grid and lets you place widgets in any specific cell. In this section, we consider the easiest and most common method: `pack()`. This method has a number of basic options:

expand Can be set to `TRUE` or `FALSE`. If `TRUE`, the widget moves to fill available space.

fill Does the widget fill space allocated to it: `NONE` default, `X` fill horizontally, `Y` fill vertically, or `BOTH` fill both.

side What side of the containder does the widget pack against: `TOP` default, `BOTTOM`, `LEFT`, or `RIGHT`.

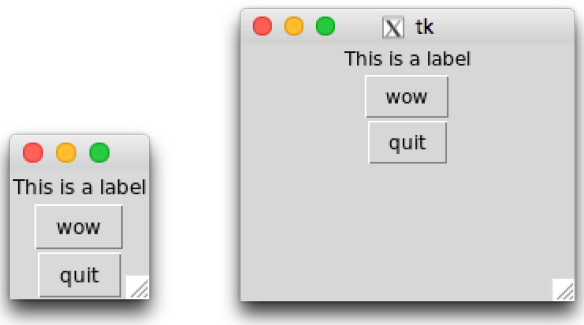
padx, pady How much extra space on the x- or y-axis should there be outside the widget?

ipadx, ipady How much extra space on the x- or y-axis should there be 'inside" the widget?

Here is a very simple example of a GUI with a label and two buttons packed using default values.

```
from tkinter import *

#start GUI
w = Tk()
#make and place label
l = Label(text='This is a label')
l.pack()
#make and place button
b1 = Button(text='wow',
   command=lambda: print('wow'))
b1.pack()
#make and place another button
b2 = Button(text='quit',command=quit)
b2.pack()

#go...
mainloop()
```

gui9.py



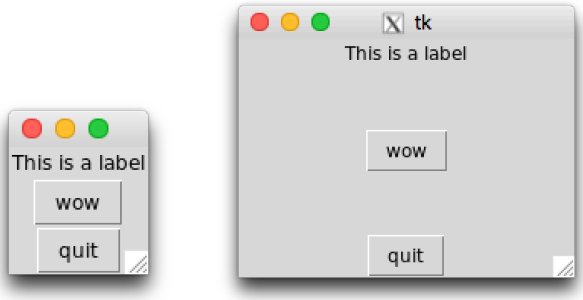
Note how the three widgets are sized proportionally to the text they display. Notice

too that they are organized top-down in the order they were packed. Finally, notice how when we make the window bigger by dragging the lower right corner, the three widgets stay pressed against the upper edge.

Let's now set `expand` to `TRUE` for one of the buttons:

```
from tkinter import *

#start GUI
w = Tk()
#make and place a label
l = Label(text='This is a label')
l.pack()
#make a button
b1 = Button(text='wow',
   command=lambda: print('wow'))
#place with expand=TRUE
b1.pack(expand=TRUE)
#make and place another button
b2 = Button(text='quit',command=quit)
b2.pack()

#go...
mainloop()
```

gui10.py

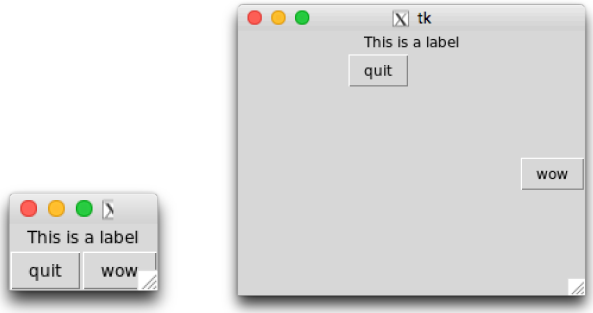


We see no difference when the window initially displays, but when we resize it, we see that the area around `b1` expands to fill the available space pushing `b2` to the bottom.

We can also change what side widgets line up against. Here we set `side` to `RIGHT` for `b1`:

```
from tkinter import *

#all the same except packfor b1
w = Tk()
l = Label(text='This is a label')
l.pack()
b1 = Button(text='wow',
   command=lambda: print('wow'))
#here's the difference
b1.pack(side=RIGHT)
b2 = Button(text='quit',command=quit)
b2.pack()

mainloop()
```

gui11.py



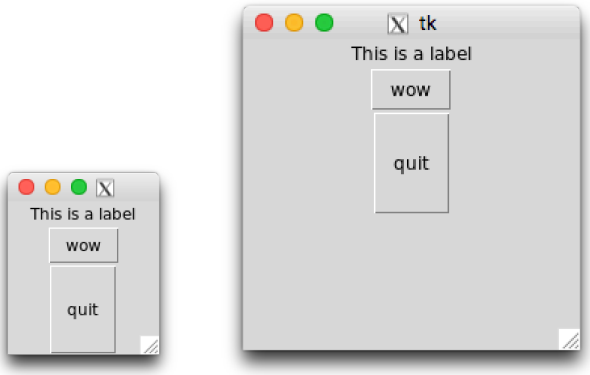
Here, packing `b1` to the right puts it next to `b2` when the window initially displays, but all the way to the right when the window is resized.

Let's now look at the padding options. In the following program, we set `padx` for `b1` and `ipady` for `b2`:

```
from tkinter import *

#start GUI
w = Tk()
#make and place label
```

```
l = Label(text='This is a label')
l.pack()
#make a button
b1 = Button(text='wow',
   command=lambda: print('wow'))
#padding on x-axis
b1.pack(padx=30)
#make another button
b2 = Button(text='quit',command=quit)
#padding on y-axis
b2.pack(ipady=20)

#go...
mainloop()
```

gui12.py



Here `padx` puts extra space to the left annd right of `b1`, making the initial window wider. The setting for `ipady` for `b2` makes the button itself taller. When the window is resized, we no longer see the effect of `padx`.

11.5 More widgets

Let's now consider just a couple more widgets. First, we have the specialized `messagebox` widget. This comes in three varieties: error, warning, info. The following program exemplifies:

```
from tkinter import *
#special import for messageboxes!
from tkinter import messagebox

#start GUI
root = Tk()
#hide main window
root.withdraw()
#error message
messagebox.showerror(
   "Error","An error occurred")
#warning message
messagebox.showwarning(
   "Warning","You are warned!")
#info message
messagebox.showinfo(
   "Info","You are informed.")
#quit
quit()
```

gui13.py

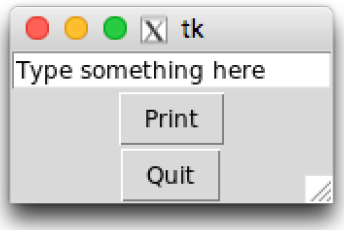
Note that we have used the `withdraw()` method so the main window is not displayed.

One very useful widget is `Entry` which allows you to enter text. The following program creates an `Entry` field bound to a textvariable `t`. When `b1` is pressed, the value of `t` is printed. The value of `t` is whatever text is in the `Entry` widget.

```
from tkinter import *

#function to print Entry contents
def printit():
   print('Entry:',t.get())

#start GUI
```

```
r = Tk()
#set up stringvar AFTER GUI starts
t = StringVar()
#set value of t
t.set('Type something here')
#Entry field linked to t variable
e = Entry(r,textvariable=t)
e.pack()
#button to print contents of Entry
b1 = Button(text='Print',
   command=printit)
b1.pack()
#quit button
b2 = Button(text='Quit',
   command=quit)
b2.pack()

mainloop()
```

gui14.py



One useful feature for an `Entry` widget is to invoke a function if the user types `return` after typing in something. It's a little tricky to do this: you have to bind the return to the entry field. One complication is that the name of the return key is `'<return>'`. The other complication is that the `bind()` method automatically passes the "event" as an argument to the function. In this case, our `printit()` function does not take an argument. We use a `lambda` expression to capture that argument as `x` and then, effectively, discard it before invoking `printit()`. Here's the code:

```
from tkinter import *
```

```
#function to print contents of Entry
def printit():
   print('Entry:',t.get())

#start GUI
r = Tk()
#string variable for Entry
t = StringVar()
#set value of variable
t.set('Type something here')
#Entry field
e = Entry(r,textvariable=t)
e.pack()
#link Entry to return key!
e.bind('<Return>', lambda x: printit())
#one button
b1 = Button(text='Print',
   command=printit)
b1.pack()
#another button
b2 = Button(text='Quit',
   command=quit)
b2.pack()

#go...
mainloop()
```

gui15.py

The window looks the same here as in the previous case.

11.6 Stemming with a GUI

Recall the stemming program we built in Section 7.2. The final version of the code `manip19.py` assembled everything together in a function `stem()` and then called that function on a word given as a command-line argument.

Our first step is to remove the code that runs `stem()` on a command-line argu-

ment (the last three lines). This new program, `gui16.py` (not shown here), can then be imported by the GUI we will develop here.

Let's build up our GUI in steps. First, we want a window and a button to quit the program:

```
from tkinter import *
import gui16

r = Tk()
b1 = Button(text='Quit',command=quit)
b1.pack()
mainloop()
```

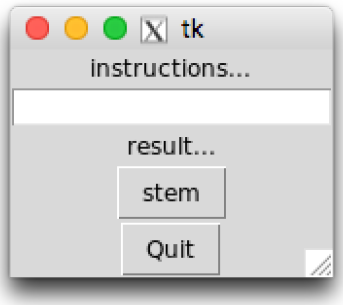
gui17.py

Let's have a `Label` that displays instructions to the user, an `Entry` that the user will type a word into, another button that will apply `stem()` to the word typed in the entry, and finally another `Label` to display the result:

```
from tkinter import *
#import stemmer code
import gui16

#start GUI
r = Tk()
#label for instructions
linfo = Label(text='instructions...')
linfo.pack()
#entry for the the word to stem
e = Entry()
e.pack()
#where we'll put the result
```

```
lres = Label(text='result...')
lres.pack()
#apply the stemmer code
bstem = Button(text='Stem')
bstem.pack()
#quit
bquit = Button(text='Quit',command=quit)
bquit.pack()
#go...
mainloop()
```

gui18.py

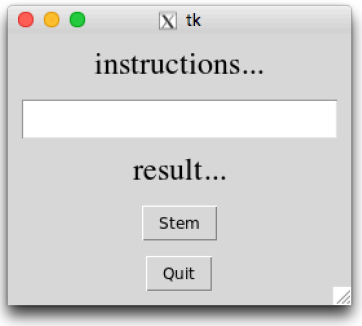


Only the `bquit` button does anything at this stage, but we can assess whether we have all the elements we need and whether they are laid out to our satisfaction. The following revision tweaks the widgets and their placement to match my own personal esthetic.

```
from tkinter import *
#import stemmer code
import gui16

#a pleasing font
f = ('times',18)

#start GUI
r = Tk()
#instructions in pleasing font
linfo = Label(text='instructions...',font=f)
#put some space on all sides
```

```
linfo.pack(pady=10,padx=10)
#entry in the same font
e = Entry(font=f)
#a little space on the side
e.pack(padx=10)
#result goes here in the same font
lres = Label(text='result...',font=f)
#a little space above and below
lres.pack(pady=10)
#the button to do everything
bstem = Button(text='Stem')
bstem.pack()
#quit button
bquit = Button(text='Quit',command=quit)
bquit.pack(pady=10)
#go...
mainloop()
```

gui19.py

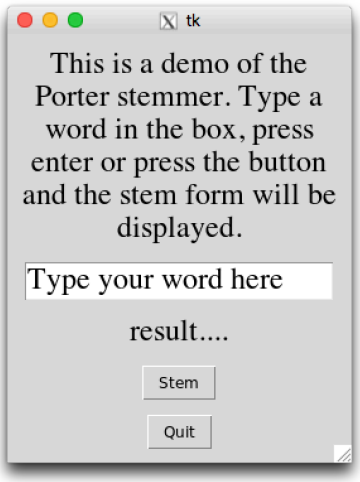


Let's now add the text of our instructions and textvariables for the `Entry` and second `Label`:

```
from tkinter import *
#the stemming code
import gui16

#more verbose instructions
instructions = '''This is a demo of the
```

```
Porter stemmer. Type a
word in the box, press
enter or press the button
and the stem form will be
displayed.'''

#that pleasing font again
f = ('times',18)

#start the GUI
r = Tk()

#text variable for the entry
ev = StringVar()
ev.set('Type your word here')
#text variable for the result
lv = StringVar()
lv.set('result....')

#instruction label
linfo = Label(text=instructions,font=f)
linfo.pack(pady=10,padx=10)
#entry variable tied to ev
e = Entry(font=f,textvariable=ev)
e.pack(padx=10)
#result variable tied to lv
lres = Label(textvariable=lv,font=f)
lres.pack(pady=10)
#the button that does everything
bstem = Button(text='Stem')
bstem.pack()
#quit button
bquit = Button(text='Quit',command=quit)
bquit.pack(pady=10)
#go...
mainloop()
```

gui20.py

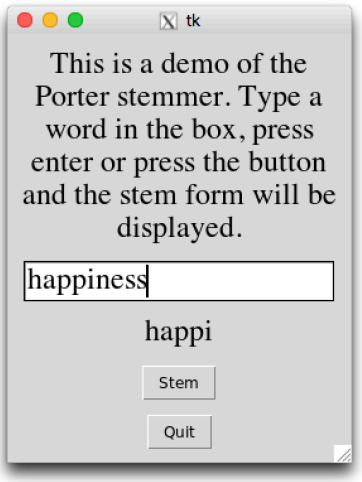


We now add the function called by `bstem` to invoke the stemmer.

```
from tkinter import *
#import for stemming code
import gui16

#instructions
instructions = '''This is a demo of the
Porter stemmer. Type a
word in the box, press
enter or press the button
and the stem form will be
displayed.'''

#pleasing font
f = ('times',18)

#invoking the stemming function
def guistem():
    #get what the user entered
    w = ev.get()
    #stem it
    res = gui16.stem(w)
    #display the result
```

```
    lv.set(res)

#start the gui
r = Tk()

#entry textvariable
ev = StringVar()
ev.set('Type your word here')
#result textvariable
lv = StringVar()
lv.set('result....')

#make and place instructoins
linfo = Label(text=instructions,font=f)
linfo.pack(pady=10,padx=10)
#make and place user entry
e = Entry(font=f,textvariable=ev)
e.pack(padx=10)
#make and place result label
lres = Label(textvariable=lv,font=f)
lres.pack(pady=10)
#stemming button
bstem = Button(text='Stem',command=guistem)
bstem.pack()
#quit button
bquit = Button(text='Quit',command=quit)
bquit.pack(pady=10)
#go...
mainloop()
```

gui21.py



The function is actually extremely simple. It collects the contents of the `Entry`, applies the `stem()` function to it, and then sets the value of the second label.

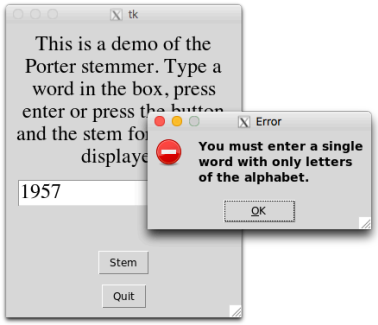
Finally, we add some error checking. What happens if the user enters nothing in the entry box, enters more than one word, enters non-alphabetic letters. We expand the `guistem()` function to respond to these errors.

```
from tkinter import *
#import specifically for messagebox
from tkinter import messagebox
#import for stemming code
import gui16

#the instructions
instructions = '''This is a demo of the
Porter stemmer. Type a
word in the box, press
enter or press the button
and the stem form will be
displayed.'''

#an error message
error = '''You must enter a single
word with only letters
of the alphabet.'''
```

```
#the pleasing font
f = ('times',18)

#function for the stemming button
def guistem():
    #get what the user entered
    w = ev.get()
    #check if it's a single word
    if re.search('^[a-zA-Z]+$',w):
        #if so stem it
        res = gui16.stem(w)
        #display result
        lv.set(res)
    #if not...
    else:
        #set result to nothing
        lv.set('')
        #display the error message
        messagebox.showerror('Error',error)

#start the GUI
r = Tk()

#textvariable for entry
ev = StringVar()
ev.set('Type your word here')
#textvariable for result
lv = StringVar()
lv.set('result....')

#label for instructions
linfo = Label(text=instructions,font=f)
linfo.pack(pady=10,padx=10)
#entry for the word to stem
e = Entry(font=f,textvariable=ev)
e.pack(padx=10)
#label for result
```

```
lres = Label(textvariable=lv,font=f)
lres.pack(pady=10)
#button to trigger stemming
bstem = Button(text='Stem',command=guistem)
bstem.pack()
#quit button
bquit = Button(text='Quit',command=quit)
bquit.pack(pady=10)
#go...
mainloop()
```

gui22.py



The change is fairly simple. We retrieve whatever is in the `Entry` and check if it is entirely letters of the alphabet. If so, we proceed as before. If not, we set the result `Label` to `''` and we display an error `messagebox`.

11.7 Exercises

1. There are a number of other widgets we haven't discussed. Research these on the web, choose one, and write a program that uses it.
2. Tweak the code for `gui22.py` so that if the user enters more than one word, each one will be stemmed and displayed.
3. Our final program in this chapter created a GUI for a big program from a preceding chapter. Do this for another of those larger programs.
4. Buttons can be *active* or *inactive*. Inactive buttons cannot be pressed. Write a

program that manipulates this.