


Quick answers to common problems

# Programming ArcGIS with Python Cookbook

## *Second Edition*

Over 85 hands-on recipes to teach you how to automate your ArcGIS for Desktop geoprocessing tasks using Python

**Eric Pimpler**

[PACKT] PUBLISHING open source* community experience distilled

## In this package, you will find:

- The author biography
- A preview chapter from the book, Chapter 1 '**Fundamentals of the Python Language for ArcGIS**'
- A synopsis of the book's content
- More information on **Programming ArcGIS with Python Cookbook Second Edition**

# About the Author

**Eric Pimpler** is the founder and owner of GeoSpatial Training Services (`http://geospatialtraining.com/`) and has over 20 years of experience implementing and teaching GIS solutions using Esri, Google Earth/Maps, open source technology. Currently, Eric is focusing on ArcGIS scripting with Python and the development of custom ArcGIS Server web and mobile applications using JavaScript. Eric is the author of *Programming ArcGIS with Python Cookbook and Building Web* and *Mobile ArcGIS Server Applications with JavaScript*, both by *Packt Publishing*.

Eric has a bachelor's degree in geography from Texas A&M University and a master's degree in applied geography with a focus on GIS from Texas State University.

# Preface

ArcGIS is an industry-standard geographic information system from Esri.

This book will show you how to use the Python programming language to create geoprocessing scripts, tools, and shortcuts for the ArcGIS for Desktop environment.

It will make you a more effective and efficient GIS professional by showing you how to use the Python programming language with ArcGIS for Desktop to automate geoprocessing tasks, manage map documents and layers, find and fix broken data links, edit data in feature classes and tables, and much more.

*Programming ArcGIS with Python Cookbook Second Edition*, starts by covering fundamental Python programming concepts in an ArcGIS for Desktop context. Using a how-to instruction style, you'll then learn how to use Python to automate common important ArcGIS geoprocessing tasks.

In this book, you will also cover specific ArcGIS scripting topics that will help save you time and effort when working with ArcGIS. Topics include managing map document files, automating map production and printing, finding and fixing broken data sources, creating custom geoprocessing tools, and working with feature classes and tables, among others.

In *Programming ArcGIS with Python Cookbook Second Edition*, you'll learn how to write geoprocessing scripts using a pragmatic approach designed around accomplishing specific tasks in a cookbook style format.

# What this book covers

*Chapter 1*, *Fundamentals of the Python Language for ArcGIS*, will cover many of the basic language constructs found in Python. Initially, you'll learn how to create new Python scripts or edit existing scripts. From there, you'll get into language features, such as adding comments to your code, variables, and the built-in typing systems that makes coding with Python easy and compact. Furthermore, we'll look at the various built-in data types that Python offers, such as strings, numbers, lists, and dictionaries. In addition to this, we'll cover statements, including decision support and looping structures for making decisions in your code, and/or looping through a code block multiple times.

*Chapter 2*, *Managing Map Documents and Layers*, will use the ArcPy mapping module to manage map document and layer files. You will learn how to add and remove geographic layers from map document files, insert layers into data frames, and move layers around within the map document. You will also learn how to update layer properties and symbology.

*Chapter 3*, *Finding and Fixing Broken Data Links,* will teach you how to generate a list of broken data sources in a map document file and apply various ArcPy mapping functions to fix these data sources. You will learn how to automate the process of fixing data sources across many map documents.

*Chapter 4*, *Automating Map Production and Printing*, will teach you how to automate the process of creating production-quality maps. These maps can then be printed, exported to image file formats, or exported to PDF files for inclusion in map books.

*Chapter 5*, *Executing Geoprocessing Tools from Scripts*, will teach you how to write scripts that access and run geoprocessing tools provided by ArcGIS.

*Chapter 6*, *Creating Custom Geoprocessing Tools*, will teach you how to create custom geoprocessing tools that can be added to ArcGIS and shared with other users. Custom geoprocessing tools are attached to a Python script that processes or analyzes geographic data in some way.

*Chapter 7*, *Querying and Selecting Data*, will teach you how to execute the Select by Attribute and Select by Location geoprocessing tools from a script to select features and records. You will learn how to construct queries that supply an optional where clause for the Select by Attribute tool. The use of feature layers and table views as temporary datasets will also be covered.

*Chapter 8*, *Using the ArcPy Data Access Module with Feature Classes and Tables*, will teach you how to create geoprocessing scripts that select, insert, or update data from geographic data layers and tables. With the new ArcGIS 10.1 Data Access module, geoprocessing scripts can create in-memory tables of data, called cursors, from feature classes and tables. You will learn how to create various types of cursors, including search, insert, and update.

*Chapter 9*, *Listing and Describing GIS Data*, will teach you how to obtain descriptive information about geographic datasets through the use of the ArcPy Describe function. As the first step in a multistep process, geoprocessing scripts frequently require that a list of geographic data be generated followed by various geoprocessing operations that can be run against these datasets.

*Chapter 10*, *Customizing the ArcGIS Interface with Add-ins*, will teach you how to customize the ArcGIS interface through the creation of Python add-ins. Add-ins provide a way of adding user interface items to ArcGIS for Desktop through a modular code base designed to perform specific actions. Interface components can include buttons, tools, toolbars, menus, combo boxes, tool palettes, and application extensions. Add-ins are created using Python scripts and an XML file that define how the user interface should appear.

*Chapter 11*, *Error Handling and Troubleshooting*, will teach you how to gracefully handle errors and exceptions as they occur while a geoprocessing script is executing. ArcPy and Python errors can be trapped with the Python try/except structure and handled accordingly.

*Chapter 12*, *Using Python for Advanced ArcGIS*, covers the use of the ArcGIS REST API with Python to access services exposed by ArcGIS Server and ArcGIS Online. You will learn how to make HTTP requests and parse the responses, export maps, query map services, perform geocoding, and more. Also covered in this chapter are some miscellaneous topics related to ArcPy FieldMap and FieldMappings, as well as working with ValueTables.

*Chapter 13*, *Using Python with ArcGIS Pro*, covers some distinctions between the new ArcGIS Pro environment and ArcGIS for Desktop related to Python and, in particular, the Python Window for writing and executing code.

*Appendix A*, *Automating Python Scripts*, will teach you how to schedule geoprocessing scripts to run at a prescribed time. Many geoprocessing scripts take a long time to fully execute and need to be scheduled to run during nonworking hours on a regular basis. You will learn how to create batch files containing geoprocessing scripts and execute these at a prescribed time.

*Appendix B*, *Five Python Recipes Every GIS Programmer Should Know*, will teach you how to write scripts that perform various general purpose tasks with Python. Tasks, such as reading and writing delimited text files, sending e-mails, interacting with FTP servers, creating ZIP files, and reading and writing JSON and XML files, are common. Every GIS programmer should know how to write Python scripts that incorporate these functionalities.

# 1

# Fundamentals of the Python Language for ArcGIS

Python supports many of the programming constructs found in other languages. In this chapter, we'll cover many of the basic language constructs found in Python. Initially, we'll cover how to create new Python scripts and edit existing scripts. From there, we'll delve into language features, such as adding comments to your code, creating and assigning data to variables, and built-in variable typing with Python, which makes coding with Python easy and compact.

Next, we'll look at the various built-in data types that Python offers, such as strings, numbers, lists, and dictionaries. Classes and objects are a fundamental concept in object-oriented programming and in the Python language. We'll introduce you to these complex data structures, which you'll use extensively when you write geoprocessing scripts with ArcGIS.

In addition to this, we'll cover statements, including decision support and looping structures to make decisions in your code, and/or looping through a code block multiple times along with the `with` statement, which is used extensively with the `cursor` objects from the ArcPy data access module that are used to insert, search, and update data. Finally, you'll learn how to access modules that provide additional functionality to the Python language. By the end of this chapter, you will have learned the following:

- How to create and edit new Python scripts in IDLE
- How to create and edit scripts in the ArcGIS Python window
- The language features of Python
- Comments and data variables
- Built-in data types (strings, numbers, lists, and dictionaries)

- Complex data structures
- Looping structures
- Additional Python functionalities

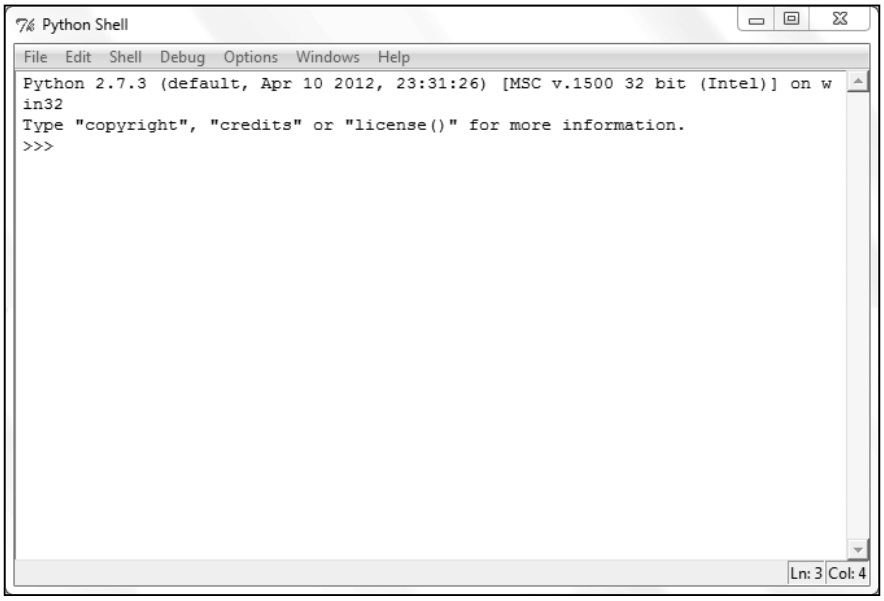
# Using IDLE for Python script development

As mentioned in the preface, when you install ArcGIS for Desktop, Python is also installed along with a tool called **IDLE** that allows you to write your own code. IDLE stands for **Integrated DeveLopment Environment**. Since it is available with every ArcGIS for Desktop installation, we'll use IDLE for many of the scripts that we write in this book along with the Python window embedded in ArcGIS for Desktop. As you progress as a programmer, you may find other development tools that you prefer over IDLE. There are many other development environments that you may want to consider, including PyScripter, Wingware, Komodo, and others. The development environment you choose is really a matter of preference. You can write your code in any of these tools.

## The Python shell window

To start the IDLE development environment for Python, you can navigate to **Start** | **All Programs** | **ArcGIS** | **Python 2.7** | **IDLE**. Please note that the version of Python installed with ArcGIS will differ depending upon the ArcGIS version that you have installed. For example, ArcGIS 10.3 uses Python 2.7, whereas ArcGIS 10.0 uses version 2.6 of Python.

A Python shell window similar to this screenshot will be displayed:

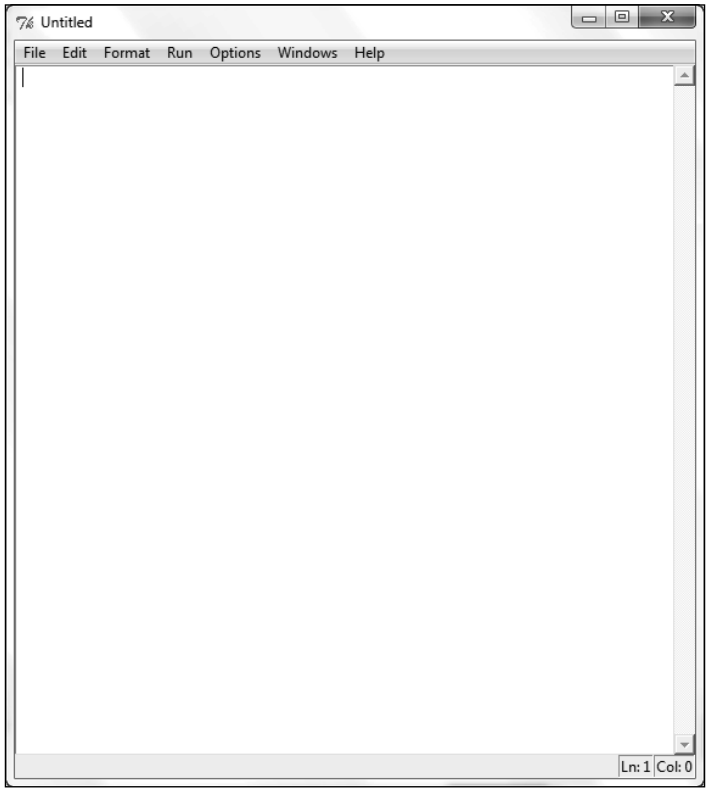


The Python shell window is used for output and error messages generated by scripts. A common mistake for beginners is to assume that the geoprocessing scripts will be written in this shell window. This is not the case. You will need to create a separate code window to hold your scripts.

Although the shell window isn't used to write entire scripts, it can be used to interactively write code and get immediate feedback. ArcGIS has a built-in Python shell window that you can use in a similar way. We'll examine the ArcGIS Python window in the next chapter.

## The Python script window

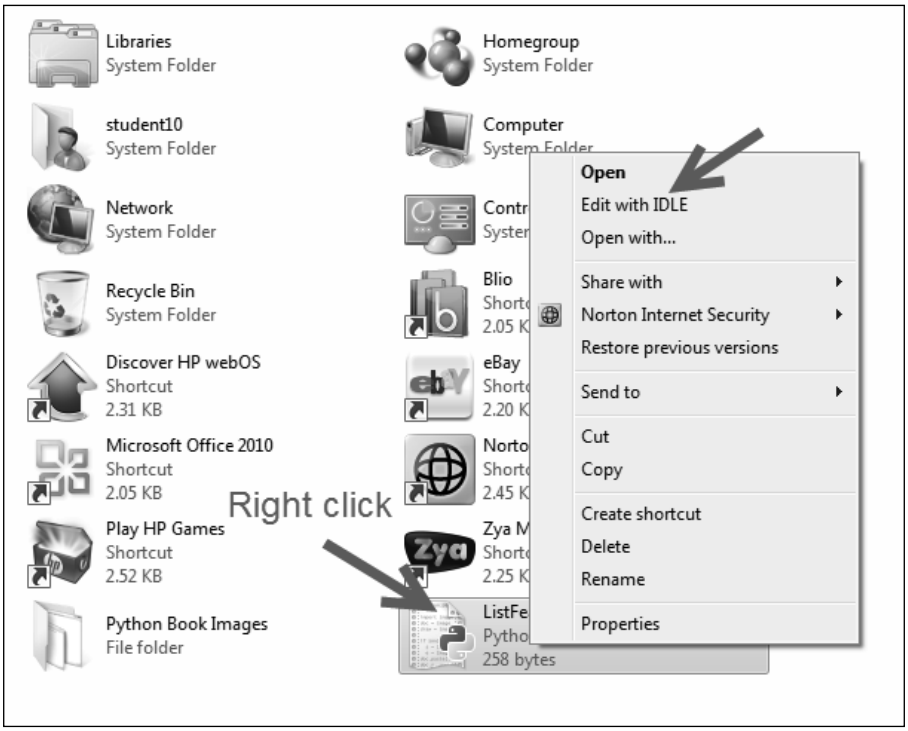
Your scripts will be written in IDLE inside a separate window known as the **Python script window**. To create a new code window, navigate to **File** | **New Window** from the IDLE shell window. A window similar to this will be displayed:



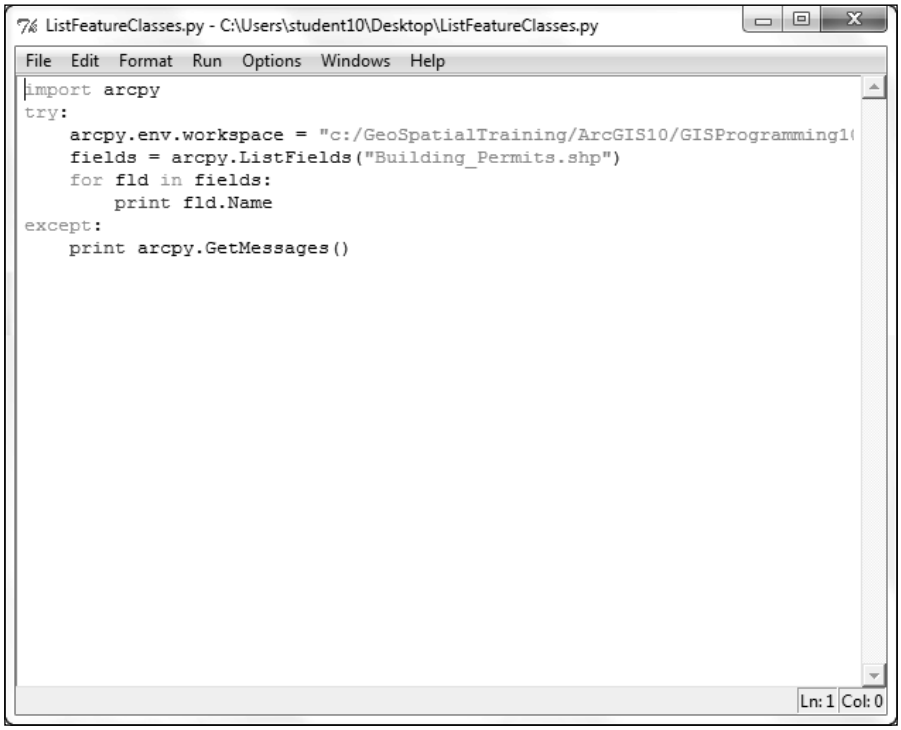

Your Python scripts will be written inside this new code window. Each script will need to be saved to a local or network drive. By default, scripts are saved with a `.py` file extension to signify that it is a Python script.

## Editing existing Python scripts

Existing Python script files can be opened by selecting **File** | **Open** from the IDLE shell window. Additionally, a Python script can be opened from Windows Explorer by right-clicking on the file and selecting **Edit with IDLE**, which brings up a new shell window along with the script loaded in the Python script editor. You can see an example of this in the following screenshot:



In this instance, we have loaded the `ListFeatureClasses.py` script with IDLE. The code is loaded inside the script window:



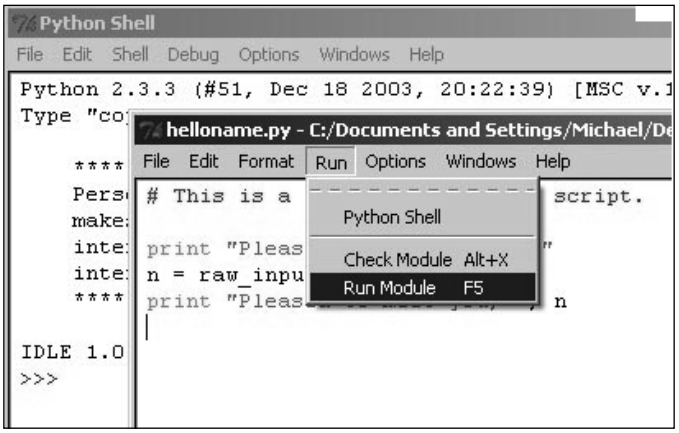

Now that the code window is open, you can begin writing or editing code. You can also perform some basic script debugging with the IDLE interface. Debugging is the process of identifying and fixing errors in your code.

## Executing scripts from IDLE

Once you've written a geoprocessing script in the IDLE code window or opened an existing script, you can execute the code from the interface. IDLE does provide functionality that allows you to check the syntax of your code before running the script. In the code window, navigate to **Run** | **Check Module** to perform a syntax check of your code.

Any syntax errors will be displayed in the shell window. If there aren't any syntax errors, you should just see the prompt in the shell window. While the IDLE interface can be used to check for syntax errors, it doesn't provide a way to check for logical errors in your code nor does it provide more advanced debugging tools found in other development environments, such as PyScripter or Wingware.

Once you're satisfied that no syntax errors exist in your code, you can run the script. Navigate to **Run** | **Run Module** to execute the script:




Any error messages will be written to the shell window along with the output from the `print` statements and system-generated messages. The `print` statement simply outputs text to the shell window. It is often used to update the status of a running script or to debug the code.

# Using the ArcGIS Python window

In this recipe, you'll learn how to use the ArcGIS Python window. In the last section, you learned how to use the IDLE development environment for Python, so this section will give you an alternative to write your geoprocessing scripts. Either development environment can be used, but it is common for people to start writing scripts with the ArcGIS for Desktop Python window and then move on to IDLE or another development environment when scripts become more complex.

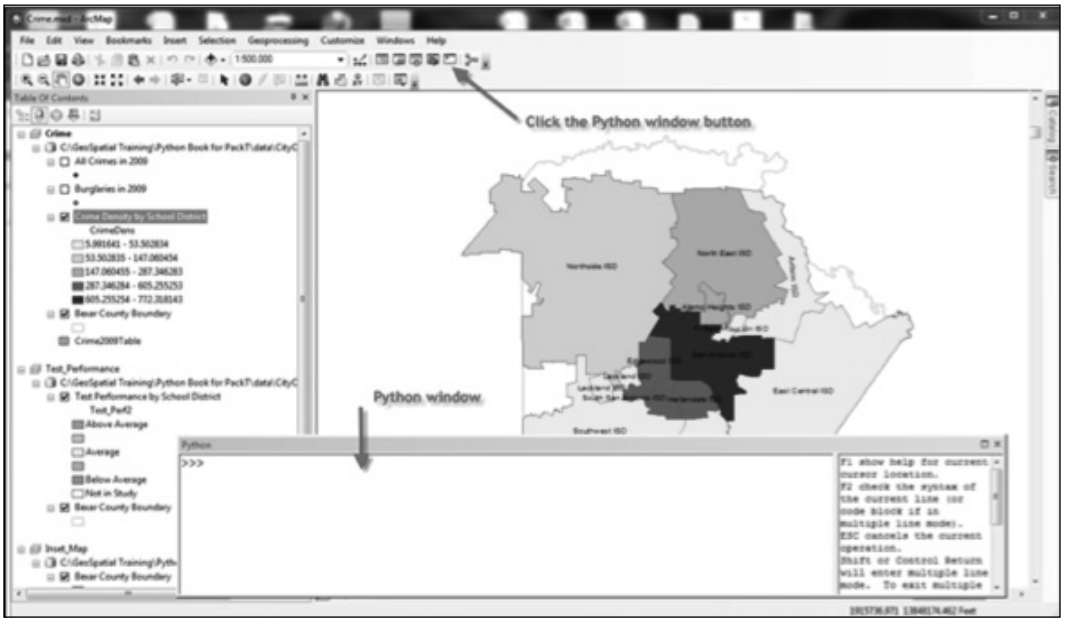
## The ArcGIS Python window

The ArcGIS Python window is an embedded, interactive Python window in ArcGIS for Desktop 10.x. It is newer and ideal for testing small blocks of code, learning Python basics, building quick and easy workflows, and executing geoprocessing tools. For new programmers, the ArcGIS Python window is a great place to start!

The ArcGIS Python window has a number of capabilities in addition to being the location to write your code. You can save the content of the window to a Python script file on a disk or load an existing Python script into the window. The window can be either pinned or floating. While floating, the window can be expanded or contracted as you wish. The window can also be pinned to various parts of the ArcGIS display. You can also format the font and text colors displayed in the window by right-clicking on the window and selecting **Format**.

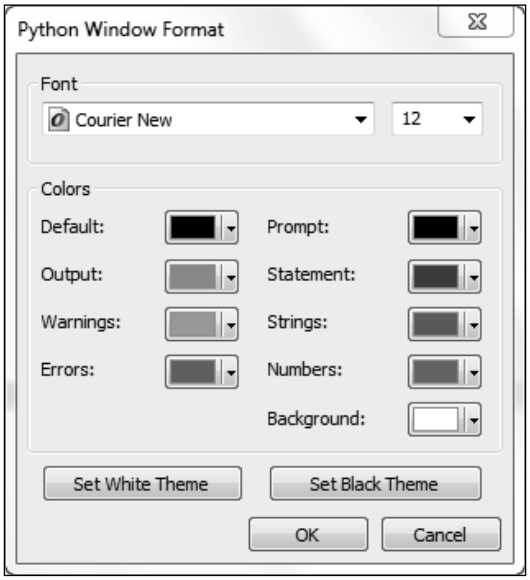
## Displaying the ArcGIS Python window

The Python window can be opened by clicking on the Python window button on the Standard ArcGIS for Desktop toolbar, as seen in the screenshot. This is a floating window, so you can resize as needed and also dock it at various places on the **ArcMap** interface:

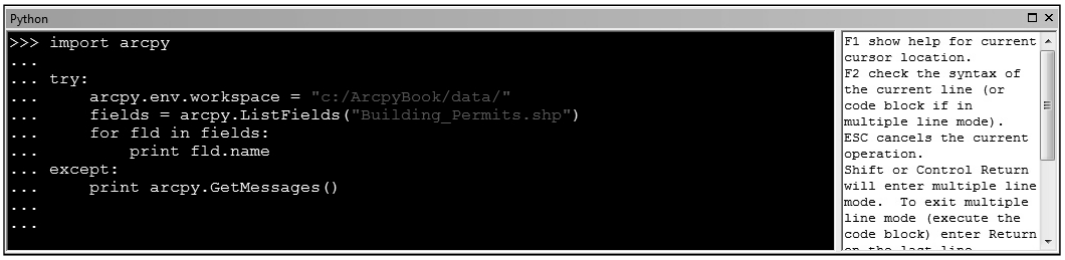



The Python window is essentially a shell window that allows you to type in statements one line at a time, just after the >>> line input characters. On the right-hand side of the divider, you will find a help window.

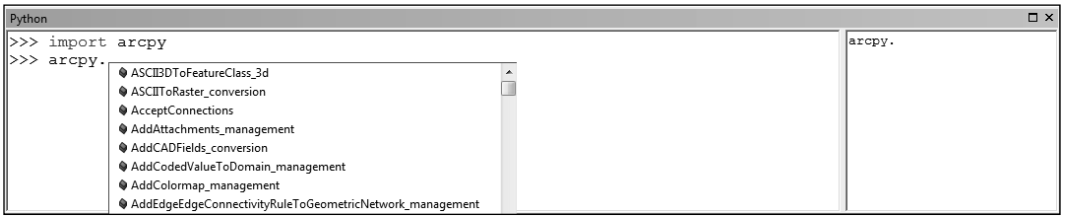
You can load an existing script by right-clicking inside the Python window and selecting **Load...** from the menu. You can also format the font and text colors displayed in the window by right-clicking on the window and selecting **Format**. You will be provided with White and Black themes; you can select fonts and colors individually:



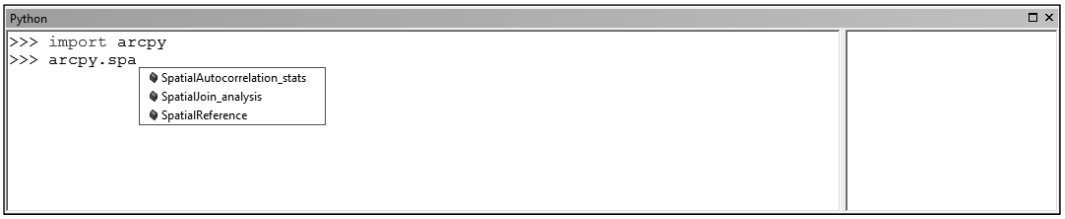

Click on the **Set Black Theme** button to see an example. If you spend a lot of time writing code, you may find that darker themes are easier on your eyes:



The ArcGIS Python window also provides code-completion functionalities that make your life as a programmer much easier. You can try this functionality by opening the ArcGIS Python Window and typing `arcpy` followed by a dot on the first line. ArcPy is a module-oriented package, which means that you access the properties and methods of an object using a dot notation. Notice that a drop-down list of available items is provided. These are the tools, functions, classes, and extensions that are available for this particular object. All objects have their own associated items, so the list of items presented will differ depending on the object that you have currently selected:




This is an auto-filtering list, so as you begin typing the name of the tool, function, class, or extension, the list will be filtered according to what you have typed:



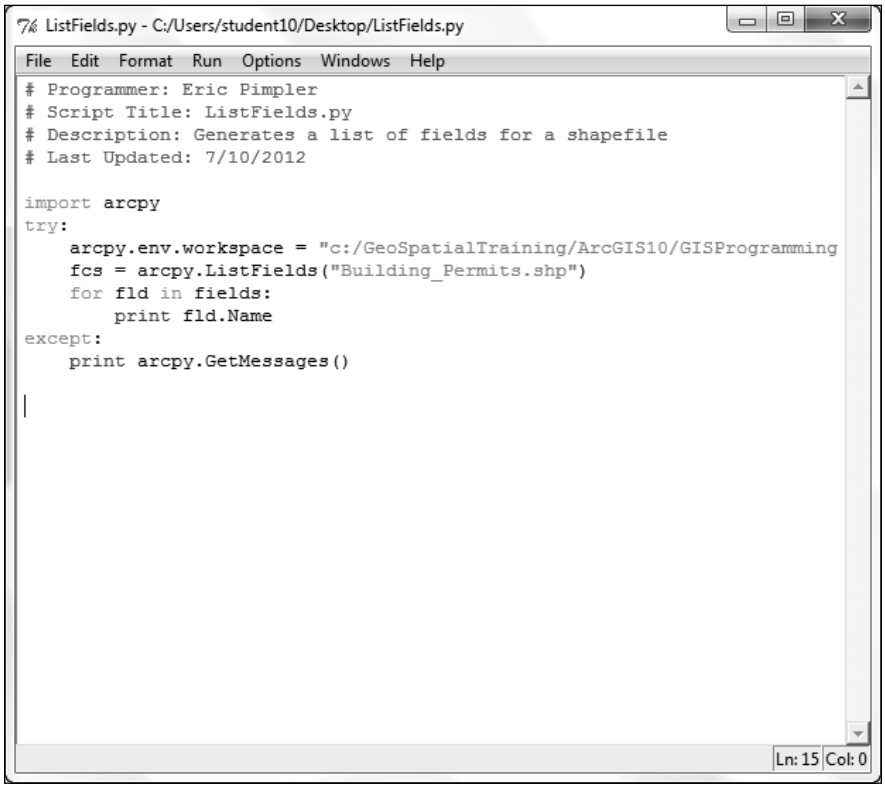

You can choose to have the Python window auto-complete the text for you by selecting an item from the list using your mouse or by using the arrow keys to highlight your choice, and then using the *Tab* key to enter the command. This autocompletion feature makes you a faster, more efficient programmer. Not only is it easy to use, but it also dramatically cuts down the number of typos in your code.

# Python language fundamentals

To effectively write geoprocessing scripts for ArcGIS, you are going to need to understand at least the basic constructs of the Python language. Python is easier to learn than most other programming languages, but it does take some time to learn and effectively use it. This section will teach you how to create variables, assign various data types to variables, understand the different types of data that can be assigned to variables, use different types of statements, use objects, read and write files, and import third-party Python modules.

## Commenting code

Python scripts should follow a common structure. It is a commonly accepted practice that the beginning of each script should serve as documentation, detailing the script name, author, and a general description of the processing provided by the script. This introductory documentation will help you and other programmers in the future to quickly scan the details and purpose of a script. This documentation is accomplished in Python through the use of comments. Comments are lines of code that you add to your script that serve as a documentation of what functionality the script provides. These lines of code begin with a single pound sign (#) or a double pound sign (##), and are followed by whatever text you need to document the code. The Python interpreter does not execute these lines of code. They are simply used to document your code. In the next screenshot, the commented lines of code are displayed with a single pound sign that prefixes the line of code. You should also strive to include comments throughout your script to describe important sections of your script. This will be useful to you (or another programmer) when the time comes to update your scripts:





**Downloading the example code**

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

## Importing modules

Although Python includes many built-in functions, you will frequently need to access specific bundles of functionality, which are stored in external modules. For instance, the `Math` module stores specific functions related to processing numeric values and the `R` module provides statistical analysis functions. We haven't discussed the topic of functions yet, but basically functions are a named block of code that execute when called. Modules are imported through the use of the `import` statement. When writing geoprocessing scripts with ArcGIS, you will always need to import the `arcpy` module, which is the Python package that is used to access GIS tools and functions provided by ArcGIS. The `import` statements will be the first lines of code (not including comments) in your scripts. The following line of code imports the `arcpy` and `os` modules. The Python `os` module provides a way of interfacing with the underlying operating system:

```
import arcpy
import os
```

## Variables

At a high level, you can think of a variable as an area in your computer's memory that is reserved to store values while the script is running. Variables that you define in Python are given a name and a value. The values assigned to variables can then be accessed by different areas of your script as needed, simply by referring to the variable name. For example, you might create a variable that contains a feature class name, which is then used by the **Buffer** tool to create a new output dataset. To create a variable, simply give it a name followed by the assignment operator, which is just an equals sign (=), and then a value:

```
fcParcels = "Parcels"
fcStreets = "Streets"
```

The following table illustrates the variable name and value assigned to the variable using the preceding code example:

| Variable name | Variable value |
|---|---|
| `fcParcels` | `Parcels` |
| `fcStreets` | `Streets` |

There are certain naming rules that you must follow when creating variables, including the following:

- It can contain letters, numbers, and underscores
- The first character must be a letter
- No special characters can be used in a variable name other an underscore
- Python keywords and spaces are not permitted

There are a few dozen Python keywords that must be avoided, including `class`, `if`, `for`, `while`, and others. These keywords are typically highlighted in a different font color from other Python statements.

Here are some examples of legal variable names in Python:

- `featureClassParcel`
- `fieldPopulation`
- `field2`
- `ssn`
- `my_name`

These are some examples of illegal variable names in Python:

- `class` (Python keyword)
- `return` (Python keyword)
- `$featureClass` (illegal character, must start with a letter)
- `2fields` (must start with a letter)
- `parcels&Streets` (illegal character)

Python is a case-sensitive language, so pay particular attention to the capitalization and naming of variables in your scripts. Case-sensitivity issues are probably the most common source of errors for new Python programmers, so always consider this as a possibility when you encounter errors in your code. Let's look at an example. The following is a list of three variables; note that although each variable name is the same, the casing is different, resulting in three distinct variables:

- `mapsize = "22x34"`
- `MapSize = "8x11"`
- `Mapsize = "36x48"`

If you print these variables, you will get the following output:

```
print(mapsize)
>>> 22x34

print(MapSize)
>>> 8x11  #output from print statement

print(Mapsize)
>>>36x48  #output from print statement
```

Python variable names need to be consistent throughout the script. The best practice is to use camel casing, wherein the first word of a variable name is all lowercase and then each successive word begins with an uppercase letter. This concept is illustrated in the following example with the `fieldOwnerName` variable name. The first word (`field`) is all lowercase followed by an uppercase letter for the second word (`Owner`) and third word (`Name`):

```
fieldOwnerName
```

In Python, variables are dynamically typed. **Dynamic typing** means that you can define a variable and assign data to it without specifically defining that a variable name will contain a specific type of data. Commonly used data types that can be assigned to variables include the following:

| Data type | Example value | Code example |
|---|---|---|
| String | `"Streets"` | `fcName = "Streets"` |
| Number | `3.14` | `percChange = 3.14` |
| Boolean | `True` | `ftrChanged = True` |
| List | `"Streets", "Parcels", "Streams"` | `lstFC = ["Streets", "Parcels", "Streams"]` |
| Dictionary | `'0':Streets,'1':Parcels` | `dictFC = {'0':Streets,'1':Parcels]` |
| Object | `Extent` | `spatialExt = map.extent` |

We will discuss each of these data types in greater detail in the coming sections.

For instance, in C#, you would need to define a variable's name and type before using it. This is not necessary in Python. To use a variable, simply give it a name and value, and you can begin using it right away. Python does the work behind the scenes to figure out what type of data is being held in the variable.

In the following C# code example, we've created a new variable called `aTouchdown`, which is defined as an integer variable, meaning that it can contain only integer data. We then assign the `6` value to the variable:

```
int aTouchdown;
aTouchdown = 6;
```

In Python, this variable can be created and assigned data through dynamic typing. The Python interpreter is tasked with dynamically figuring out what type of data is assigned to the variable:

```
aTouchdown = 6
```

There may be times when you know that your script will need a variable, but don't necessarily know ahead of time what data will be assigned to the variable. In these cases, you could simply define a variable without assigning data to it. Here, you will find a code example that depicts creating a variable without assigning data:

```
aVariable = ''
aVariable = NULL
```

Data that is assigned to the variable can also be changed while the script is running.

Variables can hold many different kinds of data, including primitive data types, such as strings and numbers, along with more complex data, such as lists, dictionaries, and even objects. We're going to examine the different types of data that can be assigned to a variable along with various functions that are provided by Python to manipulate the data.

## Built-in data types

Python has a number of built-in data types. The first built-in type that we will discuss is the `string` data type. We've already seen several examples of `string` variables, but these types of variables can be manipulated in a lot of ways, so let's take a closer look at this data type.

### Strings

Strings are ordered collections of characters that store and represent text-based information. This is a rather dry way of saying that string variables hold text. String variables are surrounded by single or double quotes when being assigned to a variable. Examples could include a name, feature class name, a `Where` clause, or anything else that can be encoded as text.

### String manipulation

Strings can be manipulated in a number of ways in Python. String concatenation is one of the more commonly used functions and is simple to accomplish. The `+` operator is used with `string` variables on either side of the operator to produce a new `string` variable that ties the two string variables together:

```
shpStreets = "c:\\GISData\\Streets" + ".shp"
print(shpStreets)
```

Running this code example produces the following result:

```
>>>c:\GISData\Streets.shp
```

String equality can be tested using Python's `==` operator, which is simply two equals signs placed together. Don't confuse the equality operator with the assignment operator, which is a single equals sign. The equality operator tests two variables for equality, while the assignment operator assigns a value to a variable:

```
firstName = "Eric"
lastName = "Pimpler"
firstName == lastName
```

Running this code example produces the following result because the `firstName` and `lastName` variables are not equal:

```
>>>False
```

Strings can be tested for containment using the `in` operator, which returns `True` if the first operand is contained in the second:

```
fcName = "Floodplain.shp"
print(".shp" in fcName)
>>>True
```

I have briefly mentioned that strings are an ordered collection of characters. What does this mean? It simply means that we can access individual characters or a series of characters from the string and that the order of the characters will remain the same until we change them. Some collections, such as a dictionary, do not maintain a set order. In Python, this is referred to as **indexing** in the case of accessing an individual character, and **slicing** in the case of accessing a series of characters.

Characters in a string are obtained by providing the numeric offset contained within square brackets after a string. For example, you could obtain the first string character in the `fc` variable by using the `fc[0]` syntax. Python is a zero-based language, meaning the first item in a list is `0`. Negative offsets can be used to search backwards from the end of a string. In this case, the last character in a string is stored at the `-1` index. Indexing always creates a new variable to hold the character:

```
fc = "Floodplain.shp"
print(fc[0])
>>>'F'
print(fc[10])
>>>'.'
print(fc[13])
>>>'p'
```

The following image illustrates how strings are an ordered collection of characters with the first character occupying the **0** position, the second character occupying the **1** position, and each successive character occupying the next index number:




While string indexing allows you to obtain a single character from a `string` variable, string slicing enables you to extract a contiguous sequence of strings. The format and syntax is similar to indexing, but with the addition of a second offset, which is used to tell Python which characters to return.

The following code example provides an example of string slicing. The `theString` variable has been assigned a value of `Floodplain.shp`. To obtain a sliced variable with the contents of Flood, you would use the `theString[0:5]` syntax:

```
theString = "Floodplain.shp"
print(theString[0:5])
>>>Flood
```



Python slicing returns the characters beginning with the first offset up to, but not including, the second offset. This can be particularly confusing for new Python programmers and is a common source of errors. In our example, the returned variable will contain the `Flood` characters. The first character, which occupies the `0` position, is `F`. The last character returned is the `4` index, which corresponds to the `d` character. Notice the `5` index number is not included since Python slicing only returns characters up to, but not including, the second offset

Either of the offsets can be left off. This, in effect, creates a wild card. In the case of `theString[1:]`, you are telling Python to return all characters starting from the second character to the end of the string. In the second case, `theString[:-1]`, you are telling Python to start at character zero and return all characters except the last.

Python is an excellent language to manipulate strings and there are many additional functions that you can use to process this type of data. Most of these are beyond the scope of this text, but in general, all the following string manipulation functions are available:

- String length
- Casing functions for conversion to upper and lowercase
- The removal of leading and trailing whitespace
- Finding a character within a string
- The replacement of text
- Splitting into a list of words based on a delimiter
- Formatting

Your Python geoprocessing scripts for ArcGIS will often need to reference the location of a dataset on your computer or, perhaps, a shared server. References to these datasets will often consist of paths stored in a variable. In Python, pathnames are a special case that deserve some extra mention. The backslash character in Python is a reserved escape character and a line continuation character, thus there is a need to define paths using two back slashes, a single forward slash, or a regular single backslash prefixed with `r`. These pathnames are always stored as strings in Python. You'll see an example of this in the following section.

The example for an illegal path reference is as follows:

```
fcParcels = "c:\Data\Parcels.shp"
```

The example for legal path references are as follows:

```
fcParcels = "c:/Data/Parcels.shp"
fcParcels = "c:\\Data\\Parcels.shp"
fcParcels = r"c:\Data\Parcels.shp"
```

## Numbers

Python also has built-in support for numeric data, including `int`, `long`, `float`, and `complex` values. Numbers are assigned to variables in much the same way as strings, with the exception that you do not enclose the value in quotes and obviously, it must be a numeric value.

Python supports all the commonly used numeric operators, including addition, subtraction, multiplication, division, and modulus or remainder. In addition to this, functions used to return the absolute value, conversion of strings to numeric data types, and rounding are also available.

Although Python provides a few built-in mathematical functions, the math module can be used to access a wide variety of more advanced `math` functions. To use these functions, you must specifically import the `math` module as follows:

```
import math
```

Functions provided by the `math` module include those that return the ceiling and floor of a number, the absolute value, trigonometric functions, logarithmic functions, angular conversion, and hyperbolic functions. It is worth noting that there is no simple function to calculate mean or average and these will have to be coded to be calculated. More details about the `math` module can be found by navigating to **All Programs** | **ArcGIS** | **Python 2.7** | **Python Manuals**. After opening the python manual, navigate to **Python Standard Library** | **Numeric and Mathematical Modules**. You can also reference this for any data types, syntax, built-in functions, and other things that you wish to understand in more detail, of which there are too many to be covered here.

## Lists

A third built-in data type provided by Python is lists. A list is an ordered collection of elements that can hold any type of data supported by Python as well as being able to hold multiple data types at the same time. This could be numbers, strings, other lists, dictionaries, or objects. So, for instance, a list variable could hold numeric and string data at the same time. Lists are zero-based, with the first element in the list occupying the **0** position. This is illustrated here:




Each successive object in the list is incremented by one. Additionally, lists have the special capability of dynamically growing and shrinking.

Lists are created by assigning a series of values enclosed by brackets. To pull a value from a list, simply use an integer value in brackets along with the variable name. The following code example provides an illustration of this:

```
fcList = ["Hydrants", "Water Mains", "Valves", "Wells"]
fc = fcList[0] ##first item in the list - Hydrants
print(fc)
>>>Hydrants
fc = fcList[3]  ##fourth item in the list - Wells
print(fc)
>>>Wells
```

You can add a new item to an existing list by using the `append()` method, as seen in this code example:

```
fcList.append("Sewer Pipes")
print(fcList)
>> Hydrants, Water Mains, Valves, Wells, Sewer Pipes
```

You can also use slicing with lists to return multiple values. To slice a list, you can provide two offset values separated by a colon, as seen in the following code example. The first offset indicates the starting index number and the second indicates the stopping point. The second index number will not be returned. **Slicing** a list always returns a new list:

```
fcList = ["Hydrants", "Water Mains", "Valves", "Wells"]
fc = fcList[0:2] ##get the first two items – Hydrants, Water Mains
```

Lists are dynamic in nature, meaning that you can add and remove items from an existing list as well as change the existing contents. This is all done without the need to create a new copy of the list. Changing values in a list can be accomplished either through indexing or slicing. Indexing allows you to change a single value, while slicing allows you to change multiple list items.

Lists have a number of methods that allow you to manipulate the values that are part of the list. You can sort the contents of the list in either an ascending or descending order through the use of the `sort()` method. Items can be added to a list with the `append()` method, which adds an object to the end of the list, and with the `insert()` method, which inserts an object at a position within the list. Items can be removed from a list with the `remove()` method, which removes the first occurrence of a value from the list, or the `pop()` method, which removes and returns the object at the end of the list. The contents of the list can also be reversed with the `reverse()` method.

## Tuples

Tuples are similar to lists but with some important differences. Just like lists, tuples contain a sequence of values. The contents of a tuple can include any type of data just like lists. However, unlike lists, the contents of a tuple are static. After a tuple has been created, you can't make any changes to the sequence of the values nor can you add or remove values. This can be a good thing for situations where you want data to always occupy a specific position. Creating a tuple is as simple as placing a number of comma-separated values inside parentheses, as shown in the following code example:

```
fcTuples = ("Hydrants", "Water Mains", "Valves", "Wells")
```

You've probably noticed that creating a tuple is very similar to creating a list. The only difference is the use of parentheses instead of square braces around the values.

Similar to lists, tuple indices start with an index value of `0`. Access to values stored in a tuple occurs in the same way as lists. This is illustrated in the following code example:

```
fcTuples = ("Hydrants", "Water Mains", "Valves", "Wells")
print(fcTuples[1])
>>>Water Mains
```

Tuples are typically used in place of a list when it is important for the contents of the structure to be static. You can't ensure this with a list, but you can with a tuple.

## Dictionaries

Dictionaries are a second type of collection object in Python. They are similar to lists, except that dictionaries are an unordered collection of objects. Instead of fetching objects from the collection through the use of an offset, items in a dictionary are stored and fetched by a key. Each key in a dictionary has an associated value, as seen here:




Similar to lists, dictionaries can grow and shrink in place through the use of methods on `dictionary`. In the following code example, you will learn to create and populate a dictionary and see how values can be accessed through the use of a key. Dictionaries are created with the use of curly braces. Inside these braces, each key is followed by a colon and then a value is associated with the key. These key/value pairs are separated by commas:

```
##create the dictionary
dictLayers = {'Roads': 0, 'Airports': 1, 'Rail': 2}

##access the dictionary by key
print(dictLayers['Airports'])
>>>1
print(dictLayers['Rail'])
>>>2
```

Basic `dictionary` operations include getting the number of items in a dictionary, acquiring a value using a key, determining if the key exists, converting the keys to a list, and getting a list of values. The `dictionary` objects can be changed, expanded, and shrunk in place. What this means is that Python does not have to create a new `dictionary` object to hold the altered version of the dictionary. Assigning values to a `dictionary` key can be accomplished by stating the key value in brackets and setting it equal to some value.



Unlike lists, dictionaries can't be sliced due to the fact that their contents are unordered. Should you have the need to iterate over all the values in a dictionary, simply use the `keys()` method, which returns a collection of all the keys in the dictionary and can then be used individually to set or get their value.

## Classes and objects

Classes and objects are a fundamental concept in object-oriented programming. While Python is more of a procedural language, it also supports object-oriented programming. In object-oriented programming, classes are used to create object instances. You can think of classes as blueprints for the creation of one or more objects. Each object instance has the same properties and methods, but the data contained in an object can and usually will differ. Objects are complex data types in Python composed of properties and methods, and can be assigned to variables just like any other data type. Properties contain data associated with an object, while methods are actions that an object can perform.

These concepts are best illustrated with an example. In ArcPy, the `extent` class is a rectangle specified by providing the coordinate of the lower-left corner and the coordinate of the upper-right corner in map units. The `extent` class contains a number of properties and methods. Properties include `XMin`, `XMax`, `YMin`, `YMax`, `spatialReference`, and others. The minimum and maximum of `x` and `y` properties provide the coordinates for the extent rectangle. The `spatialReference` property holds a reference to a `spatialReference` object for `extent`. Object instances of the `extent` class can be used both to set and get the values of these properties through dot notation. An example of this is seen in the following code example:

```
# get the extent of the county boundary
ext = row[0].extent
# print out the bounding coordinates and spatial reference
print("XMin: " + str(ext.XMin))
print("XMax: " + str(ext.XMax))
print("YMin: " + str(ext.YMin))
print("YMax: " + str(ext.YMax))
print("Spatial Reference: " + ext.spatialReference.name)
```

Running this script yields the following output:

```
XMin: 2977896.74002
XMax: 3230651.20622
YMin: 9981999.27708
YMax:10200100.7854
Spatial Reference:
NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet
```

The `extent` class also has a number of methods, which are actions that an object can perform. In the case of this particular object, most of the methods are related to performing some sort of geometric test between the `extent` object and another geometry. Examples include `contains()`, `crosses()`, `disjoint()`, `equals()`, `overlaps()`, `touches()`, and `within()`.

One additional object-oriented concept that you need to understand is **dot notation**. Dot notation provides a way of accessing the properties and methods of an object. It is used to indicate that a property or method belongs to a particular class.

The syntax for using dot notation includes an object instance followed by a dot and then the property or method. The syntax is the same regardless of whether you're accessing a property or a method. A parenthesis and zero or more parameters at the end of the word following the dot indicates that a method is being accessed. Here are a couple of examples to better illustrate this concept:

```
Property: extent.XMin
Method: extent.touches()
```

## Statements

Each line of code that you write with Python is known as a **statement**. There are many different kinds of statements, including those that create and assign data to variables, decision support statements that branch your code based on a test, looping statements that execute a code block multiple times, and others. There are various rules that your code will need to follow as you create the statements that are part of your script. You've already encountered one type of statement: variable creation and assignment.

### Decision support statements

The `if/elif/else` statement is the primary decision-making statement in Python and tests for a `True/False` condition. Decision statements enable you to control the flow of your programs. Here are some example decisions that you can make in your code: if the variable holds a point feature class, get the `X`, `Y` coordinates; if the feature class name equals `Roads`, then get the `Name` field.

Decision statements, such as `if/elif/else`, test for a `True/False` condition. In Python, a `True` value means any nonzero number or nonempty object. A `False` value indicates *not true* and is represented in Python with a zero number or empty object. Comparison tests return values of one or zero (true or false). Boolean and/or operators return a true or false operand value:

```
if fcName == 'Roads':
  arcpy.Buffer_analysis(fc, "c:\\temp\\roads.shp", 100)
elif fcName == 'Rail':
```

```
    arcpy.Buffer_analysis(fc, "c:\\temp\\rail.shp", 50)
else:
    print("Can't buffer this layer")
```

The Python code must follow certain syntax rules. Statements execute one after another until your code branches. Branching typically occurs through the use of `if/elif/else`. In addition to this, the use of looping structures, such as `for` and `while`, can alter the statement flow. Python automatically detects statement and block boundaries, so there is no need for braces or delimiters around your blocks of code. Instead, indentation is used to group statements in a block. Many languages terminate statements with the use of a semicolon, but Python simply uses the end of line character to mark the end of a statement. Compound statements include a ":" character. Compound statements follow this pattern, that is, header terminated by a colon. Blocks of code are then written as individual statements and are indented underneath the header.

## Looping statements

Looping statements allow your program to repeat lines of code over and over as necessary. `The while` loops repeatedly execute a block of statements as long as the test at the top of the loop evaluates to `True`. When the condition test evaluates to `False`, Python begins interpreting code immediately after the `while` loop. In the next code example, a value of `10` has been assigned to the `x` variable. The test for the `while` loop then checks to see if `x` is less than `100`. If `x` is less than `100`, the current value of `x` is printed to the screen and the value of x is incremented by `10`. Processing then continues with the `while` loop test. The second time, the value of `x` will be `20`; so the test evaluates to `True` once again. This process continues until `x` is equal to or greater than `100`. At this time, the test will evaluate to `False` and processing will stop. It is very important that `the while` statements have some way of breaking out of the loop. Otherwise, you will wind up in an infinite loop. An infinite loop is a sequence of instructions in a computer program that loops endlessly, either due to the loop having no terminating condition, having one that can never be met, or one that causes the loop to start over:

```
x = 10
while x < 100:
     print(x)
     x = x + 10
```

The `for` loops execute a block of statements a predetermined number of times. They come in two varieties—a counted loop to run a block of code a set number of times, and a list loop that enables you to loop through all the objects in a list. The list loop in the following example executes once for each value in the dictionary and then stops looping:

```
dictLayers = {"Roads":"Line","Rail":"Line","Parks":"Polygon"}
for key in dictLayers:
  print(dictLayers[key])
```

There are times when it will be necessary for you to break out of the execution of a loop. The `break` and `continue` statements can be used to do this. The `break` jumps out of the closest enclosing loop, while `continue` jumps back to the top of the closest enclosing loop. These statements can appear anywhere inside the block of code.

## Try statements

A `try` statement is a complete, compound statement that is used to handle exceptions. Exceptions are a high-level control device used primarily for error interception or triggering. Exceptions in Python can either be intercepted or triggered. When an error condition occurs in your code, Python automatically triggers an exception, which may or may not be handled by your code. It is up to you as a programmer to catch an automatically triggered exception. Exceptions can also be triggered manually by your code. In this case, you would also need to provide an exception handling routine to catch these manually triggered exceptions.

There are two basic types of `try` statements: `try/except/else` and `try/finally`. The basic `try` statement starts with a `try` header line followed by a block of indented statements. Then, this is followed by one or more optional `except` clauses that name the exceptions that are to be caught. After this, you will find an optional `else` clause at the end:

```
import arcpy
import sys

inFeatureClass = arcpy.GetParameterAsText(0)
outFeatureClass = arcpy.GetParameterAsText(1)

try:
  # If the output feature class exists, raise an error

  if arcpy.Exists(inFeatureClass):
    raise overwriteError(outFeatureClass)
  else:
    # Additional processing steps
    print("Additional processing steps")

except overwriteError as e:
  # Use message ID 12, and provide the output feature class
```

```
    #  to complete the message.

    arcpy.AddIDMessage("Error", 12, str(e))
```

The `try/except/else` statement works as follows. Once inside a `try` statement, Python marks the fact that you are in a `try` block and knows that any exception condition that occurs at this point will be sent to the various `except` statements for handling. If a matching exception is found, the code block inside the `except` block is executed. The code then picks up the full `try` statement, which will be mentioned shortly. The `else` statements are not executed in this case. Each statement inside the `try` block is executed. Assuming that no exception conditions occur, the code pointer will then jump to the `else` statement and execute the code block contained by the `else` statement before moving to the next line of code that follows the try block.

The other type of `try` statement is the `try/finally` statement, which allows for finalization actions. When a `finally` clause is used in a `try` statement, its block of statements always run at the very end, whether an error condition occurs or not.

Here is how the `try/finally` statement works: if an exception occurs, Python runs the `try` block, then the `except` block, followed by the `finally` block, and then execution continues past the entire `try` statement. If an exception does not occur during execution, Python runs the `try` block, then the `finally` block. This is useful when you want to make sure an action happens after a code block runs, regardless of whether an error condition occurs. Cleanup operations, such as closing a file or a connection to a database, are commonly placed inside a `finally` block to ensure that they are executed regardless of whether an exception occurs in your code:

```
import arcpy

try:
  if arcpy.CheckExtension("3D") == "Available":
    arcpy.CheckOutExtension("3D")
  else:
    # Raise a custom exception
    raise LicenseError

  arcpy.env.workspace = "D:/GrosMorne"
  arcpy.HillShade_3d("WesternBrook", "westbrook_hill", 300)
  arcpy.Aspect_3d("WesternBrook", "westbrook_aspect")

except LicenseError:
  print("3D Analyst license is unavailable")
except:
  print(arcpy.GetMessages(2))
finally:
  # Check in the 3D Analyst extension
  arcpy.CheckInExtension("3D")
```

## With statements

The `with` statement is handy when you have two related operations that need to be executed as a pair with a block of code in between. A common scenario to use the `with` statements is opening, reading, and closing a file. Opening and closing a file are the related operations, and reading a file and doing something with the contents is the block of code in between. When writing geoprocessing scripts with ArcGIS, the new `cursor` objects introduced with version 10.1 of ArcGIS are ideal when using the `with` statements. We'll discuss the `cursor` objects in great detail in a later chapter, but I'll briefly describe these objects now. Cursors are an in-memory copy of records from the attribute table of a feature class or table. There are various types of cursors. Insert cursors allow you to insert new records, search cursors are a read-only copy of records, and update cursors allow you to edit or delete records. Cursor objects are opened, processed in some way, and closed automatically using a `with` statement.

The closure of a file or cursor object is handled automatically by the `with` statement, resulting in cleaner, more efficient coding. It's basically like using a `try/finally` block, but with fewer lines of code. In the following code example, the `with` block is used to create a new search cursor, read information from the cursor, and implicitly close the cursor:

```
import arcpy

fc = "c:/data/city.gdb/streets"

# For each row print the Object ID field, and use the SHAPE@AREA
# token to access geometry properties

with arcpy.da.SearchCursor(fc, ("OID@", "SHAPE@AREA")) as cursor:
  for row in cursor:
    print("Feature {0} has an area of {1}".format(row[0], row[1]))
```

## Statement indentation

Statement indentation deserves a special mention as it is critical to the way Python interprets code. Compound statements in Python use indentation to create a group of statements. This includes the `if/then`, `for`, `while`, `try`, and `with` statements. The Python interpreter uses indentation to detect these code blocks. The beginning of a compound statement is defined through the use of a colon. All lines following the beginning of the compound statement should be indented the same distance. You can use any number of spaces to define the indentation, but you should use the same indentation level for each statement. A common practice is to define indentation through the use of a tab. When the Python interpreter encounters a line that is less indented, it will assume that the code block has ended. The following code illustrates this concept through the use of a `try` statement. Notice that there is a colon after the `try` statement. This indicates that the statements that follow are part of a compound statement and should be indented. These statements will form a code block.

Also, an `if` statement is inside the `try` statement. This too is a compound statement as defined by the colon at the end of the statement. Therefore, any statements that are part of the `if` statement should be further indented. You should also notice that there is a statement that is not indented inside the `if` statement, but is rather at the same level. This `statement4` is part of the `try` code block but not part of the `if` code block:

```
try:
  if <statement1>:
    <statement2>
    <statement3>
  <statement4> <……..>
except:
  <statement>
  <……..>
except:
  <statement>
  <……..>
```

Many languages, including JavaScript, Java, and .NET, use curly braces to indicate a group of statements. Python uses indentation instead of curly braces in an attempt to cut down on the amount of code you have to write and to make code more readable. Anyone who has ever used these other languages can attest to the difficulty in reading code that contains many curly braces. However, indentation does take some getting used to and is critical to the way that Python executes lines of code.

## File I/O

You will often find it necessary to retrieve or write information to files on your computer. Python has a built-in object type that provides a way to access files for many tasks. We're only going to cover a small subset of the file manipulation functionality provided, but we'll touch on the most commonly used functions, including opening and closing files, and reading and writing data to a file.

Python's `open()` function creates a file object, which serves as a link to a file residing on your computer. You must call the `open()` function on a file before reading and/or writing data to a file. The first parameter for the `open()` function is a path to the file you'd like to open. The second parameter corresponds to a mode, which is typically read (`r`), write (`w`), or append (`a`). A value of `r` indicates that you'd like to open the file for read-only operations, while a value of `w` indicates you'd like to open the file for write operations. In the event that you open a file that already exists for write operations, this will overwrite any data currently in the file, so you must be careful with the write mode. The append mode (`a`) will open a file for write operations, but instead of overwriting any existing data, it will append the new data to the end of the file. The following code example shows the use of the `open()` function to open a text file in a read-only mode:

```
with open('Wildfires.txt','r') as f:
```

Notice that we have also used the `with` keyword to open the file, ensuring that the file resource will be *cleaned up* after the code that uses it has finished executing.

After a file has been opened, data can be read from it in a number of ways and using various methods. The most typical scenario would be to read data one line at a time from a file through the `readline()` method. The `readline()` function can be used to read the file one line at a time into a string variable. You would need to create a looping mechanism in your Python code to read the entire file line by line. If you would prefer to read the entire file into a variable, you can use the `read()` method, which will read the file up to the **End Of File** (**EOF**) marker. You can also use the `readlines()` method to read the entire contents of a file, separating each line into individual strings, until the EOF is found.

In the following code example, we have opened a text file called `Wildfires.txt` in the read-only mode and used the `readlines()` method on the file to read its entire contents into a variable called `lstFires`, which is a Python list containing each line of the file as a separate string value in the list. In this case, the `Wildfire.txt` file is a comma-delimited text file containing the latitude and longitude of the fire along with the confidence values for each fire. We then loop through each line of text in `lstFires` and use the `split()` function to extract the values based on a comma as the delimiter, including the latitude, longitude, and confidence values. The latitude and longitude values are used to create a new `Point` object, which is then inserted into the feature class using an insert cursor:

```
import arcpy, os
try:

  arcpy.env.workspace = "C:/data/WildlandFires.mdb"
  # open the file to read
  with open('Wildfires.txt','r') as f:   #open the file

    lstFires = f.readlines() #read the file into a list
    cur = arcpy.InsertCursor("FireIncidents")

    for fire in lstFires: #loop through each line
      if 'Latitude' in fire: #skip the header
        continue
      vals = fire.split(",") #split the values based on comma
      latitude = float(vals[0]) #get latitude
      longitude = float(vals[1]) #get longitude
      confid = int(vals[2]) #get confidence value
      #create new Point and set values
      pnt = arcpy.Point(longitude,latitude)
      feat = cur.newRow()
      feat.shape = pnt
      feat.setValue("CONFIDENCEVALUE", confid)
      cur.insertRow(feat) #insert the row into featureclass
```

```
except:
    print(arcpy.GetMessages()) #print out any errors
finally:
  del cur
  f.close()
```

Just as is the case with reading files, there are a number of methods that you can use to write data to a file. The `write()` function is probably the easiest to use and takes a single string argument and writes it to a file. The `writelines()` function can be used to write the contents of a list structure to a file. In the following code example, we have created a list structure called `fcList`, which contains a list of feature classes. We can write this list to a file using the `writelines()` method:

```
outfile = open('c:\\temp\\data.txt','w')
fcList = ["Streams", "Roads", "Counties"]
outfile.writelines(fcList)
```

# Summary

In this chapter, we covered some of the fundamental Python programming concepts that you'll need to understand before you can write effective geoprocessing scripts. We began the chapter with an overview of the IDLE development environment to write and debug Python scripts. You learned how to create a new script, edit existing scripts, check for syntax errors, and execute scripts. We also covered the basic language constructs, including importing modules, creating and assigning variables, if/else statements, looping statements, and the various data-types including strings, numbers, Booleans, lists, dictionaries, and objects. You also learned how to read and write text files.

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