Python GUI Programming with Tkinter

Develop responsive and powerful GUI applications with Tkinter

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By Alan D. Moore

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To my children, may you never be afraid to try, even when you don't have all the answers.

Contributors

About the author

Alan D. Moore is a data analyst and software developer who has been solving problems with Python since 2006. He's developed both open source and private code using frameworks like Django, Flask, Qt, and, of course, Tkinter, and contributes to various open source Python and Javascript projects.

Alan maintains a blog by the name `alandmoore`, where he writes mainly about Python, Linux, free software, and his home studio recordings.

Alan lives in Franklin, Tennessee, where he works for the county government, and with his wife, Cara, raises a crew of children who are just as geeky as their dad.

Thanks to my wife, Cara, for her support; Caspian, for listening to me ramble about Python; Mark Soper, Tom Potter, Gayle Moore, and Albert Moore for the wise advice; David Andrews for his expertise; Alok Dhuri, Priyanka Sawant, Vibhuti Gawde, and the Packt team for their hard work and patience; and all the helpful people in the Python and Tkinter communities.

About the reviewer

David Andrews is CTO at a small but growing healthcare technology startup. He has spent many years as a consultant developer in several different industries including sports, finance, publishing, and insurance. His expertise lies in process automation and identifying technological solutions to core business inefficiencies.

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I would like to thank Alan particularly for involving me in this process. It has been a true honor. I would also like to thank the good people involved in the publishing process for their patience and guidance as we worked through this.

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Preface

Becoming a programmer is not just about learning programming languages; it takes more than a mastery of syntax rules to build applications that enable users to perform work, manage data, or enjoy a game. As programmers, we also need to be able to convert user requests and expectations into designs and pick the best technologies to implement them. We need to be able to organize large code bases, test them, and maintain them in a way that keeps them manageable and free from careless errors.

This book not only teaches you how to use the Tkinter GUI toolkit and a few other libraries; it will also teach you many of the skills you need to move from a writer of short scripts to a writer of medium-sized graphical applications. By the time you've finished the book, you should feel confident that you can develop a simple but useful data-oriented application.

Who this book is for

This book is for beginners who have learned the basics of Python but haven't written much beyond simple scripts or REPL sessions. We'll walk you step-by-step through designing and creating a larger application, and we'll introduce you to skills that will help you advance as a programmer.

It's also aimed at those who have used Python for data science, web development, or system administration, but who now want to branch out into creating GUI applications. We'll go through the knowledge and skills required to create local GUI applications.

Finally, this book may also be useful for experienced Python programmers who just want to learn Tkinter, as most of the book details the finer points of using Tkinter classes.

What this book covers

`Chapter 1`, *Introduction to Tkinter*, introduces you to the basics of the Tkinter library and walks you through creating a Hello World application. It will also introduce you to IDLE as an example of a Tkinter application.

`Chapter 2`, *Designing GUI Applications with Tkinter*, goes through the process of turning a set of user requirements into a design that we can implement.

`Chapter 3`, *Creating Basic Forms with Tkinter and ttk Widgets*, shows you how to create a basic data entry form that appends data to a CSV file.

`Chapter 4`, *Reducing User Error with Validation and Automation*, demonstrates how to automatically populate and validate data in our form's inputs.

`Chapter 5`, *Planning for the Expansion of Our Application*, familiarizes you with how to break a small script into multiple files and build a Python module that you can import. It also contains some general advice on how to manage a larger code base.

`Chapter 6`, *Creating Menus with Menu and Tkinter Dialogs*, outlines the creation of a main menu using Tkinter. It will also show the use of several built-in dialog types to implement common menu functionality.

`Chapter 7`, *Navigating Records with Treeview*, details the construction of a records navigation system using the Tkinter Treeview and the conversion of our application from append-only to full read, write, and update capabilities.

`Chapter 8`, *Improving the Look with Styles and Themes*, informs you of how to change the colors, fonts, and widget styles of your application, and how to use them to make your application more usable.

`Chapter 9`, *Maintaining Cross-Platform Compatibility*, goes over Python and Tkinter techniques to keep your application running smoothly across Windows, macOS, and Linux systems.

`Chapter 10`, *Creating Automated Tests with unittest*, discusses how to verify your code with automated unit tests and integration tests.

`Chapter 11`, *Improving Data Storage with SQL*, takes you through the conversion of our application from the CSV flat-files to SQL data storage. You'll learn all about SQL and relational data models as well.

`Chapter 12`, *Connecting to the Cloud*, covers how to work with cloud services such as web services and FTP to download and upload data.

`Chapter 13`, *Asynchronous Programming with Thread and Queue*, explains how to use asynchronous and multithreaded programming to keep our application responsive during long-running processes.

`Chapter 14`, *Visualizing Data Using the Canvas Widget*, teaches you how to work with the Tkinter `Canvas` widget to create visualizations and animations.

`Chapter 15`, *Packaging with setuptools and cx_Freeze*, explores preparing your Python application for distribution as a Python package or a standalone executable.

To get the most out of this book

This book expects that you know the basics of Python 3. You should know how to write and run simple scripts using built-in types and functions, how to define your own functions and classes, and how to import modules from the standard library.

You can follow this book if you run Windows, macOS, Linux, or even BSD. Ensure that you have Python 3 and Tcl/Tk installed (`Chapter 1`, *Introduction to Tkinter*, contains instructions for Windows, macOS, and Linux) and that you have an editing environment with which you are comfortable (we suggest IDLE since it comes with Python and uses Tkinter). In the later chapters, you'll need access to the internet so that you can install Python packages and the PostgreSQL database.

Download the example code files

You can download the example code files for this book from your account at `www.packtpub.com`. If you purchased this book elsewhere, you can visit `www.packtpub.com/support` and register to have the files emailed directly to you.

You can download the code files by following these steps:

1. Log in or register at `www.packtpub.com`.
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Once the file is downloaded, please make sure that you unzip or extract the folder using the latest version of:

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

The code bundle for the book is also hosted on GitHub at `https://github.com/PacktPublishing/Python-GUI-Programming-with-Tkinter`. In case there's an update to the code, it will be updated on the existing GitHub repository.

We also have other code bundles from our rich catalog of books and videos available at `https://github.com/PacktPublishing/`. Check them out!

Conventions used

There are a number of text conventions used throughout this book.

`CodeInText`: Indicates code words in text, database table names, folder names, filenames, file extensions, pathnames, dummy URLs, user input, and Twitter handles. Here is an example: "Determine the appropriate `input` widget for each data field."

A block of code is set as follows:

```
def has_five_or_less_chars(string):
    return len(string) <= 5

    wrapped_function = root.register(has_five_or_less_chars)
    vcmd = (wrapped_function, '%P')
    five_char_input = ttk.Entry(root, validate='key', validatecommand=vcmd)
```

When we wish to draw your attention to a particular part of a code block, the relevant lines or items are set in bold:

```
[default]
exten => s,1,Dial(Zap/1|30)
exten => s,2,Voicemail(u100)
exten => s,102,Voicemail(b100)
exten => i,1,Voicemail(s0)
```

Any command-line input or output is written as follows:

```
pip install --user psycopg2-binary
```

Bold: Indicates a new term, an important word, or words that you see onscreen. For example, words in menus or dialog boxes appear in the text like this. Here is an example: "Once installed, launch pgAdmin and create a new admin user for yourself by selecting Object | Create | Login/Group Role."

Warnings or important notes appear like this.

Tips and tricks appear like this.

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Reviews

Introduction to Tkinter

Welcome, Python coder! If you've learned the basics of Python and want to start designing powerful GUI applications, this book is for you.

By now, you have no doubt experienced the power and simplicity of Python. Perhaps you've written web services, performed data analysis, or administered servers. Perhaps you've written a game, automated routine tasks, or simply played around with code. But now you're ready to tackle the GUI.

With so much emphasis on web, mobile, and server-side programming, the development of simple desktop GUI applications seems increasingly like a lost art; many otherwise experienced developers have never learned to create one. What a tragedy! Desktop computers still play a vital role in work and home computing, and the ability to build simple, functional applications for this ubiquitous platform should be a part of every software developer's toolbox. Fortunately, for Python coders, that ability is well within reach thanks to Tkinter.

In this chapter, you will cover the following topics:

- Discovering Tkinter—a fast, fun, and easy-to-learn GUI library built right into the Python standard library
- Learning about IDLE—an editor and development environment written in Tkinter and bundled with Python
- Creating two `Hello World` applications to learn the basics of writing a Tkinter GUI

Introducing Tkinter and Tk

The Tk widget library originates from the **Tool Command Language** (**Tcl**) programming language. Tcl and Tk were created by John Ousterman while he was a professor at Berkeley in the late 1980s as an easier way to program engineering tools being used at the university. Because of its speed and relative simplicity, Tcl/Tk rapidly grew in popularity among academic, engineering, and Unix programmers. Much like Python itself, Tcl/Tk originated on the Unix platform and only later migrated to macOS and Windows. Tk's practical intent and Unix roots still inform its design today, and its simplicity compared to other toolkits is still a major strength.

Tkinter is a Python interface to the Tk GUI library and has been a part of the Python standard library since 1994 with the release of Python version 1.1, making it the de facto GUI library for Python. Documentation for Tkinter, along with links for further study, can be found in the standard library documentation at `https://docs.python.org/3/library/tkinter.html`.

Choosing Tkinter

Python coders who want to build a GUI have several toolkit options to choose from; unfortunately, Tkinter is often maligned or ignored as a legacy option. To be fair, it's not a glamorous technology that you can describe in trendy buzzwords and glowing hype. However, Tkinter is not only adequate for a wide variety of applications, it also has the following advantages that can't be ignored:

- **It's in the standard library**: With few exceptions, Tkinter is available wherever Python is available. There is no need to install `pip`, create virtual environments, compile binaries, or search the web for installation packages. For simple projects that need to be done quickly, this is a clear advantage.
- **It's stable**: While Tkinter development has not stopped, it is slow and evolutionary. The API has been stable for years, the changes mainly being additional functionality and bug fixes. Your Tkinter code will likely run unaltered for years or decades to come.
- **It's only a GUI toolkit**: Unlike some other GUI libraries, Tkinter doesn't have its own threading library, network stack, or filesystem API. It relies on regular Python libraries for such things, so it's perfect for applying a GUI to existing Python code.
- **It's simple and no-nonsense**: Tkinter is straightforward, old-school object-oriented GUI design. To use Tkinter, you don't have to learn hundreds of widget classes, a markup or templating language, a new programming paradigm, client-server technologies, or a different programming language.

Tkinter is not perfect, of course. It also has the following disadvantages:

- **Look and feel**: It's often derided for its look and feel, which still bear a few artifacts from the 1990s Unix world. This has improved a great deal in the last few years, thanks to updates in Tk itself and the addition of themed widget libraries. We'll learn how to fix or avoid some of Tkinter's more archaic defaults throughout the book.

- **Complex widgets**: It also lacks more complex widgets, like rich text or HTML rendering widgets. As we'll see later in this book, Tkinter gives us the ability to create complex widgets by customizing and combining its simple ones.

Tkinter might be the wrong choice for a game UI or slick commercial application; however, for data-driven applications, simple utilities, configuration dialogs, and other business logic applications, Tkinter offers all that is needed and more.

Installing Tkinter

Tkinter is included in the Python standard library for the Windows and macOS distributions. That means that, if you have Python on these platforms, you don't need to do anything to install Tkinter.

However, we're going to be exclusively focused on Python 3.x for this book; so, you need to make sure that this is the version you've got installed.

Installing Python 3 on Windows

You can obtain Python 3 installers for Windows from the `python.org` website by performing the following steps:

1. Go to `http://www.python.org/downloads/windows`.
2. Select the latest Python 3 release. At the time of writing, the latest version is 3.6.4, with 3.7 promising to be out by publishing time.
3. Under the Files section, select the Windows executable installer appropriate to your system's architecture (x86 for 32-bit Windows, x86_64 for 64-bit Windows).
4. Launch the downloaded installer.
5. Click on Customize installation. Make sure the tcl/tk and IDLE option is checked (it should be by default).
6. Continue through the installer with all defaults.

Installing Python 3 on macOS

As of this writing, macOS ships with Python 2 and Tcl/Tk 8.5 built in. However, Python 2 is scheduled to be deprecated in 2020, and the code in this book will not work with it, so macOS users will need to install Python 3 to follow this book.

Let's perform the following steps to install Python3 on macOS:

1. Go to `http://www.python.org/downloads/mac-osx/`.
2. Select the latest Python 3 release. At the time of writing, the latest version is 3.6.4, but 3.7 should be out by publication time.
3. Under the Files section, select and download `macOS 64-bit/32-bit installer`.
4. Launch the `.pkg` file that you've downloaded and follow the steps of the install wizard, selecting defaults.

There is currently no recommended way to upgrade to Tcl/Tk 8.6 on macOS, though it can be done with third-party tools if you wish. Most of our code will work with 8.5, though special mention is made when something is 8.6 only.

Installing Python 3 and Tkinter on Linux

Most Linux distributions include both Python 2 and Python 3, however, Tkinter is not always bundled with it or installed by default.

To find out if Tkinter is installed, open a Terminal and try the following command:

```
python3 -m tkinter
```

This should open a simple window showing some information about Tkinter. If you get `ModuleNotFoundError` instead, you will need to use your package manager to install your distribution's Tkinter package for Python 3. In most major distributions, including Debian, Ubuntu, Fedora, and openSUSE, this package is called `python3-tk`.

Introducing IDLE

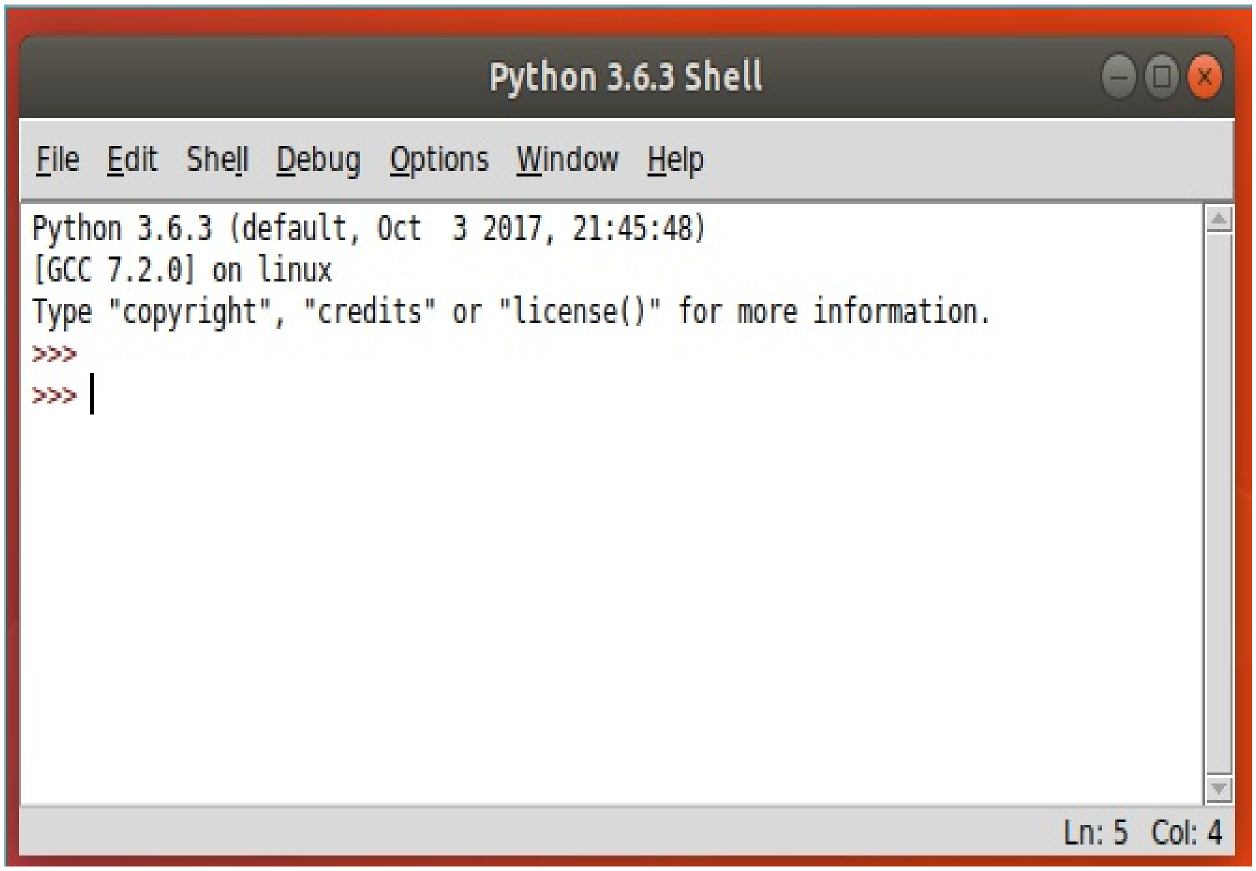
IDLE is an integrated development environment that is bundled with the Windows and macOS Python distributions (it's readily available in most Linux distributions as well, usually as IDLE or IDLE3). IDLE is written in Python using Tkinter, and it provides us with not only an editing environment for Python, but also a great example of Tkinter in action. So, while IDLE's rudimentary feature set may not be considered professional grade by many Python coders, and while you may already have a preferred environment for writing Python code, I encourage you to spend some time using IDLE as you go through this book.

Let's get familiar with IDLE's two primary modes: **shell** mode and **editor** mode.

Using the shell mode of IDLE

When you launch IDLE, you begin in shell mode, which is simply a Python **Read-Evaluate-Print-Loop** (**REPL**) similar to what you get when you type `python` in a terminal window.

Take a look at the shell mode in the following screenshot:



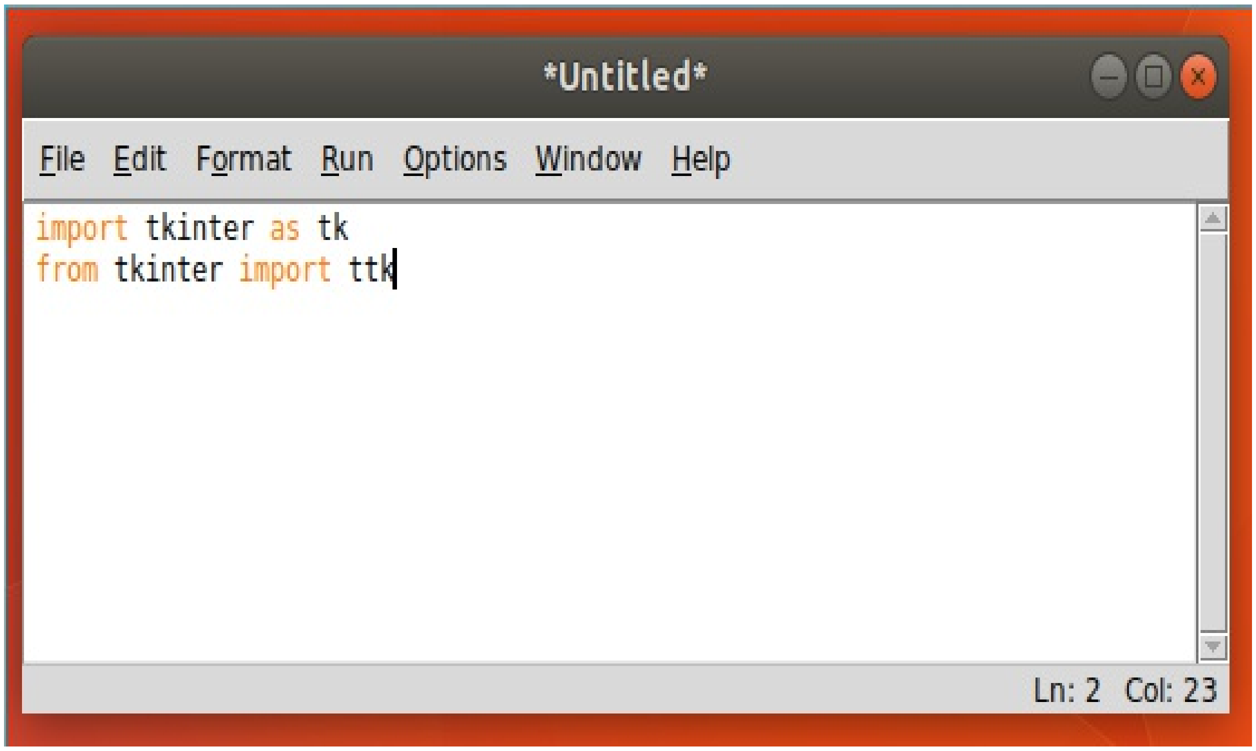
```
Python 3.6.3 (default, Oct  3 2017, 21:45:48)
[GCC 7.2.0] on linux
Type "copyright", "credits" or "license()" for more information.
>>>
>>> 
```

IDLE's shell has some nice features that you don't get from the command-line REPL, like syntax highlighting and tab-completion. The REPL is essential to the Python development process, as it gives you the ability to test code in real time and inspect classes and APIs without having to write complete scripts. We'll use the shell mode in later chapters to explore the features and behaviors of modules. If you don't have a shell window open, you can open one by clicking on Start, then selecting Run, and searching for Python shell.

Using the editor mode of IDLE

Editor mode is for creating Python script files, which you can later run. When the book tells you to create a new file, this is the mode you'll use. To open a new file in the editor mode, simply navigate to File | New File in the menu or hit *Ctrl* + *N* on the keyboard.

The following is a window where you can start typing a script:

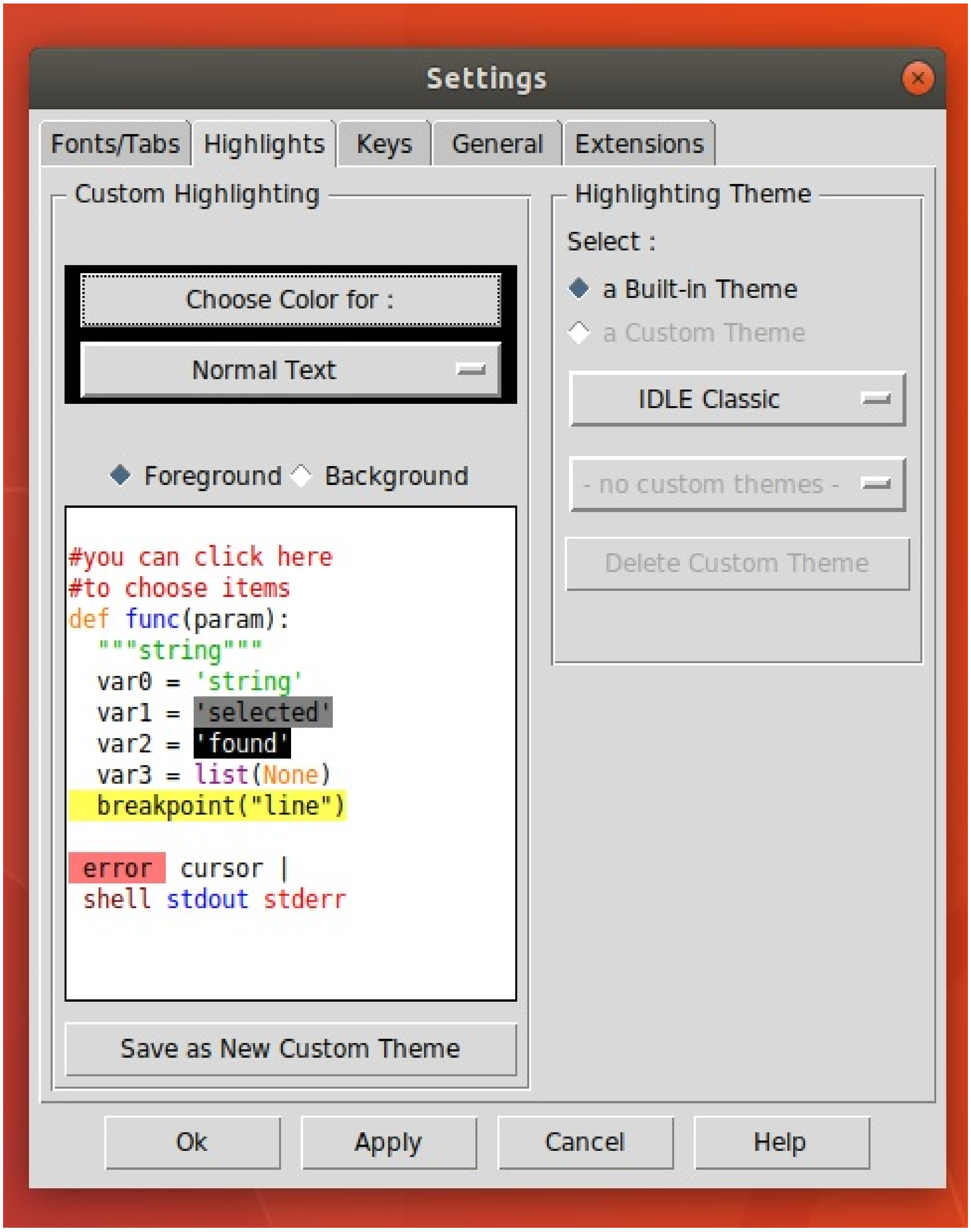


```
import tkinter as tk
from tkinter import ttk
```

You can run your script without leaving IDLE by hitting *F5* in the editor mode; the output will show up in a shell window.

IDLE as a Tkinter example

Before we start coding with Tkinter, let's take a quick look at what you can do with it by inspecting some of IDLE's UI. Navigate to Options | Configure IDLE from the main menu to open IDLE's configuration settings, where you can change IDLE's fonts, colors and theme, keyboard shortcuts, and default behaviors, as shown in the following screenshot:



Normal Text

[✓ Foreground] Background

```
#you can click here
#to choose items
def func(param):
  """string"""
  var0 = 'string'
  var1 = 'selected'
  var2 = 'found'
  var3 = list(None)
  breakpoint("line")

 error  cursor |
 shell stdout stderr
```

Select :

[✓ a Built-in Theme] a Custom Theme

IDLE Classic

- no custom themes -

Consider some of the following components that make up this user interface:

- There are drop-down lists and radio buttons that allow you to select between different options
- There are many push buttons that you can click on to execute actions
- There is a text window that can display multi-colored text
- There are labeled frames that contain groups of components

Each of these components is known as a **widget**; we're going to meet these widgets and more throughout this book and learn how to use them as they've been used here. We'll begin, however, with something much simpler.

Creating a Tkinter Hello World

Let's learn the basics of Tkinter by creating a simple `Hello World` script for Tkinter by performing the following steps:

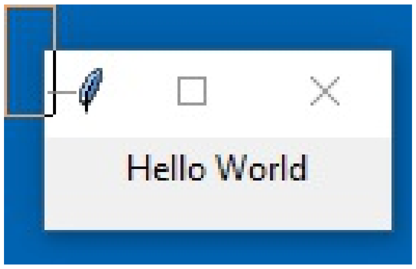
1. Create a new file in IDLE or your favorite editor, enter the following code, and save it as `hello_tkinter.py`:

```
"""Hello World application for Tkinter"""

from tkinter import *
from tkinter.ttk import *

root = Tk()
label = Label(root, text="Hello World")
label.pack()
root.mainloop()
```

2. Run this in IDLE by hitting *F5* or in your terminal by typing the following command:

```
python3 hello_tkinter.py
```

   You should see a very tiny window pop up with the text Hello World as shown in the following screenshot:



3. Close the window and return to your editor screen. Let's break down this code and talk about what it does:
   - `from tkinter import *`: This imports the Tkinter library into the global namespace. This isn't best practice, because it fills your namespace with a lot of classes, which you might accidentally overwrite, but it's okay for very small scripts.

- `from tkinter.ttk import *`: This imports the `ttk` or **themed** Tk widget library. We'll be using this library throughout the book, as it adds a number of useful widgets and improves the look of existing widgets. Since we're doing the star import here, our Tk widgets will be replaced by the better-looking `ttk` widgets wherever applicable (for instance, our `Label` object).
- `root = Tk()`: This creates our root or master application object. This represents the primary top-level window and main execution thread of the application, so there should be one and only one instance of Tk for every application.
- `label = Label(root, text="Hello World")`: This creates a new `Label` object. As the name implies, a `Label` object is just a widget for displaying text (or images). Looking closer at this line, we see the following:
  - The first argument we pass to `Label()` is the `parent` or master widget. Tkinter widgets are arranged in a hierarchy starting with the root window, each widget being contained by another. Any time you create a widget, your first argument will be the widget object that contains the new widget. In this case, we're placing our `Label` object on the main application window.
  - The second argument is a keyword argument that specifies the text to be displayed on the `Label` object.
  - We store the new `Label` instance in a variable, `label`, so that we can do more to it later.
- `label.pack()`: This places the new label widget onto its `parent` widget. In this case, we're using the `pack()` method, which is the simplest of three **geometry manager** methods you can use. We'll learn about these in more detail in future chapters.
- `root.mainloop()`: This final line starts our main event loop. This loop is responsible for processing all the events—keystrokes, mouse clicks, and so on—and it will run until the program is quit. This is usually the last line of any Tkinter script, since any code after it won't run until the main window is closed.

Take a few moments and play around with this script by adding more widgets before the `root.mainloop()` call. You can add more `Label` objects or try `Button` (which creates a clickable button) or `Entry` (which creates a text entry field).

Just like `Label`, these widgets are initialized with a `parent` object (use `root`) and a `text` parameter. Don't forget to call `pack()` on your widget to add them to the window.

You can also try commenting out the `ttk` import, to see if you notice a difference in the look of the widgets. Depending on your OS, it may look different or not.

Creating a better Hello World Tkinter

Creating a GUI the way we just did works okay for very small scripts, but a much more scalable approach is to subclass Tkinter widgets to create component widgets that we will then assemble into a completed application.

> ***Subclassing*** *is simply a way of creating a new class based on an existing one, adding or changing only what is different in the new class. We will use subclassing extensively in this book to extend the functionality of Tkinter widgets.*

Let's build a more robust `Hello World` script that demonstrates some patterns we'll use throughout the remainder of the book. Take a look at the following steps:

1. Create a file called `better_hello_tkinter.py` and begin with the following lines:

```
"""A better Hello World for Tkinter"""
import tkinter as tk
from tkinter import ttk
```

   This time, we aren't doing the star imports; instead, we'll keep Tkinter and the `ttk` objects in their own namespaces. This keeps our global namespace from being cluttered up and eliminates a potential source of bugs.

> *Star imports (`from module import *`) are seen often in Python tutorials and example code, but in production code they should be avoided. Python modules can contain any number of classes, functions, or variables; when you do a star import, you import all of them, which can lead to one import overwriting the objects imported from another module. If you find a module name cumbersome to type over and over, alias it to something short, as we've done with Tkinter.*

2. Next, we create a new class called `HelloView`, as follows:

```
class HelloView(tk.Frame):
    """A friendly little module"""

    def __init__(self, parent, *args, **kwargs):
        super().__init__(parent, *args, **kwargs)
```

Our class is subclassed from `Tkinter.Frame`. The `Frame` class is a generic Tk widget that is typically used as a container for other widgets. We can add any number of widgets to the `Frame` class, then treat the whole thing as though it were a single widget. This is a lot simpler in the long run than individually placing every last button, label, and input on a single master window. The first order of business in the constructor is to call `super().__init__()`. The `super()` function gives us a reference to the super class (the class we've subclassed, in this case, `tk.Frame`). By calling the super class constructor and passing along `*args` and `**kwargs`, our new `HelloWidget` class can take any arguments that `Frame` can take.

In older versions of Python, `super()` had to be invoked with the name of the child class and a reference to the current instance, such as `super(MyChildClass, self)`. Python 3 allows you to call it with no arguments, but you will probably encounter code that uses the older invocation.

3. Next, we're going to create two Tkinter variable objects to store the name and greeting strings, as follows:

```
        self.name = tk.StringVar()
        self.hello_string = tk.StringVar()
        self.hello_string.set("Hello World")
```

Tkinter has a collection of variable types including `StringVar`, `IntVar`, `DoubleVar`, and `BooleanVar`. You might wonder why we'd use these when Python has perfectly good data types for all of these (and more!). Tkinter variables are more than just containers for data: they have special functionality that regular Python variables lack, such as the ability to automatically propagate changes to all the widgets that reference them or trigger an event when they're changed. Here we'll use them as a way to access the data in a widget without having to keep or pass around references to the widget itself.

Notice that setting a value to a Tkinter variable requires use of the `set()` method, rather than direct assignment. Likewise, retrieving the data requires use of a `get()` method. Here, we set the value of `hello_string` to `Hello World`. We start building our view by creating a `Label` object and `Entry`, as follows:

```
        name_label = ttk.Label(self, text="Name:")
        name_entry = ttk.Entry(self, textvariable=self.name)
```

The `Label()` invocation looks familiar, but the `Entry` object gets a new argument: `textvariable`. By passing a Tkinter `StringVar` variable to this argument, the contents of the `Entry` box will be bound to the variable, and we can access it without needing to reference the widget. Whenever a user enters text in the `Entry` object, `self.name` will immediately be updated wherever it appears.

4. Now, let's create `Button`, as follows:

```
            ch_button = ttk.Button(self, text="Change",
                command=self.on_change)
```

In the preceding code, we again have a new argument, `command`, which takes a reference to a Python function or method. We call a function or method passed this way a callback, and, as you might expect, this callback will be called when the button is clicked. This is the simplest way to bind functions to a widget; later, we'll learn a more flexible method that will allow us to bind various keystrokes, mouse clicks, and other widget events to function or method calls.

Make sure you don't actually call your callback at this point—it should be `self.on_change`, not `self.on_change()`. The callback should be a reference to the function or method, not the output from it.

5. Let's create another `Label`, as follows, this time to display our text:

```
        hello_label = ttk.Label(self, textvariable=self.hello_string,
            font=("TkDefaultFont", 64), wraplength=600)
```

Here we've passed our other `StringVarvariable` variable, `self.hello_string` to the `textvariable` argument; on a label, the `textvariable` variable determines what will be displayed. By doing this, we can change the text on the label by simply changing `self.hello_string`. We'll also set a much larger font by using the `font` argument, which takes a tuple in the format `(font_name, font_size)`.

You can enter any font name you want here, but it must be installed on the system to work. Tk has some built-in aliases that map to sensible fonts on every platform, such as `TkDefaultFont` used here. We'll learn more about using fonts in Tkinter in `Chapter 8`, Improving the Look with Styles and Themes.

The wraplength argument specifies how wide the text can be before it wraps to the next line. We want our text to wrap when it reaches the edge of the window; by default, label text does not wrap, so it would be cut off at the edge of the window. By setting the wrap length to 600 pixels, our text will wrap at the width of the screen.

6. So far, our widgets have been created, but not yet placed on HelloView. Let's arrange our widgets as follows:

```
name_label.grid(row=0, column=0, sticky=tk.W)
name_entry.grid(row=0, column=1, sticky=(tk.W + tk.E))
        ch_button.grid(row=0, column=2, sticky=tk.E)
        hello_label.grid(row=1, column=0, columnspan=3)
```

In this case, we're adding our widgets using the grid() geometry manager, rather than the pack() geometry manager we used before. As the name implies, grid() allows us to position widgets on their parent object using rows and columns, much like a spreadsheet or HTML table. Our first three widgets are arranged across three columns in row 0, while hello_label will be on the second row (row 1). The sticky argument takes a cardinal direction (N, S, E, or W—you can either use strings or the Tkinter constants), which specifies which side of the cell the contents must stick to. You can add these together to stick the widget to multiple sides; for example, by sticking the name_entry widget to both the east and west sides, it will stretch to fill the whole width of the column. The grid() call for hello_label uses the columnspan argument. As you might expect, this causes the widget to span three grid columns. Since our first row established three columns for the grid layout, we need to span all three if we want this widget to fill the width of the application. Finally, we'll finish the __init__() method by adjusting the grid configuration:

```
self.columnconfigure(1, weight=1)
```

In the preceding code, the columnconfigure() method is used to make changes to a widget's grid columns. Here, we're telling it to weight column 1 (the second column) more than the others. By doing this, the second column of the grid (where our entry lives) will expand horizontally and squash surrounding columns to their minimum widths. There is also a `rowconfigure()` method for making similar changes to grid rows.

7. Before we finish our `HelloModule` class, we have to create the callback for `ch_button`, as follows:

```
        def on_change(self):
            if self.name.get().strip():
                self.hello_string.set("Hello " + self.name.get())
            else:
                self.hello_string.set("Hello World")
```

    To get the value of the text entry, we call the `get()` method of its text variable. If this variable contains any characters (notice we strip the white space), we'll set our hello text to greet the name entered; otherwise, we'll just greet the whole world.

Notice by using the `StringVar` objects we don't have to interact directly with the widgets. This saved us from having to keep a lot of widget references in our class, but, more importantly, our variable could be updated from any number of sources or update any number of destinations without us having to explicitly write code to do so.

8. With `HelloView` created, we move onto the actual application class, as follows:

```
        class MyApplication(tk.Tk):
            """Hello World Main Application"""

            def __init__(self, *args, **kwargs):
                super().__init__(*args, **kwargs)
                self.title("Hello Tkinter")
                self.geometry("800x600")
                self.resizable(width=False, height=False)
```

    This time, we subclass `Tk`, which will represent our main application object. There is some debate in the Tkinter world whether or not this is best practice. Since there can be only one `Tk` object in the application, it could theoretically create problems if we want multiple `MyApplication` objects somewhere down the line; for simple, single-window applications, it's perfectly fine.

9. As with our module, we call `super().__init__()` and pass along any

arguments. Notice we don't need a `parent` widget this time, since the `Tk` object is the root window and has no `parent`. Then there are the following three calls to configure our application window:

- `self.title()`: This call sets the window title, which usually appears in the task list and/or window bar in our OS environment.
- `self.geometry()`: This call sets the size of our window in pixels, in the format `x * y` (width x height).
- `self.resizable()`: This call sets whether the program window can be resized. We're disabling resizing here, both in width and height.

10. We finish our application class by adding our view to the main window, as follows:

```
        HelloView(self).grid(sticky=(tk.E + tk.W + tk.N + tk.S))
        self.columnconfigure(0, weight=1)
```

Notice that we create and place `HelloView` in a single line of code. We do this in situations where we don't need to keep a reference to the widget, but since `grid()` does not return a value, you'll have to stick to the two-statement version if you want to access the widget later in your code.

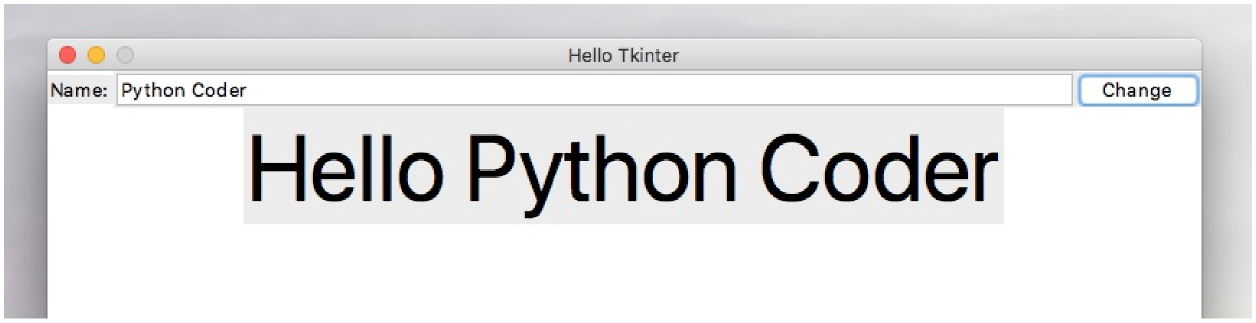
Because we want the view to fill the application window, our `grid()` call sticks it to all sides of its cell, and our `columnconfigure()` call causes the first column to expand. Note that we've omitted the `row` and `column` arguments; without them, and `grid()` simply uses the first column of the next available row (in this case, `0`, `0`).

11. With our classes defined, we'll start the actual execution of the code, as follows:

```
if __name__ == '__main__':
    app = MyApplication()
    app.mainloop()
```

In Python, `if __name__ == '__main__':` is a common idiom to check if a script is being run directly, such as when we type `python3 better_hello_world.py` at a terminal. If we were to import this file as a module into another Python script, this check would be false and the code after would not be run. It's a good practice to put your program's main execution code below this check so that you can safely reuse your classes and functions in larger applications.

Remember that `MyApplication` is a subclass of `Tk`, so it acts as the root window. We only need to create it and then start its main loop. Take a look at the following screenshot:



This was certainly overkill for a `Hello World` application, but it demonstrates the use of subclassing to segment our application into modules, which will vastly simplify layouts and code organization as we build larger programs.

Summary

Now that you've installed Python 3, learned to use IDLE, gotten a taste of the simplicity and power of Tkinter, and have seen how to begin structuring it for more complicated applications, it's time to start writing a real application.

In the next chapter, you'll start your new job at ABQ AgriLabs and be presented with a problem that will need to be solved with your programming skills and Tkinter. You will learn how to dissect this problem, develop a program specification, and design a user-friendly application that will be part of the solution.

Designing GUI Applications with Tkinter

Software applications are developed in three repeating phases: understanding a problem, designing a solution, and implementing the solution. These phases repeat throughout the life of an application, refining and honing it until it is either optimal or obsolete.

In this chapter, we'll learn about the following topics:

- Introducing and analyzing a scenario in the workplace that will need a software solution
- Documenting the requirements of the solution
- Developing a design for a piece of software that implements the solution

A problem at ABQ AgriLabs

Congratulations! Your Python skills have landed you a great data analyst job at ABQ AgriLabs. So far, your job is fairly simple: collating and doing simple data analysis on the CSV files sent to you daily from the lab's data entry staff.

There is a problem, though. You've noted with frustration that the quality of the CSV files from the lab is sadly inconsistent. Data is missing, typos abound, and often the files have to be re-entered in a time-consuming process. The lab director has noticed this as well and, knowing that you are a skilled Python programmer, she thinks you might be able to help.

You've been enlisted to program a solution that will allow the data entry staff to enter lab data into a CSV file with fewer mistakes. Your application needs to be simple and allow as little room for error as possible.

Assessing the problem

Spreadsheets are often a first stop for computer users who need to keep track of data. Their table-like layouts and computational features seem to make them ideal for the task. However, as a set of data grows and is added to by multiple users, the shortcomings of spreadsheets become apparent: they don't enforce data integrity, their table-like layout can be visually confusing when dealing with long rows of sparse or ambiguous data, and users can easily delete or overwrite data if they aren't being careful.

To improve this situation, you propose to implement a simple GUI data entry form that appends data to a CSV file in the format we need. Forms can help to improve data integrity in the several ways:

- Allowing only the correct type of data to be entered (for example, only allowing numerals in a number field)
- Limiting choices to only valid options
- Auto-filling information like current dates, times, and so on
- Verifying that entered data is within expected ranges or matches expected patterns
- Ensuring that all data has been filled in

By implementing such a form, we can greatly reduce the number of errors being entered by the data entry staff.

Gathering information about the problem

To build the data entry form application, you need to gather details about what it needs to accomplish. Fortunately, you already know the output part of the equation: you need a CSV file containing data about the plants growing in the plots of each laboratory and the environmental conditions at each plot. You work with these files every day, so you're pretty familiar with the field layout.

However, you don't know everything about the data or the process of entering it; you'll need to talk to the other staff involved to find out more information.

First, you'll need to find out more detail about the data being recorded. This isn't always as easy as it sounds. Software needs absolute, black-and-white rules when dealing with data; people, on the other hand, tend to think in generalities about their data, and they often don't consider the exact details of limits or edge cases without some prompting.

As a programmer, it's your job to come up with questions that will bring out the information you need.

You decide you should start with the lab technicians and learn more about the data they're collecting. You come up with the following questions:

- What values are acceptable for each field? Are any fields constrained to a set of values?
- What units are represented by each of the numeric fields?
- Are numeric fields truly number-only fields? Would they ever need letters or symbols?
- What range of numbers is acceptable for each numeric field?
- How do you record data and how long does it take?

Data isn't the only consideration. If we're making a program to help reduce user error, we also have to understand those users and how they work. In the case of this application, our users will be the data entry staff. We need to ask them questions about their needs and workflow to understand how to create an application that works well for them.

We come up with the following list of questions:

- In what format do you get the data you're entering?
- When is the data received and how soon is it entered? What's the latest it might be entered?
- Are there fields that could be automatically populated? Should users be able to override the auto values?
- What's the overall technical ability of the users?
- What do you like about the current solution? What do you dislike?
- Do users have visual or manual impairments that should be accommodated?

Finally, we need to understand the technology involved with operating our application—the computers, networks, servers, and platforms being used to accomplish the task.

You decide to add the following questions, which you'll assess yourself when you meet with the data entry staff:

- What kind of computer does data entry use?
- What platform does it run?
- How fast or powerful is it?
- Is Python available on these systems?
- Which Python libraries are available?

What you found out

You start by writing down the following basics about ABQ that you know:

- Your ABQ facility has five greenhouses, each operating with a different climate, marked A, B, C, D, and E
- Each greenhouse has 20 plots (labeled 1 through 20)
- There are currently four seed samples, each coded with a six-character label
- Each plot has 20 seeds of a given sample planted in it, as well as its own environmental sensor unit

Information about the data being collected

Your talk with the lab technicians revealed a lot about the data. Four times a day, at 8:00, 12:00, 16:00, and 20:00, each technician checks the plots in one or two labs. They use a paper form to record values at each plot, recording all values to two decimal places. This usually takes 30 to 40 minutes per lab, and the whole process typically takes 90 minutes.

Each plot has an environmental sensor that detects the light, temperature, and humidity at the plot. Unfortunately, these devices are prone to failure, indicated by an `Equipment Fault` light on the unit. Technicians record if this light is lit, since it invalidates the environmental data.

Finally, the technicians tell you about the units and acceptable ranges for the fields, which you record in the following chart:

Field	Data type	Notes
`Date`	`Date`	The data collection date. Almost always the current date
`Time`	`Time`	The start of the period during which measurements were taken. One of 8:00, 12:00, 16:00, or 20:00
`Lab`	`Character`	The lab ID, which will be A to E
`Technician`	`Text`	The name of the technician recording data
`Plot`	`Int`	The plot ID, which will be 1 through 20
`Seed Sample`	`Text`	ID string for seed sample. Always a six-character code containing digits 0 to 9 and capital letters A to Z

Fault	Boolean	True if environmental equipment registered a failure, otherwise false
Humidity	Decimal	Absolute humidity in g/m^3, roughly between 0.5 and 52.0
Light	Decimal	Amount of sunlight at the plot center in kilolux, between 0 and 100
Temperature	Decimal	Degrees C, should not go below 4 or above 40
Blossoms	Int	The number of blossoms in the plot must be 0 or more, but unlikely to ever approach 1,000
Fruit	Int	The number of fruits in the plot must be 0 or more, but unlikely to ever approach 1,000
Plants	Int	The number of growing plants, between 0 and 20.
Max height	Decimal	The height of the tallest plant in cm. At least 0, unlikely to approach 1,000.
Median height	Decimal	The median height of plants in the plot, in cm. At least 0, unlikely to approach 1,000
Min height	Decimal	The height of the smallest plant in cm. At least 0, unlikely to approach 1,000
Notes	Long Text	Additional observations about the plant, data, instruments, and so on

Information about the users of the application

Your session with the data entry staff yielded good information about their workflow, requirements, and technology.

The lab technicians drop off their paper forms as they're completed. The data is typically entered right away and usually on the same day as it's handed in.

The technicians are currently using LibreOffice on a Debian Linux workstation to enter the data. Using copy and paste, they can bulk-fill fields with repeated data like date, time, and technician. The autocompletion feature of LibreOffice is often helpful in text fields, but sometimes causes accidental data errors in the number fields.

The workstation being used is several years old, but performs adequately. You get a chance to look at it and find that Python and Tkinter are already installed.

There are four data entry clerks in total, but only one working at any one time; while interviewing the clerks, you learn that one has red-green color blindness, and another has trouble using a mouse due to RSI issues. All are reasonably computer literate.

Documenting specification requirements

Now that you've assembled your data about the application, it's time to write up a **specification**. Software specifications can range from very formal, contractual documents that include time estimates and deadlines, to a simple set of descriptions of what the programmer intends to build. The purpose of the specification is to give everyone involved in the project a point of reference for what the developer will create. It spells out the problem to be solved, the functionality required, and the scope of what the program should and shouldn't do.

Your scenario is rather informal and your application is simple, so you do not need a detailed formal specification in this case. However, a basic write-up of what you know will make sure that you, your boss, and the users are all on the same page.

Contents of a simple specification

We'll start our specification with the following outline of the items we need to write:

- **Description**: This is one or two sentences that describe the primary purpose, function, and goals of the application. Think of it as the program's mission statement.
- **Functionality required**: This section is a list of specific things the program needs to be able to do to be minimally functional. It can include both hard requirements, such as detailed output and input formats, and soft requirements—goals that are not quantifiably attainable, but that the program should strive toward (for example, "reduce user errors as much as possible").
- **Functionality not required**: This section is a list of things the program does not need to do; it exists to clarify the scope of the software and make sure nobody expects unreasonable things from the application.
- **Limitations**: This is a list of constraints under which the program must operate, both technological and human.

- **Data dictionary**: This is a detailed list of the data fields the application will deal with and their parameters. These can get quite lengthy but are a critical reference as the application expands and the data gets utilized in other contexts.

Writing the ABQ data entry program specification

You could write a specification in your favorite word processor, but ideally the specification is a part of your code; it will need to be kept with the code and synchronized with any changes to the application. For that reason, we're going to write it in our text editor using the **reStructuredText** markup language.

For Python documentation, reStructuredText, or reST, is the official markup language. The Python community encourages the use of reST to document Python projects, and many packaging and publication tools used in the Python community expect the reST format. We'll cover reST in more depth in `Chapter 5`*, Planning for the Expansion of Our Application, but you can find the official documentation at* `http://docutils.sourceforge.net/rst.html`*.*

Let's begin writing our specification, one section at a time as follows:

1. Begin the specification with the name of the application and a short description. This should contain a summary of the program's purpose, as follows:

```
======================================
 ABQ Data Entry Program specification
======================================

Description
-----------
The program is being created to minimize data entry errors for lab
```

2. Now, let's list the requirements. Remember that hard requirements are objectively attainable goals—input and output requirements, calculations that must be done, features that must be present, whereas our soft requirements are subjective or best-effort goals. Look through your findings from the last section, and consider which needs are which. You should come up with something like the following:

```
Functionality Required
----------------------
```

```
        The program must:

        * allow all relevant, valid data to be entered, as per the field cl
        * append entered data to a CSV file
          - The CSV file must have a filename
            of abq_data_record_CURRENTDATE.csv, where
            CURRENTDATE is the date of the checks in
            ISO format (Year-month-day)
          - The CSV file must have all the fields as per the chart
        * enforce correct datatypes per field

        The program should try, whenever possible, to:

        * enforce reasonable limits on data entered
        * Auto-fill data
        * Suggest likely correct values
        * Provide a smooth and efficient workflow
```

3. Next, we'll reign in the scope of the program with the `Functionality Not Required` section. Remember that this is only an entry form for now; editing or deletion will be handled in the spreadsheet application. We'll clarify this as follows:

```
        Functionality Not Required
        --------------------------

        The program does not need to:

        * Allow editing of data. This can be done in LibreOffice if necess
        * Allow deletion of data.
```

4. For the `Limitations` section, remember that we have some users with physical constraints, as well has hardware and operating system constraints. Add it as follows:

```
    Limitations
    -----------

    The program must:

    * Be efficiently operable by keyboard-only users.
    * Be accessible to color blind users.
    * Run on Debian Linux.
    * Run acceptably on a low-end PC.
```

5. Finally, the data dictionary, this is essentially the table we've made previously, but we'll break out range, data types, and units for quick reference, as follows:

```
    +-----------+---------+-----+------------+-------------------+
```

Field	Datatype	Units	Range	Descripton
Date	Date			Date of record
Time	Time		8, 12, 16, 20	Time period
Lab	String		A - E	Lab ID
Technician	String			Technician name
Plot	Int		1 - 20	Plot ID
Seed sample	String			Seed sample ID
Fault	Bool			Fault on sensor
Light	Decimal	klx	0 - 100	Light at plot
Humidity	Decimal	g/m^3	0.5 - 52.0	Abs humidity at plot
Temperature	Decimal	°C	4 - 40	Temperature at plot
Blossoms	Int		0 - 1000	# blossoms in plot
Fruit	Int		0 - 1000	# fruits in plot
Plants	Int		0 - 20	# plants in plot
Max height	Decimal	cm	0 - 1000	Ht of tallest plant
Min height	Decimal	cm	0 - 1000	Ht of shortest plant
Median height	Decimal	cm	0 - 1000	Median ht of plants
Notes	String			Miscellaneous notes

That's our specification for now! The specification is very likely to grow, change, or evolve in complexity as we discover new needs.

Designing the application

With our specification in hand and our requirements clear, it's time to start designing our solution. We'll start with the form GUI component itself.

We're going to create a basic design for our form in the following three steps:

1. Determine the appropriate `input` widget for each data field
2. Group together related items to create a sense of organization
3. Layout our widgets in their groups on a form sheet

Exploring Tkinter input widgets

Like all toolkits, Tkinter offers a variety of `input` widgets for different kinds of data. However, `ttk` offers additional widget types and enhances some (but not all!) of Tkinter's native widgets. The following table offers advice on which widgets are most appropriate for different kinds of data entry:

Widget	Description	Used for
`ttk.Entry`	Basic text entry	Single-line strings
`ttk.Spinbox`	Text entry with increment/decrement arrows	Numbers
`Tkinter.Listbox`	Box with a list of choices	Choice between several values
`Tkinter.OptionMenu`	Drop-down list with choices	Choice between several values
`ttk.Combobox`	Drop-down list with optional text entry	Choice between several values plus text entry
`ttk.Checkbutton`	Checkbox with label	Boolean values
`ttk.Radiobutton`	Like checkbox, but only one of a set can be selected	Choice between small set of values
`Tkiner.Text`	Multiline text entry box	Long, multiline strings
`Tkinter.Scale`	Mouse-operated slider	Bounded number data

Let's consider which of these widgets are appropriate for the data that needs to be entered:

- There are several `Decimal` fields, many with clear boundary ranges with `Min height`, `Max height`, `Median height`, `Humidity`, `Temperature`, and `Light`. You could use a `Scale` widget for these, but it's not really appropriate for precise data entry, since it requires careful positioning to get an exact value. It's also mouse-operated and that violates your specification requirements. Instead, use the `Spinbox` widget for these.

- There are also some `Int` fields, such as `Plants`, `Blossoms`, and `Fruit`. Again, the `Spinbox` widget is the right choice.
- There are a couple of fields with a limited set of possible values—`Time` and `Lab`. The `Radiobutton` or `Listbox` widgets could work for these, but both take up a lot of space and are less keyboard-friendly as they require selection with arrow keys. There is also `OptionMenu`, but it is also mouse or arrow keys only. For these, use the `Combobox` widget instead.
- Plot is a tricky case. At face value, it looks like an `Int` field, but think about it. The plots could just as well be identified by letters, or symbols, or names. Numbers just happen to be an easy set of values with which to assign arbitrary identifiers. The `Plot ID`, like the `Lab ID`, is a constrained set of values; so, it would make more sense to use a `Combobox` widget here.
- The `Notes` field is multiline text, so the `Text` widget is appropriate here.
- There is one `Boolean` field, `Fault`. It could be handled with `Radiobutton` or `Combobox`, but `Checkbutton` is the optimal choice—it's compact and reasonably keyboard-friendly.
- The remaining lines are simple, one-line character fields. We'll use `Entry` for those fields.
- You might be wondering about the `Date` field. Tkinter has no special widget for dates; so, we'll use a generic `Entry` widget here for the time being.

Our final analysis will be as follows:

Field	Widget type
`Blossoms`	`ttk.Spinbox`
`Date`	`ttk.Entry`
`Fault`	`ttk.Checkbutton`
`Fruit`	`ttk.Spinbox`
`Humidity`	`ttk.Spinbox`
`Lab`	`ttk.Combobox`
`Light`	`ttk.Spinbox`

Max height	ttk.Spinbox
Median height	ttk.Spinbox
Min height	ttk.Spinbox
Notes	Tkinter.Text
Plants	ttk.Spinbox
Plot	ttk.Combobox
Seed Sample	ttk.Entry
Technician	ttk.Entry
Temperature	ttk.Spinbox
Time	ttk.Combobox

Grouping our fields

Humans tend to get confused when staring at a huge wall of inputs in no particular order. You can do your users a big favor by breaking up the input form into sets of related fields. Of course, that assumes that your data has related sets of fields, doesn't it?

After looking over your fields, you identify the following related groups:

- The `Date`, `Lab`, `Plot`, `Seed Sample`, `Technician`, and `Time` fields are identifying data or metadata about the record itself. You could group these together under a heading like `Record information`.
- The `Blossoms`, `Fruit`, three `Height` fields, and `Plants` fields are all measurements that have to do with the plants in the `Plot` field. You could group these together as `Plant data`.
- The `Humidity`, `Light`, `Temperature`, and `Equipment Fault` fields, are all information from the environmental sensor. You could group these as `Environmental data`.
- The `Notes` field could be related to anything, so it's in a category of its own.

To group the preceding fields in Tkinter, we could just insert labels between each set of fields, but it's worth exploring the various options we have for grouping widgets together:

Widget	Description
`ttk.LabelFrame`	Frame with label text and an optional border
`ttk.NoteBook`	Tabbed widget that allows multiple pages
`Tkinter.PanedWindow`	Allows for multiple re-sizable frames in horizontal or vertical arrangement

We don't want our form on multiple pages, nor will users need to resize the sections, but the `LabelFrame` widget sounds perfect for our needs.

Laying out the form

So far, we know that we have 17 inputs, which are grouped as follows:

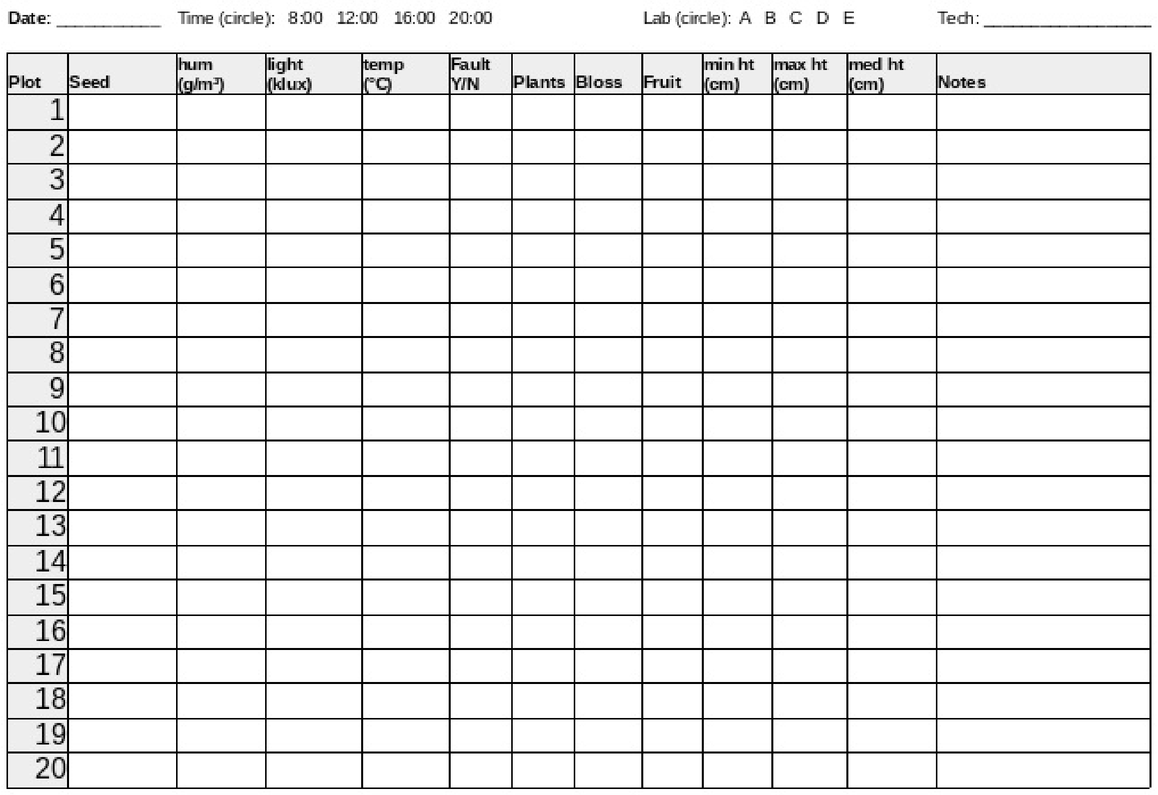
- Six fields under `Record information`
- Four fields under `Environmental data`
- Six fields under `Plant data`
- One large `Notes` field

We want to group the preceding inputs using `LabelFrame`.

Notice that two of the first three sections have widgets in multiples of three. That suggests that we could arrange them in a grid with three items across. How should we order the fields within each group?

Ordering of fields seems like a trivial item, but for the user it can make a significant difference in usability. Users who have to jump around a form haphazardly to match their workflow are more likely to make mistakes.

As you learned, the data is entered from paper forms filled out by the lab technicians. You obtained a copy of the form, as shown in the following screenshot:



Date: ___________ Time (circle): 8:00 12:00 16:00 20:00 Lab (circle): A B C D E Tech: _________________

Plot	Seed	hum (g/m³)	light (klux)	temp (°C)	Fault Y/N	Plants	Bloss	Fruit	min ht (cm)	max ht (cm)	med ht (cm)	Notes
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

It looks like items are mostly grouped the way our records are grouped, so we'll use the ordering on this form to order our fields. That way, data entry clerks can zip right through the form without having to bounce around the screen.

TIP *When designing a new application to replace some part of an existing workflow, it's important to learn and respect that workflow. While we'll have to adjust that workflow to actually improve it, we don't want to make another part of someone's job harder just to make the part we're working on simpler.*

One last consideration in our design is where to place field labels in relation to the fields. There is a good deal of debate in the UI design community over the best placement of labels, but the consensus is that one of the following two options is best:

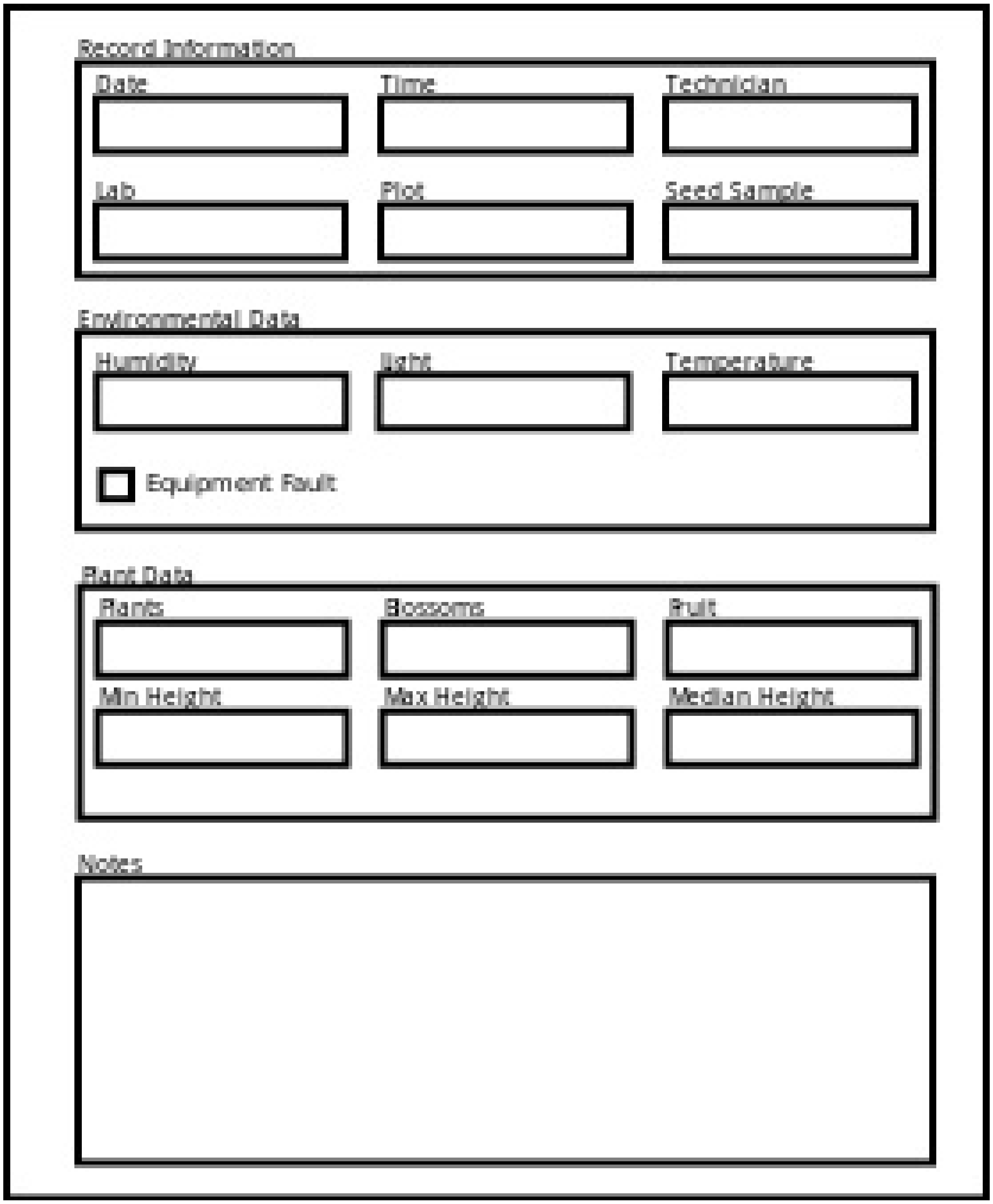
- Labels above fields
- Labels to the left of fields

You might try sketching out both to see which you prefer, but for this application labels above fields will probably work better for the following reasons:

- Since both fields and labels are rectangular in shape, our form will be more compact by stacking them
- It's a lot easier to make the layout work, since we don't have to find a label width that works for all the labels without distancing them too far from the fields

The one exception is the check button field; check buttons are typically labeled to the right of the widget.

Take a moment to make a mockup of your form, using paper and pencil, or a drawing program. Your form should look as follows:



Record Information

Date	Time	Technician
Lab	Plot	Seed Sample

Environmental Data

Humidity	light	Temperature

☐ Equipment Fault

Plant Data

Plants	Blossoms	Fruit
Min Height	Max Height	Median Height

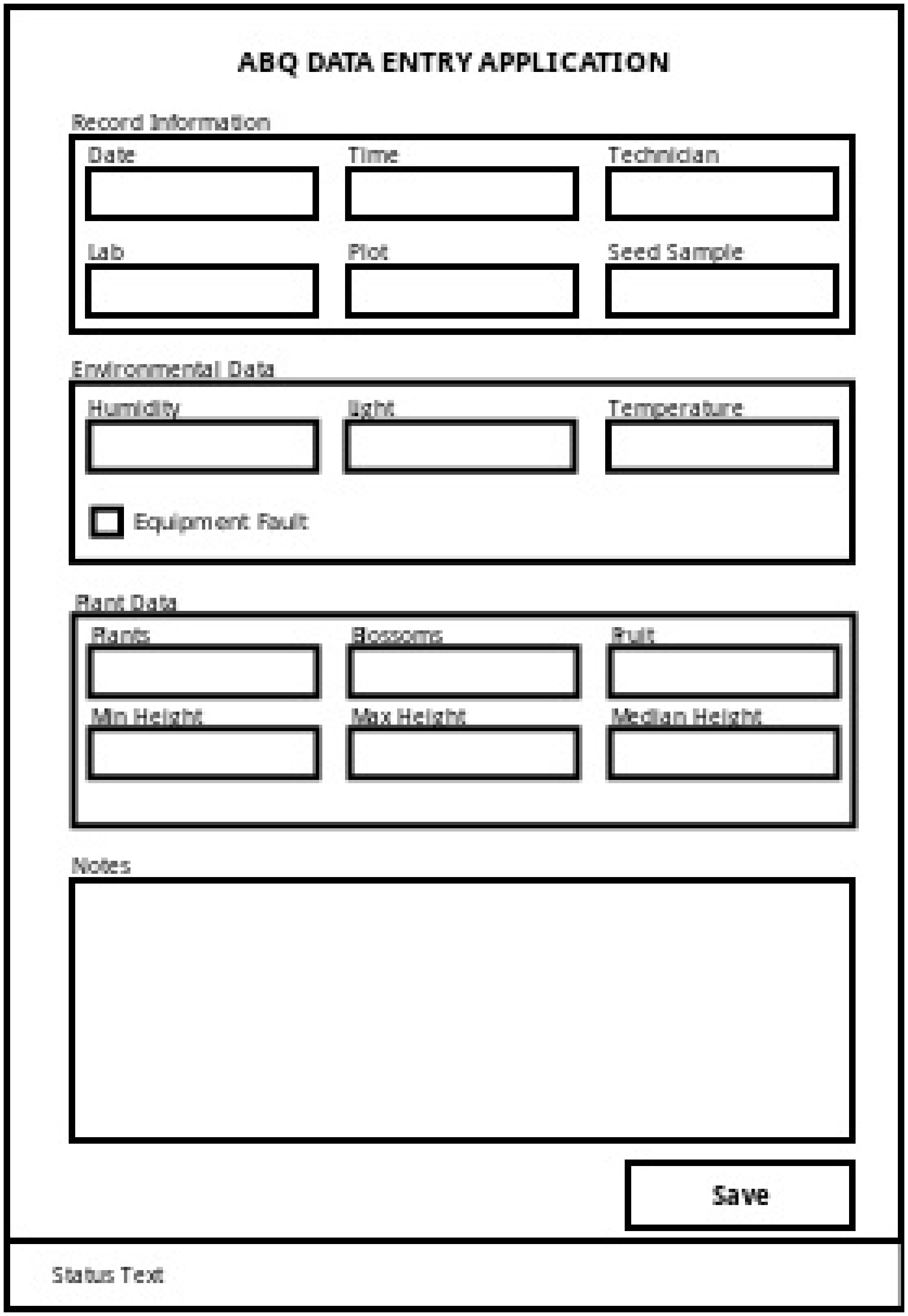
Notes

Laying out the application

With your form designed, it's time to consider the rest of the application's GUI:

- You'll need a save button to trigger storage of the entered data
- Sometimes, we might need to provide status information to the user; applications typically have a status bar that displays these kinds of messages
- Finally, it might be good to have a header indicating what the form is

Adding the following things to our sketch, we have something like the following screenshot:



Looks good! This is definitely a form we can implement in Tkinter. Your final step is to show these designs to your users and the director for any feedback or approval.

Keep stakeholders involved as much as possible in your application design process. This reduces the possibility that you'll have to go back and redesign your application later.

Summary

In this chapter, you worked through the first two phases of application development: understanding the problem and designing a solution. You learned how to develop an application specification by interviewing users and examining the data and requirements, creating an optimal form layout for your users, and learned which widgets are available in Tkinter for dealing with different kinds of input data. Most importantly, you learned that developing an application doesn't begin with code, but with research and planning.

In the next chapter, you'll create a basic implementation of your designs with Tkinter and Python. We will get familiar with the Tkinter widgets required to create our form, build the form, and place the form within the application. We'll also learn how to make our form trigger callback actions and discover how to structure our code to ensure efficiency and consistency.

Creating Basic Forms with Tkinter and ttk Widgets

Good news! Your design has been reviewed and approved by the director. Now it's time to start implementing it!

In this chapter, you'll cover the following topics:

- Evaluating your technology choices in light of the design
- Getting to know our selected Tkinter and `ttk` widgets
- Implementing and testing the form and application

Let's get coding!

Evaluating our technology choices

Our first implementation of the design will be a very simple application that delivers the core functionality of the specification and little else. This is known as a **minimum viable product** or **MVP**. Once we've established an MVP, we'll have a better understanding of how to develop it into a final product.

Before we get to that, let's take a moment to evaluate our technology choices.

Choosing a technology

Naturally, we're going to build this form using Python and Tkinter. However, it's worth asking whether Tkinter is really a good choice of technology for the application. We need to take the following things into consideration when choosing the GUI toolkit used to implement this form:

- **Your current expertise and knowledge**: Your expertise is in Python, but you have little experience in creating GUIs. For the fastest time to deliver, you need an option that works well with Python and isn't complicated to learn. You also want something established and stable, as you won't have time to keep up with new developments in the toolkit. Tkinter works here.
- **The target platforms**: You will be developing the application on a Windows PC, but it will need to run on Debian Linux, so the choice of GUI should be cross-platform. The computer it will run on is old and slow, so your program needs to be frugal with resources. Tkinter also works here.
- **Application functionality**: Your application needs to be able to display basic form fields, validate the data entered, and write it to CSV. Tkinter can handle these frontend requirements, and Python can handle the CSV file easily.

Given the options available for Python, Tkinter is a good choice. It's got a short learning curve, it's lightweight, it's readily available on both your development and target platforms, and it contains the functionality necessary for the form.

*Python has other options for GUI development, including **PyQT**, **Kivy**, and **wxPython**. These have different strengths and weaknesses compared to Tkinter, but if you find Tkinter doesn't fit well for a project, one of these might be a better option.*

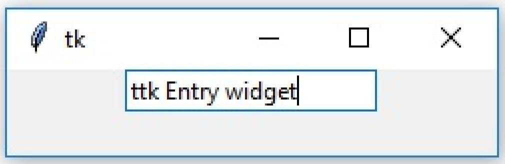
Exploring Tkinter widgets

When we designed our application, we picked out a widget class that most closely matched each field we needed. These were the `Entry`, `Spinbox`, `Combobox`, `Checkbutton`, and `Text` widgets. We also determined that we'd need the `Button` and `LabelFrame` widgets to implement the application layout. Before we start writing our class, let's take a look at each of these widgets.

Some of our widgets are in Tkinter, others are in the `ttk` *themed widget set, and a few are in both libraries. We prefer the* `ttk` *versions wherever they exist, since they look better across platforms. Pay careful attention to the library from which we import each widget.*

The Entry widget

The `ttk.Entry` widget is a basic, one-line character entry, as shown in the following screenshot:



You can create an entry by executing the following code:

```
my_entry = ttk.Entry(parent, textvariable=my_text_var)
```

In the preceding code, the commonly used arguments to `ttk.Entry` are as follows:

- `parent`: This argument sets the `parent` widget for the entry.
- `textvariable`: This is a Tkinter `StringVar` variable whose value will be bound to this `input` widget.
- `show`: This argument determines which character will be displayed when you type into the box. By default, it's the character you type, but this can be replaced (for example, for password entry you might specify `*` or dot to be shown instead).
- `Entry`: This widget, like all the `ttk` widgets, supports additional formatting and styling options, which we will discuss in detail in `Chapter 8`, *Improving the Look with Styles and Themes*.

Among all the preceding arguments, use of the `textvariable` argument is optional; without it, we can extract the value in the `Entry` widget, using its `get()` method. Binding a variable to our `input` widget has some advantages, however. First, we don't have to keep or pass around a reference to the widget itself. This will make it easier to reorganize our software into separate modules in later chapters. Also, changes to the value of the input are automatically propagated to the variable and vice versa.

The Spinbox widget

The `ttk.Spinbox` widget adds increment and decrement buttons to a regular `Entry` widget, making it suitable for numerical data.

Prior to Python 3.7, `Spinbox` was only available in Tkinter, not `ttk`. If you're using Python 3.6 or an older version, use the `Tkinter.Spinbox` widget instead. The sample code uses the Tkinter version for compatibility.

A `Spinbox` widget is created as follows:

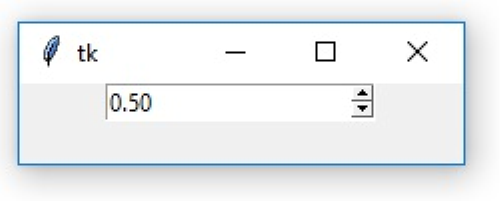
```
my_spinbox = tk.Spinbox(
    parent,
    from_=0.5,
    to=52.0,
    increment=.01,
    textvariable=my_double_var)
```

As seen in the preceding code, the `Spinbox` widget takes some extra constructor arguments to control the increment and decrement button behavior, as follows:

- `from_`: This argument determines the lowest value to which the arrows decrement. The ending underscore is needed because `from` is a Python keyword; in Tcl/`Tk` it's just `from`.
- `to`: This argument determines the highest value to which the arrows increment.
- `increment`: This argument represents the amount at which arrows increment or decrement.
- `values`: This argument takes a list of string or number values that can be incremented through.

Note that both `from_` and `to` are required if you use either; that is, you cannot just specify a lower limit, doing so will either cause an exception or strange behavior.

Take a look at the `Spinbox` widget in the following screenshot:



The `Spinbox` widget is not just for numbers, even though that's primarily how we'll be using it. It can also take a list of strings, which can be selected using the arrow buttons. Because it can be used for strings or numbers, the `textvariable` argument takes the `StringVar`, `IntVar`, or `DoubleVar` data types.

Be aware that none of these parameters actually limit what can be typed into a `Spinbox` *widget. It's nothing more than an* `Entry` *widget with buttons tacked on, and you can type not only values outside the valid range, but letters and symbols as well. Doing so can cause an exception if you've bound the widget to a non-string variable. In* `Chapter 4`*, Reducing User Error with Validation and Automation, we'll learn how to make the* `Spinbox` *limit entry to valid characters only.*

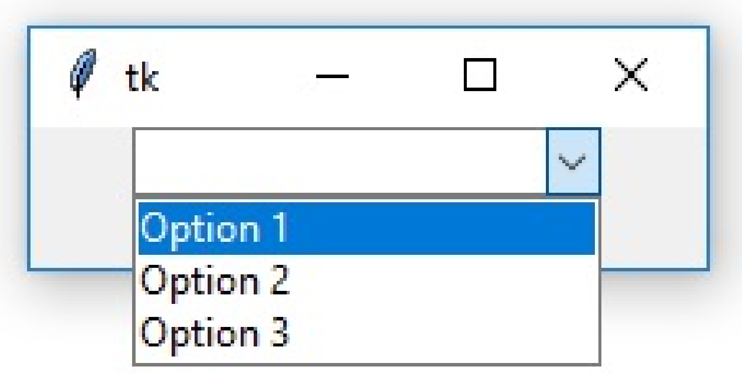
The Combobox widget

The `ttk.Combobox` argument is an `Entry` widget that adds a drop-down select menu. To populate the drop-down menu, simply pass in a `values` argument with a list of the strings, which the user can select.

You can execute the following code to create a `Combobox` widget:

```
combobox = ttk.Combobox(
    parent, textvariable=my_string_var,
    values=["Option 1", "Option 2", "Option 3"])
```

The preceding code will generate the following widget:



If you're used to HTML `<SELECT>` *widgets or drop-down widgets in other toolkits, the* `ttk.Combobox` *widget may seem strange to you. It's really an* `Entry` *widget with a drop-down menu to select some preset strings. Just like the* `Spinbox` *widget, it doesn't limit the values that can be typed in. In* `Chapter 4`*, Reducing User Error with Validation and Automation, we'll modify it to make it more like a conventional drop-down widget.*

The Checkbutton widget

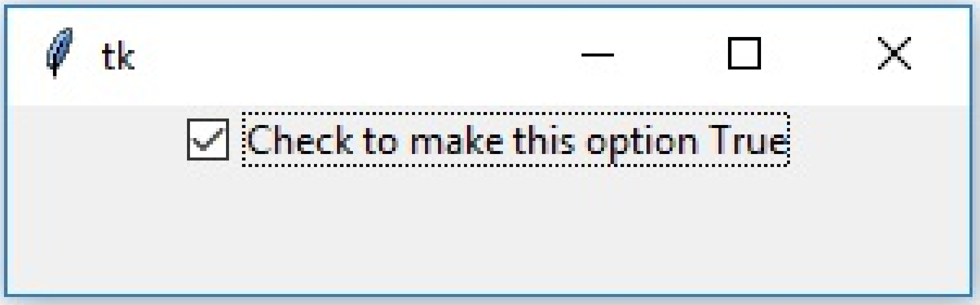
The `ttk.Checkbutton` widget is a labeled checkbox for entering boolean data. Unlike `Spinbox` and `Combobox`, it is not derived from the `Entry` widget and its arguments are different as follows:

- `text`: This argument sets the label for the widget.
- `variable`: This argument is `BooleanVar`, to which the checked status is bound.
- `textvariable`: Unlike the `Entry` based widgets, this argument can be used to bind a variable to the label text of the widget. You won't use this often, but you should know it exists in case you mistakenly assign your variable to it.

You can execute the following code to create a `Checkbutton` widget:

```
my_checkbutton = ttk.Checkbutton(
    parent, text="Check to make this option True",
    variable=my_boolean_var)
```

The `Checkbox` widget appears as a clickable box with a label by it, as shown in the following screenshot:



The Text widget

The `Text` widget is much more than just a multiline `Entry` widget. It has a powerful tagging system that allows you to implement multicolored text, hyperlink-style clickable text, and more. Unlike other widgets, it can't be bound to a Tkinter `StringVar`, so setting or retrieving its contents needs to be done through its `get()`, `insert()`, and `delete()` methods.

When reading or modifying with these methods, you are required to pass in one or two **index** values to select the character or range of characters that you're operating on. These index values are strings that can take any of the following formats:

- The line number and character number separated by a dot. Lines are numbered from 1 and characters from 0, so the first character on the first line is `1.0`, while the twelfth character on the fourth line would be `4.11`.
- The `end` string or Tkinter constant `END`, indicating the end of the field.
- A numerical index plus one of the words `linestart`, `lineend`, `wordstart`, and `wordend`, indicating the start or end of the line or word relative to the numerical index. For example, `6.2 wordstart` would be the start of the word containing the third character on line 6; `2.0 lineend` would be the end of line 2.
- Any of the preceding, a plus or minus operator, and a number of characters or lines. For example, `2.5 wordend - 1 chars` would be the character before the end of the word containing the sixth character on line 2.

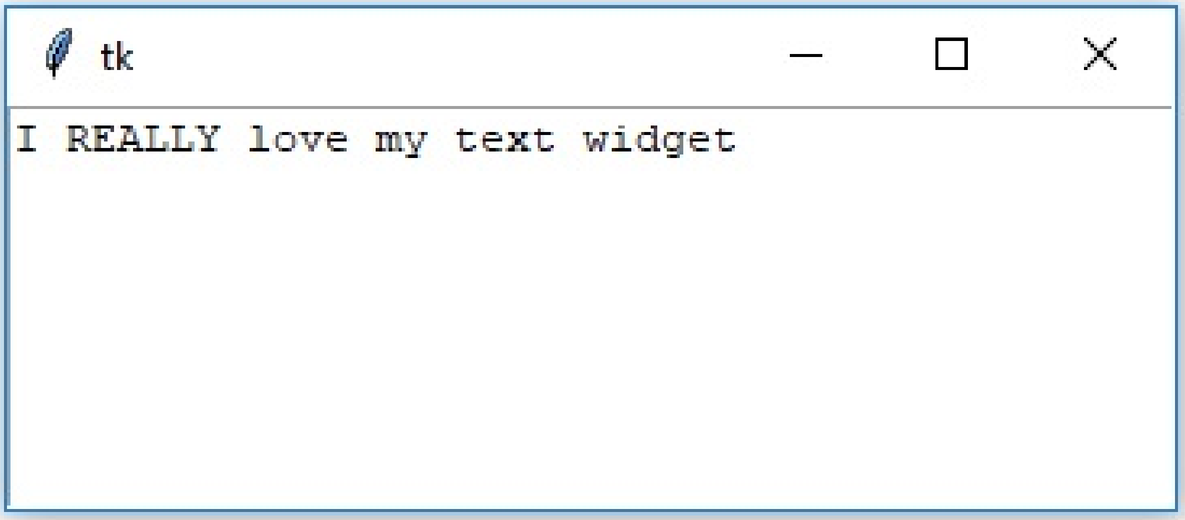
The following example shows the basics of working with a `Text` widget:

```
# create the widget.  Make sure to save a reference.
mytext = tk.Text(parent)

# insert a string at the beginning
mytext.insert('1.0', "I love my text widget!")

# insert a string into the current text
mytext.insert('1.2', 'REALLY ')
```

```
# get the whole string
mytext.get('1.0', tk.END)

# delete the last character.
# Note that there is always a newline character
# at the end of the input, so we backup 2 chars.
mytext.delete('end - 2 chars')
```

If you run the preceding code, you'll get the following output:

.

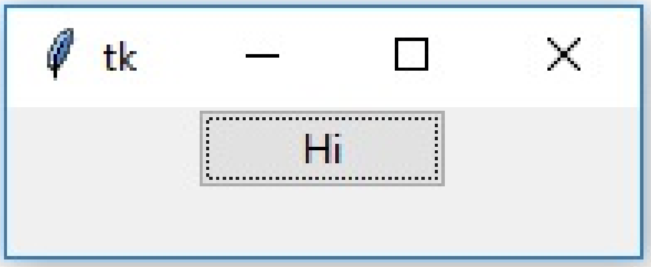


```
I REALLY love my text widget
```

For the `Notes` field in this form, we just need a simple multiline `Entry`; so, we'll only be using the most basic functionality of the `Text` widget for now.

The Button widget

The `ttk.Button` widget should also be familiar from `Chapter 1`, *Introduction to Tkinter*. It's just a straightforward button that you click with the mouse or spacebar, as shown in the following screenshot:



Just like the `Checkbutton` widget, this widget uses the `text` and `textvariable` configuration options to control the label on the button. The `Button` objects don't take `variable`, but they do take a `command` argument, which specifies a Python function to run when the button is clicked.

The following example shows the use of a `Button` object:

```
tvar = tk.StringVar()
def swaptext():
    if tvar.get() == 'Hi':
        tvar.set('There')
    else:
        tvar.set('Hi')

my_button = ttk.Button(parent, textvariable=tvar, command=swaptext)
```

The LabelFrame widget

We have chosen the `ttk.LabelFrame` widget to group the fields in our application. As the name implies, it's `Frame` with `Label` (and a box around it, usually). The `LabelFrame` widget takes a `text` argument in the constructor that sets the label, positioned in the top-left of the frame.

Tkinter and `ttk` contain many more widgets, some of which we'll encounter later in this book. Python also ships with a `widget` library called `tix`, which contains several dozen widgets. However, `tix` is very outdated, and we won't be covering it in this book. You should know that it exists, though.

Implementing the application

To start our application script, create a folder called `ABQ data entry` and a file inside it called `data_entry_app.py`.

We'll start with the following boilerplate code we learned in `Chapter 1`, *Introduction to Tkinter*:

```
import tkinter as tk
from tkinter import ttk

# Start coding here


class Application(tk.Tk):
    """Application root window"""

if __name__ == "__main__":
    app = Application()
    app.mainloop()
```

Running this script should give you a blank Tk window.

Saving some time with a LabelInput class

Every `input` widget on our form has a label associated with it. In a small application, we can just create the label and input separately, then add each to the `parent` frame as follows:

```
form = Frame()
label = Label(form, text='Name')
name_input = Entry(form)
label.grid(row=0, column=0)
name_input.grid(row=1, column=0)
```

That works fine and you could do it that way for your application, but it also creates a lot of tedious, repetitious code, and moving inputs around means changing twice as much code. Since the `label` and `input` widgets belong together, it would be smart to create a small wrapper class to contain both and establish some universal defaults.

When coding, be on the lookout for sections that contain a lot of repetitive code. You can often abstract this code into a class, function, or loop. Doing so won't just save your fingers some typing, it will ensure consistency and reduce the total amount of code you have to maintain.

Let's take a look at the following steps:

1. We'll call this class `LabelInput` and define it at the top of our code, just under the `Start coding here` comment:

```
"""Start coding here"""
class LabelInput(tk.Frame):
    """A widget containing a label and input together."""

    def __init__(self, parent, label='', input_class=ttk.Entry,
         input_var=None, input_args=None, label_args=None,
         **kwargs):
        super().__init__(parent, **kwargs)
        input_args = input_args or {}
        label_args = label_args or {}
        self.variable = input_var
```

2. We'll base the class on `Tkinter.Frame`, just as we did with `HelloWidget` back

in `Chapter 1`, *Introduction to Tkinter*. Our constructor takes a number of the following arguments:

- `parent`: This argument is a reference to the `parent` widget; all widgets we create will take this as the first argument.
- `label`: This the text for the label part of the widget.
- `input_class`: This is the class of the widget we want to create. It should be an actual callable class object, not a string. If left blank, `ttk.Entry` will be used.
- `input_var`: This is a Tkinter variable to assign to the input. It's optional, since some widgets don't use variables.
- `input_args`: This is an optional dictionary of any additional arguments for the `input` constructor.
- `label_args`: This is an optional dictionary of any additional arguments for the `label` constructor.
- `**kwargs`: Finally, we catch any additional keyword arguments in `**kwargs`. These will be passed to the `Frame` constructor.

3. The first thing we do in the constructor is call `super().__init__()` and pass in the `parent` and extra keyword arguments. We then make sure that both `input_args` and `label_args` are dictionaries, and save a reference to our input variable as `self.variable`.

Don't be tempted to use an empty dictionary (`{}`) as a default value for a method's keyword arguments. If you did so, a dictionary would be created when the method definition is evaluated and shared by all objects in the class. This would have some very strange effects on your code! The accepted practice is to pass `None` for mutable types like dictionaries and lists, then replacing `None` with an empty container in the method body.

4. We want to be able to take any kind of `input` widget and deal with it appropriately in our class; unfortunately, as we learned previously, there are small differences between the constructor arguments and behavior in different widget classes, such as the way `Combobox` and `Checkbutton` use their `textvariable` argument. At the moment, we just need to differentiate between the way button widgets like `Button` and `Checkbutton` handle variables and label text. To deal with this, we'll add the following code:

```
if input_class in (ttk.Checkbutton, ttk.Button,
ttk.Radiobutton):
    input_args["text"] = label
    input_args["variable"] = input_var
```

```
        else:
            self.label = ttk.Label(self, text=label, **label_args)
            self.label.grid(row=0, column=0, sticky=(tk.W + tk.E))
            input_args["textvariable"] = input_var
```

5. For button-type widgets, we do the following tasks differently:
    - Instead of adding a label, we just set the `text` argument. All buttons use this argument to add a `label` to the widget.
    - Instead of assigning our variable to `textvariable`, we assign it to `variable`.
6. In the case of other `input` classes, we set `textvariable` and create a `Label` widget, adding it to the first row of the `LabelInput` class.
7. Now we need to create the `input` class, as follows:

```
        self.input = input_class(self, **input_args)
        self.input.grid(row=1, column=0, sticky=(tk.W + tk.E))
```

8. This is pretty straightforward: we call the `input_class` class passed into the constructor with the `input_args` dictionary expanded to keyword arguments. Then, we add it to the grid at row `1`.
9. Lastly, we configure the `grid` layout to expand our lone column across the entire widget, as follows:

```
        self.columnconfigure(0, weight=1)
```

10. One nice thing we can do when creating custom widgets that will save us a lot of coding is to add defaults to its geometry manager methods. For example, we're going to want all our `LabelInput` objects to fill the entire grid cell that they're placed within. Instead of adding `sticky=(tk.W + tk.E)` to every `LabelInput.grid()` call, we can add it as a default value by overriding the method:

```
    def grid(self, sticky=(tk.E + tk.W), **kwargs):
        super().grid(sticky=sticky, **kwargs)
```

By defining it as a default parameter, we can still override it as usual. The `input` widgets all have a `get()` method that returns their current value. To save some redundant typing later, we'll implement a `get()` method in our `LabelInput` class that will simply pass along the request to the input or its variable. Add this method next:

```
    def get(self):
        try:
            if self.variable:
                return self.variable.get()
            elif type(self.input) == tk.Text:
                return self.input.get('1.0', tk.END)
            else:
                return self.input.get()
        except (TypeError, tk.TclError):
            # happens when numeric fields are empty.
            return ''
```

We're using a `try` block here, because Tkinter variables will throw an exception if you call `get()` under certain conditions, such as when a numeric field is empty (blank strings can't convert to a numeric value). In such a case, we'll simply return an empty value from the form. Also, we need to handle the `tk.Text` widgets differently, since they require a range to retrieve text. We're always going to want all the text from this form, so we'll just specify that here. As a complement to `get()`, we'll implement a `set()` method that passes the request to the variable or `widget`, as follows:

```
    def set(self, value, *args, **kwargs):
        if type(self.variable) == tk.BooleanVar:
                self.variable.set(bool(value))
        elif self.variable:
                self.variable.set(value, *args, **kwargs)
        elif type(self.input) in (ttk.Checkbutton,
        ttk.Radiobutton):
            if value:
                self.input.select()
            else:
                self.input.deselect()
        elif type(self.input) == tk.Text:
            self.input.delete('1.0', tk.END)
            self.input.insert('1.0', value)
        else: # input must be an Entry-type widget with no variable
            self.input.delete(0, tk.END)
            self.input.insert(0, value)
```

The `.set()` method abstracts away some of the differences between how various Tkinter widgets set their values:

- If we have a variable of class `BooleanVar`, cast `value` to `bool` and set it. `BooleanVar.set()` will only take a `bool`, not other falsy or truthy values. This ensures our variable only gets an actual boolean value.

- If we have any other kind of variable, just pass `value` to its `.set()` method.
- If we have no variable, and a button-style class, we use the `.select()` and `.deselect()` methods to select and deselect the button based on the truthy value of the variable.
- If it's a `tk.Text` class, we can use its `.delete` and `.insert` methods.
- Otherwise, we use the `.delete` and `.insert` methods of `input`, which work on the `Entry`, `Spinbox`, and `Combobox` classes. We have to do this separately from the `tk.Text` inputs, because the indexing values work differently.

This may not account for every possible `input` widget, but it covers the ones we plan to use and a few more we may need later. While building the `LabelInput` class took a lot of work, we'll see that defining the form is much simpler now.

Building the form

Instead of building our form directly on the main application window, we're going to build our form as its own object. Initially, this makes it easier to maintain a nice layout, and later down the road it will make it easier for us to expand our application. Let's perform the following steps for building our form:

1. Once again, we'll subclass `Tkinter.Frame` to build this module. After the `LabelInput` class definition, begin a new class as follows:

```
        class DataRecordForm(tk.Frame):
            """The input form for our widgets"""

            def __init__(self, parent, *args, **kwargs):
                super().__init__(parent, *args, **kwargs)
```

   This should be familiar by now. We subclass `Frame`, define our constructor, and call `super().__init__()` to initialize the underlying `Frame` object.

2. Now we're going to create a structure to hold references to all the form's `input` widgets, as follows:

```
        # A dict to keep track of input widgets
        self.inputs = {}
```

   As we create the `input` widgets, we'll store references to them in the dictionary, using the field name as a key. This will make it easier later to retrieve all our values.

Adding LabelFrame and other widgets

Our form is divided into sections with a label for and a box around each section. For each section, we'll create a `LabelFrame` widget and start adding our `LabelInput` widgets to it by performing the following steps:

1. Let's start with the record information frame by executing the following code:

```
        recordinfo = tk.LabelFrame(self, text="Record Information")
```

Remember that the `text` argument to `LabelFrame` defines the text of the label. This widget will be passed as the `parent` widget to all the inputs in the record information group.

2. Now, we'll add the first line of the `input` widgets, as follows:

```
        self.inputs['Date'] = LabelInput(recordinfo, "Date",
            input_var=tk.StringVar())
        self.inputs['Date'].grid(row=0, column=0)

        self.inputs['Time'] = LabelInput(recordinfo, "Time",
            input_class=ttk.Combobox, input_var=tk.StringVar(),
            input_args={"values": ["8:00", "12:00", "16:00", "20:00"]})
        self.inputs['Time'].grid(row=0, column=1)

        self.inputs['Technician'] = LabelInput(recordinfo,
        "Technician",
            input_var=tk.StringVar())
        self.inputs['Technician'].grid(row=0, column=2)
```

3. The `Date` and `Technician` inputs are simple text entries; we only need to pass the `parent`, `label`, and `input` variables into our `LabelInput` constructor. For the `Time` entry, we specify a list of possible values that will be used to initialize the `Combobox` widget.
4. Let's work on line 2, as follows:

```
        # line 2
        self.inputs['Lab'] = LabelInput(recordinfo, "Lab",
            input_class=ttk.Combobox, input_var=tk.StringVar(),
            input_args={"values": ["A", "B", "C", "D", "E"]})
        self.inputs['Lab'].grid(row=1, column=0)
       self.inputs['Plot'] = LabelInput(recordinfo, "Plot",
            input_class=ttk.Combobox, input_var=tk.IntVar(),
           input_args={"values": list(range(1, 21))})
        self.inputs['Plot'].grid(row=1, column=1)

        self.inputs['Seed sample'] = LabelInput(
            recordinfo, "Seed sample", input_var=tk.StringVar())
        self.inputs['Seed sample'].grid(row=1, column=2)

        recordinfo.grid(row=0, column=0, sticky=tk.W + tk.E)
```

5. Here, we have two more `Combobox` widgets and another `Entry`. These are created similarly to those in line 1. The values for `Plot` just need to be a list of numbers from 1 through 20; we can create that with Python's built-in `range()` function. Finished with the record information, we add its `LabelFrame` to the form widget with a call to `grid()`. The remaining fields are defined in essentially the same way. For example, our environmental data will look as follows:

```
         # Environment Data
         environmentinfo = tk.LabelFrame(self, text="Environment Data")
         self.inputs['Humidity'] = LabelInput(
             environmentinfo, "Humidity (g/m³)",
             input_class=tk.Spinbox, input_var=tk.DoubleVar(),
             input_args={"from_": 0.5, "to": 52.0, "increment": .01})
         self.inputs['Humidity'].grid(row=0, column=0)
```

6. Here, we've added the first of our `Spinbox` widgets, specifying the valid ranges and increment amount; you can add in the `Light` and `Temperature` inputs in the same way. Notice that our `grid()` coordinates have started over with `0, 0`; that's because we're starting a new parent object, so the coordinates begin all over again.

All of these nested grids can get confusing. Remember that whenever you call `.grid()` on a widget, the coordinates are relative to the top-left corner of the widget's parent. The parent's coordinates are relative to its parent, and so on, back up to the root window.

This section also contains the lone `Checkbutton` widget:

```
         self.inputs['Equipment Fault'] = LabelInput(
             environmentinfo, "Equipment Fault",
             input_class=ttk.Checkbutton,
             input_var=tk.BooleanVar())
         self.inputs['Equipment Fault'].grid(
             row=1, column=0, columnspan=3)
```

7. There are no real arguments to use with the `Checkbutton`, though note that

we're using a `BooleanVar` to store its value. Now, we move on to the plant data section:

```
        plantinfo = tk.LabelFrame(self, text="Plant Data")

        self.inputs['Plants'] = LabelInput(
            plantinfo, "Plants",
            input_class=tk.Spinbox,
            input_var=tk.IntVar(),
            input_args={"from_": 0, "to": 20})
        self.inputs['Plants'].grid(row=0, column=0)

        self.inputs['Blossoms'] = LabelInput(
            plantinfo, "Blossoms",
            input_class=tk.Spinbox,
            input_var=tk.IntVar(),
            input_args={"from_": 0, "to": 1000})
        self.inputs['Blossoms'].grid(row=0, column=1)
```

Notice that, unlike our decimal `Spinboxes`, we're not setting the increment for the integer fields; that's because it defaults to `1.0`, which is what we want for integer fields.

8. We're also using `1000` as a maximum for `Blossoms` although it technically shouldn't have a maximum; our `Lab Technicians` assured us that it would never approach 1,000. Since `Spinbox` requires both `to` and `from_`, if we use either, we'll go ahead and use this value.

You can also specify the strings `infinity` or `-infinity` as values. These can be cast to the `float` values, which behave appropriately.

9. The `Fruit` field and three `Height` fields will be mostly identical to these. Go ahead and create them, making sure to follow your data dictionary for the appropriate `input_args` values and `input_var` types. We finish our form fields by adding the following notes:

```
           # Notes section
           self.inputs['Notes'] = LabelInput(
               self, "Notes",
               input_class=tk.Text,
               input_args={"width": 75, "height": 10}
           )
           self.inputs['Notes'].grid(sticky="w", row=3, column=0)
```

10. There's no need for `LabelFrame` here, so we're just adding the note's `LabelInput` frame directly to the form. The `Text` widget takes the `width` and `height` arguments to specify the size of the box. We'll give it a nice generous size for note entry.

Retrieving data from our form

Now that we're finished with the form, we need a way to retrieve data from it so it can be processed by the application. We'll create a method that returns a dictionary of the form's data and, as we did with our `LabelInput` objects, maintain the Tkinter convention of calling it `get()`.

Add the following method to your form class:

```
    def get(self):
        data = {}
        for key, widget in self.inputs.items():
            data[key] = widget.get()
        return data
```

The code is simple: we loop through our instance's `inputs` object containing our `LabelInput` objects and build a new dictionary by calling `get()` on each variable.

This code demonstrates the power of both iterable objects and consistent naming schemes. If we had stored our inputs as discrete properties of the form, or neglected to normalize the `get()` method, our code would be a lot less elegant.

Resetting our form

We're almost done with our form class, but there's one more method needed. After each save of the form, we're going to need to reset it to empty fields; so, let's add a method to do that by performing the following steps:

1. Add this method to the end of the form class:

```
        def reset(self):
            for widget in self.inputs.values():
                widget.set('')
```

2. As with our `get()` method, we're iterating through the `input` dictionary and setting each `widget` to an empty value.
3. To make sure our application behaves consistently, we should call `reset()` immediately after the application loads, clearing out any `Tk` defaults that we might not want.
4. Back up to the last line of `__init__()` and add the following code line:

```
        self.reset()
```

Building our application class

Let's take a look at the following steps for building our application class:

1. Move down under the `Application` class doc string (the line that reads `Application root window`) and start an `__init__()` method for `Application`, as follows:

```
        def __init__(self, *args, **kwargs):
            super().__init__(*args, **kwargs)

            self.title("ABQ Data Entry Application")
            self.resizable(width=False, height=False)
```

2. Once again we make the familiar call to `super().__init__()`, passing along any arguments or keyword arguments.

Note that we don't pass in a `parent` widget here, since `Application` is the root window.

3. We call `.title()` to set our application's title string; this isn't required, but it will certainly help users who are running multiple applications to find our application quickly in their desktop environment.
4. We also prohibit resizing of the window with a call to `self.resizable`. This also isn't strictly necessary, but it makes it simpler for us to control our layout for the time being. Let's start adding our application components as follows:

```
        ttk.Label(
            self,
            text="ABQ Data Entry Application",
            font=("TkDefaultFont", 16)
        ).grid(row=0)
```

5. The application will start at the top with a `Label` object showing the name of the application in a larger than normal font. Notice that we don't specify `column` here; our main application layout will only have one column, so it's not strictly necessary to specify `column`, as it defaults to `0`. Next, we'll add our `DataRecordForm` as follows:

```
        self.recordform = DataRecordForm(self)
        self.recordform.grid(row=1, padx=10)
```

6. We're adding 10 pixels of padding on the left and right using the `padx` argument to `grid`. This just adds a little whitespace around the edges of the form, making it a bit more readable.
7. Let's add in the save button next, as follows:

```
        self.savebutton = ttk.Button(self, text="Save",
        command=self.on_save)
        self.savebutton.grid(sticky=tk.E, row=2, padx=10)
```

8. We've given the button a `command` value of `self.on_save`; we haven't written that method yet, so we'll need to do that before we can run our code.

When writing methods or functions to be callbacks for a GUI event, it's conventional to use the format `on_EVENTNAME`, where `EVENTNAME` is a string describing the event triggering it. We could also name this method `on_save_button_click()`, but for now `on_save()` is adequate.

9. Finally, let's add in the status bar, as follows:

```
        # status bar
        self.status = tk.StringVar()
        self.statusbar = ttk.Label(self, textvariable=self.status)
        self.statusbar.grid(sticky=(tk.W + tk.E), row=3, padx=10)
```

10. We start by creating a string variable called `self.status` and use this as `textvariable` for `ttk.Label`. All our application will need to do to update the status is call `self.status.set()` anywhere inside the class. Our GUI is completed by adding the status bar to the bottom of the application widget.

Saving to CSV

When a user clicks on save, the following chain of events needs to take place:

1. A file called `abq_data_record_CURRENTDATE.csv` is opened
2. If the file doesn't exist, it will be created, and field headers will be written to the first line
3. The data dictionary is retrieved from `DataEntryForm`
4. The data is formatted as a CSV row and appended to the file
5. The form is cleared, and the user is notified that the record was saved

We're going to need a few more Python libraries to help us out with this:

1. First, we'll need a date string for our filename. Python's `datetime` library can help us here.
2. Next, we'll need to be able to check if a file exists. Python's `os` library has a function for this.
3. Finally, we need to be able to write to a CSV file. Python has a CSV library in the standard library that would be perfect here.

Let's take a look at the following steps:

1. Back up to the top of the file and add the following imports above the Tkinter imports:

```
from datetime import datetime
import os
import csv
```

2. Now, go back to the `Application` class and start the `on_save()` method, as follows:

```
def on_save(self):
     datestring = datetime.today().strftime("%Y-%m-%d")
     filename = "abq_data_record_{}.csv".format(datestring)
     newfile = not os.path.exists(filename)
```

3. The first thing we do is create our date string. The `datetime.today()`

method returns a `datetime` at midnight of the current day; we then format this using `strftime()` to an ISO date string in the form year-month-day (using numbers 01 through 12 for the month). This gets plugged into the filename template from our specification and saved as `filename`.

4. Next, we need to determine whether the file already exists; `os.path.exists()` will return a boolean value indicating if the file exists; we negate this value and store it as `newfile`.
5. Now, let's get the data from `DataEntryForm`:

```
        data = self.recordform.get()
```

6. With the data acquired, we need to open our file and write the data into it. Add in the following code:

```
        with open(filename, 'a') as fh:
            csvwriter = csv.DictWriter(fh, fieldnames=data.keys())
            if newfile:
                csvwriter.writeheader()
            csvwriter.writerow(data)
```

The `with open(filename, 'a') as fh:` statement opens our generated filename in append mode and gives us a file handle called `fh`. Append mode means we can't read or edit any existing lines in the file, just add to the end of it, which is exactly what we want.

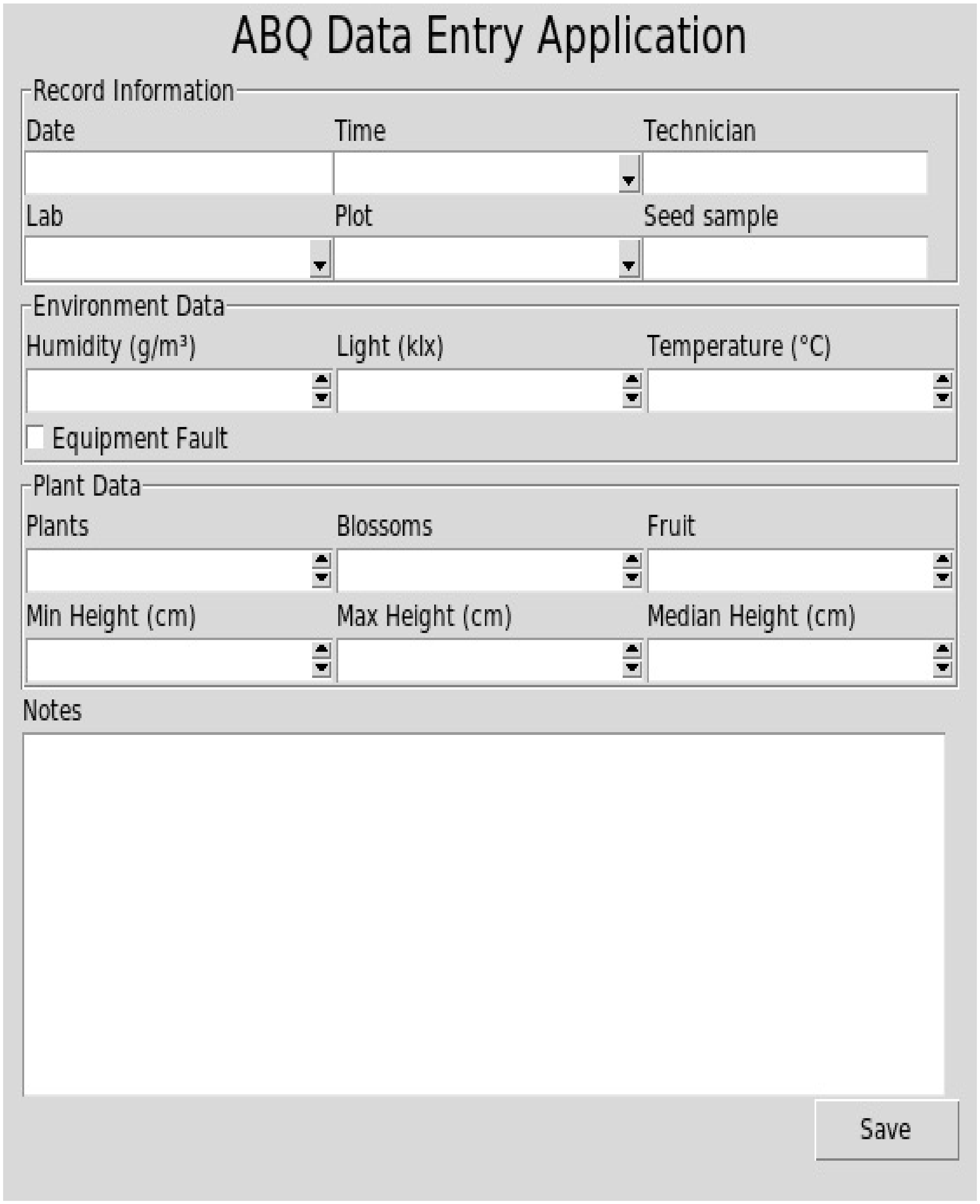
*The `with` keyword works with **context manager** objects, which our call to `open()` returns. Context managers are special objects that define code to run before and after the `with` block. By opening files using this method, they'll automatically be closed correctly at the end of the block.*

7. Next, we create a `csv.DictWriter` object using the file handle. This object will allow us to write dictionaries of data to the CSV file, matching up the dictionary keys with the CSV's header row labels. This will work better for us in the long run than the default CSV writer object, which would require the fields in the correct order every time.
8. To configure this, we have to first pass in the `fieldnames` argument to the `DictWriter` constructor. Our field names are the keys of the `data` dictionary that we get from the form. If we're working on a new file, we need to write those field names to the first row, which we do by calling `DictWriter.writeheader()`.
9. Finally, we write our `data` dictionary to a new row, using the `.writerow()` method of our `DictWriter` object. At the end of the code block, the file is

automatically closed and saved.

Finishing and testing

At this point, you should be able to run the application, enter data, and save it to the CSV file. Try it out! You should see something similar to the following screenshot:



Perhaps the first thing you notice is that clicking Save has no noticeable effect. The form stays populated, and there's no indication that anything was done. We should fix this.

We'll perform the following two things to help here:

1. First, put a notification in our status bar that the record was saved and how many records have been saved this session. For the first part, add the following code line to the end of the `Application` constructor, as follows:

```
        self.records_saved = 0
```

2. Second, clear the form after saving, so the next record can be started. Then add the following code line to the end of the `on_save()` method, as follows:

```
        self.records_saved += 1
        self.status.set(
            "{} records saved this session".format(self.records_saved))
```

   This code sets up a counter variable that will keep track of the number of records we've saved since the application was started.

3. After saving the file, we increment the value, then set our status to indicate how many records have been saved. Users will be able to see this number increase and know that their button click has done something.
4. Next, we'll reset the form after saving. Append this code to the end of `Application.on_save()`, as follows:

```
        self.recordform.reset()
```

   That will zero out the form and ready it for the next record to be entered.

5. Now, run the application again. It should clear out and give you a status indication on saving a record.

Summary

Well, we've come a long way in this chapter! You took your design from a specification and some drawings to a running application that already covers the basic functionality you need. You learned to work with basic Tkinter and `ttk` widgets, and create custom widgets to save yourself a lot of repetitive work.

In the next chapter, we're going to address the issues with our `input` widgets. We'll learn to customize the behavior of our `input` widgets, prevent erroneous keystrokes, and validate the data to make sure it's within the tolerances laid out in our specification. Along the way, we'll dig deeper into Python classes and learn more techniques for an efficient and elegant code.

Reducing User Error with Validation and Automation

Our form works, and both the director and data entry personnel are thrilled with the form design, but we're not ready for production yet! Our form doesn't yet perform the promised task of preventing or discouraging user errors. Number boxes still allow letters, combo boxes aren't limited to the choices given, and dates have to be filled in by hand. In this chapter, we're going to cover the following topics:

- Deciding on the best approach for validating user input
- Learning how to use Tkinter's validation system
- Creating custom widgets for our form that validate entered data
- Automating default values where appropriate in our form

Let's get started!

Validating user input

At first glance, Tkinter's selection of the input widgets seems a little disappointing. It doesn't give us a true number entry that only allows digits, nor a true drop-down selector that only allows items from the drop-down list to be selected. We have no date inputs, email inputs, or other specially-formatted input widgets.

But these weaknesses can become strengths. Because these widgets assume nothing, we can make them behave in a way that's appropriate to our specific needs, rather than some generic way that may or may not work optimally. For example, letters may seem inappropriate in a number entry, but are they? In Python, strings such as `NaN` and `Infinity` are valid float values; having a box that could increment numerals but also handle those string values may be very useful in some applications.

We're going to learn how to shape our widgets to our needs, but before we learn how to control this behavior, let's think about what we want to do.

Strategies to prevent data errors

There is no universal answer to how a widget should react to a user trying to enter bad data. The validation logic found in various graphics toolkits can differ greatly; when bad data is entered, an input widget might validate the user input as follows:

- Prevent the invalid keystrokes from registering at all
- Accept the input, but return an error or list of errors when the form is submitted
- Show an error when the user leaves the entry field, perhaps disabling form submission until it's corrected
- Lock the user in the entry field until valid data is entered
- Silently correct the bad data using a best-guess algorithm

The correct behavior in a data entry form (which is filled out hundreds of times a day by users who may not even be looking at it) may be different from an instrument control panel (where values absolutely must be correct to avoid a disaster) or an online user registration form (which is filled out once by a user who has never seen it before). We need to ask ourselves and our users about which behavior will best minimize errors.

After discussing this with your users on the data entry staff, you come to the following set of guidelines:

- Whenever possible, meaningless keystrokes should be ignored (for example, letters in a number field)
- An empty field should register an error (all fields are required), with the exception of `Notes`
- Fields containing bad data should be marked in some visible way with an error describing the problem
- Form submission should be disabled if there are fields with errors

Let's add the following requirements to our specification before moving on. Under the `Required Features` section, update the hard requirements as follows:

```
The program must:
...
* have inputs that:
  - ignore meaningless keystrokes
  - require a value for all fields, except Notes
  - get marked with an error if the value is invalid on focusout
* prevent saving the record when errors are present
```

So, how do we implement this?

Validation in Tkinter

Tkinter's validation system is one of those parts of the toolkit that is less than intuitive. It relies on the following three configuration options that we can pass into any input widget:

- `validate`: This option determines which type of event will trigger the validation callback
- `validatecommand`: This option takes the command that will determine if the data is valid
- `invalidcommand`: This option takes a command that will run if `validatecommand` returns `False`

This seems pretty straightforward, but there are some unexpected curves.

The values we can pass to `validate` are as follows:

Validates string	Triggers when
`none`	It is none that turns off validation
`focusin`	The user enters or selects the widget
`unfocus`	The user leaves the widget
`focus`	Either `focusin` or `focusout`
`key`	The user enters text in the widget
`all`	`focusin`, `focusout`, and `key`

The `validatecommand` argument is where things get tricky. You might think this takes the name of a Python function or method, but that's not quite it. Instead, we need to give it a tuple containing a reference to a Tcl/`Tk` function, and optionally some **substitution codes** that specify information about the triggering event that we want to pass into the function.

How do we get a reference to a Tcl/`Tk` function? Fortunately, this isn't too hard; we just pass a Python callable to the `.register()` method on any Tkinter widget. This returns a string that we can use with `validatecommand`.

Of course, validation functions aren't very useful unless we pass in some data to be validated. To do this, we add one or more substitution codes to our `validatecommand` tuple.

These codes are as follows:

Code	Value passed
`%d`	A code indicating the action being attempted: `0` for `delete`, `1` for insert, and `-1` for other events. Note that this is passed as a string, and not as an integer.
`%P`	The proposed value that the field would have after the change (key events only).
`%s`	The value currently in the field (key events only).
`%i`	The index (from `0`) of the text being inserted or deleted on key events, or `-1` on non-key events. Note that this is passed as a string, not as an integer.
`%S`	For insertion or deletion, the text that is being inserted or deleted (key events only).
`%v`	The widget's `validate` value.
`%V`	The event that triggered validation: `focusin`, `focusout`, `key`, or `forced` (indicating the text variable was changed).
`%W`	The widget's name in Tcl/`Tk`, as a string.

The `invalidcommand` option works exactly the same way, requiring the use of the

`.register()` method and substitution codes.

To see what this looks like together, consider the following code for an `Entry` widget that only accepts five characters:

```
def has_five_or_less_chars(string):
    return len(string) <= 5

wrapped_function = root.register(has_five_or_less_chars)
vcmd = (wrapped_function, '%P')
five_char_input = ttk.Entry(root, validate='key', validatecommand=vcmd)
```

Here, we've created a function that simply returns whether or not the length of a string is less than or equal to five characters. We then register this function with `Tk` using the `register()` method, saving its reference string as `wrapped_function`. Next, we build our `validatecommand` tuple using the reference string and the `'%P'` substitution code, which represents the proposed value (the value that the entry would have if the key event was accepted). You can pass in as many substitution codes as you wish, and in any order, as long as your function is written to accept those arguments. Finally, we'll create our `Entry` widget, setting the validation type to `key` and passing in our validation command tuple.

Notice we did not define an `invalidcommand` method in this case; when validation is triggered by a keystroke, returning `False` from the `validate` command will cause the keystroke to be ignored. This is not the case when triggering validation from a focus or other event type; in that case, there is no default behavior defined and an `invalidcommand` method is necessary.

Consider the following alternate, class-based version of `FiveCharEntry`, which allows you to type as much as you want, but truncates your text when you leave the field:

```
class FiveCharEntry2(ttk.Entry):
    """An Entry that truncates to five characters on exit."""

    def __init__(self, parent, *args, **kwargs):
        super().__init__(parent, *args, **kwargs)
        self.config(
            validate='focusout',
            validatecommand=(self.register(self._validate), '%P'),
            invalidcommand=(self.register(self._on_invalid),)
        )
    def _validate(self, proposed_value):
        return len(proposed_value) <= 5

    def _on_invalid(self):
        self.delete(5, tk.END)
```

This time, we've implemented validation by subclassing `Entry` and defining our validation logic in a method rather than an external function. This simplifies access to the widget in our validation methods.

The underscores at the beginning of `_validate()` and `_on_invalid()` indicate that these are internal methods meant to be accessible only within the class. While it's not necessary to make this code work correctly, and Python does not treat it any differently from a normal method, it lets other programmers know that these methods are for internal use and shouldn't be called outside the class.

We've also changed the `validate` argument to `focusout` and added an `_on_invalid()` method that truncates the value in `Entry`. Whenever the widget loses focus, the `_validate()` method will be called with the entered text. If it fails, `_on_invalid()` will be called, causing the contents to be truncated using the `Entry` widget's `delete()` method.

Creating a DateEntry widget

Let's try creating a validating version of our `Date` field. We'll make a `DateEntry` widget that prevents most erroneous keystrokes, then checks for date validity on `focusout`. If the date is invalid, we'll mark the field in some way and display an error. Let's perform the following steps to do the same:

1. Open a new file called `DateEntry.py` and begin with the following code:

```
from datetime import datetime

class DateEntry(ttk.Entry):
    """An Entry for ISO-style dates (Year-month-day)"""

    def __init__(self, parent, *args, **kwargs):
        super().__init__(parent, *args, **kwargs)
        self.config(
            validate='all',
            validatecommand=(
                self.register(self._validate),
                '%S', '%i', '%V', '%d'
            ),
        invalidcommand=(self.register(self._on_invalid), '%V')
    )
    self.error = tk.StringVar()
```

2. Since we'll need `datetime` for our validation method, we import it here at the top.
3. We subclass `ttk.Entry`, then start our constructor method with a call to `super().__init__()` as usual.
4. Next, we use `self.config()` to alter the configuration of the widget. You might wonder why we don't pass these arguments into the `super().__init__()` call; the reason is that the `self.register()` method doesn't exist until the underlying `Entry` widget has been initialized.
5. We're registering the following two methods: `self._validate` and `self._on_invalid`, which we'll write shortly:

- `_validate()`: This method will get the inserted text (`%S`), the index of insertion (`%i`), the type of event (`%V`), and the action performed (`%d`).

- `_on_invalid()`: This method will only get the event type. Since we want to validate on both keystrokes and `focusout`, we'll set `validate` to `all`. Our validation methods can figure out which event is taking place by looking at the event type (`%V`).

6. Finally, we create `StringVar` to hold our error text; this will be accessed outside the class, so we don't use the leading underscore in its name.
7. The next method we create is `_toggle_error()`, as follows:

```
    def _toggle_error(self, error=''):
        self.error.set(error)
        if error:
            self.config(foreground='red')
        else:
            self.config(foreground='black')
```

8. We're using this method to consolidate the widget's behavior in the case of an error. It starts by setting our `error` variable to the string provided. If the string is not blank, we turn on the error marking (in this case, turning the text red); if it's blank, we turn off the error marking. The `_validate()` method is as follows:

```
        def _validate(self, char, index, event, action):

            # reset error state
            self._toggle_error()
            valid = True

            # ISO dates, YYYY-MM-DD, only need digits and hyphens
            if event == 'key':
                if action == '0':  # A delete event should always validate
                    valid = True
                elif index in ('0', '1', '2', '3',
                               '5', '6', '8', '9'):
                    valid = char.isdigit()
                elif index in ('4', '7'):
                    valid = char == '-'
                else:
                    valid = False
```

9. The first thing we do is toggle off our error status and set a `valid` flag to `True`. Our input will be `innocent until proven guilty`.
10. Then, we'll look at keystroke events. `if action == '0':` tells us if the user is trying to delete characters. We always want to allow this so that the user can edit the field.

The basic format of an ISO date is: four digits, a dash, two digits, a dash, and two digits. We can test whether the user is following this format by checking whether the inserted characters match our expectation at the inserted `index`. For example, `index in ('0', '1', '2', '3', '5', '6', '8', '9')` will tell us if the character being inserted is one of the positions that requires a digit, and if so we check that the character is a digit. An index of `4` or `7` should be a dash. Any other keystroke is invalid.

Although you might expect them to be integers, Tkinter passes the action codes and indexes them as strings. Keep this in mind when writing your comparisons.

While this is a hopelessly naive heuristic for a correct date, since it allows for complete nonsense dates like `0000-97-46` or right-looking-but-still-wrong dates like `2000-02-29`, it at least enforces the basic format and removes a large number of invalid keystrokes. A completely accurate partial date analyzer is a project unto itself, so for now this will do.

Checking our date for correctness on `focusout` is simpler and much more foolproof, as follows:

```
        elif event == 'focusout':
            try:
                datetime.strptime(self.get(), '%Y-%m-%d')
            except ValueError:
                valid = False
        return valid
```

Since we have access to the final value the user meant to enter at this point, we can use `datetime.strptime()` to try to convert the string to a Python `datetime` using the format `%Y-%m-%d`. If this fails, we know the date is invalid.

To end the method, we return our `valid` flag.

Validation methods must always return a Boolean value. If, for some reason, your validation method doesn't return a value (or returns `None`), your validation will silently break without any error. Be careful to make sure your methods will always return a Boolean value, especially if you're using multiple `return` statements.

As you saw previously, for invalid keystrokes, it's sufficient to return `False` and prevent the character from being inserted, but for errors on focus events, we'll need to respond in some way.

Take a look at the `_on_invalid()` method in the following code:

```
    def _on_invalid(self, event):
        if event != 'key':
            self._toggle_error('Not a valid date')
```

We pass only the event type into this method, which we'll use to ignore keystroke events (they're already adequately handled by the default behavior). For any other event type, we'll use our `_toggle_error()` method to display the error.

To test our `DateEntry` class, add the following test code to the bottom of the file:

```
if __name__ == '__main__':
    root = tk.Tk()
    entry = DateEntry(root)
    entry.pack()
    tk.Label(textvariable=entry.error).pack()

    # add this so we can unfocus the DateEntry
    tk.Entry(root).pack()
    root.mainloop()
```

Save the file and run it to try the new `DateEntry` class. Try entering various bad dates or invalid keystrokes, and see what happens.

Implementing validated widgets in our form

Now that you know how to validate your widgets, you have your work cut out for you! We have 16 input widgets, and you'll have to write code like that shown in the previous section for all of them to get the behavior we need. Along the way, you'll need to make sure the widgets respond consistently to errors and present a consistent API to the application.

If that sounds like something you'd like to put off indefinitely, I can't blame you. Maybe there's a way we can cut down the amount of code we need to write.

Exploiting the power of multiple inheritance

So far, we have learned that Python allows us to create new classes by subclassing, inheriting features from the super class, and only adding or changing what's different about our new class. Python also supports **multiple inheritance**, where a subclass can inherit from multiple superclasses. We can exploit this feature to our advantage by creating what's called a **mixin** class.

Mixin classes contain only a specific set of functionalities that we want to be able to mix in with other classes to compose a new class.

Take a look at the following example code:

```
class Displayer():

    def display(self, message):
        print(message)

class LoggerMixin():

    def log(self, message, filename='logfile.txt'):
        with open(filename, 'a') as fh:
            fh.write(message)

    def display(self, message):
        super().display(message)
        self.log(message)

class MySubClass(LoggerMixin, Displayer):

    def log(self, message):
        super().log(message, filename='subclasslog.txt')


subclass = MySubClass()
subclass.display("This string will be shown and logged in subclasslog.txt.")
```

We implement a basic class called `Displayer` with a `display()` method that prints a message. Then, we create a mixin class called `LoggerMixin`, which both adds a `log()` method to write a message to a text file and overrides the `display()` method to add a call to `log()`. Finally, we create a subclass by inheriting from both `LoggerMixin` and `Displayer`. The subclass then overrides the `log()` method and sets a different filename.

When we create a class using multiple inheritance, the rightmost class we specify is called the **base class**, and mixin classes should be specified before it. There's no special syntax for a mixin class as opposed to any other class, but pay attention to the use of `super()` in the mixin's `display()` method. Technically, `LoggerMixin` inherits from Python's built-in `object` class, which has no `display()` method. How, then, can we call `super().display()` here?

In a multiple inheritance situation, `super()` does something a little more complex than just standing in for the superclass. It looks up the chain of inheritance using something called the **Method Resolution Order** and determines the nearest class that defines the method we're calling. Thus, when we call `MySubclass.display()`, a series of method resolutions occurs, as follows:

- `MySubClass.display()` is resolved to `LoggerMixin.display()`.
- `LoggerMixin.display()` calls `super().display()`, which is resolved to `Displayer.display()`.
- It also calls `self.log()`. Since `self`, in this case, is a `MySubClass` instance, it resolves to `MySubClass.log()`.
- `MySubClass.log()` calls `super().log()`, which is resolved back to `LoggerMixin.log()`.

If this seems confusing, just remember that `self.method()` will look for `method()` in the current class first, then follow the list of inherited classes from left to right until the method is found. The `super().method()` will do the same, except that it skips the current class.

The method resolution order of a class is stored in its `__mro__` property; you can inspect this method in a Python shell or debugger if you're having trouble with inherited methods.

Note that `LoggerMixin` is not usable on its own: it only works when combined with a class that has a `display()` method. This is why it's a mixin class because it's meant to be mixed in to enhance other classes.

A validating mixin class

Let's apply our knowledge of multiple inheritance to build a mixin that will give us some boilerplate validation logic by performing the following steps:

1. Open `data_entry_app.py` and start the class before your `Application` class definition:

```
class ValidatedMixin:
    """Adds a validation functionality to an input widget"""

    def __init__(self, *args, error_var=None, **kwargs):
        self.error = error_var or tk.StringVar()
        super().__init__(*args, **kwargs)
```

2. We start this class as usual, though we're not subclassing anything this time. The constructor also has an extra argument called `error_var`. This will allow us to pass in a variable to use for the error message; if we don't, the class creates its own. The call to `super().__init__()` will cause the base class that we mix with to execute its constructor.
3. Next, we set up validation, as follows:

```
vcmd = self.register(self._validate)
invcmd = self.register(self._invalid)

self.config(
    validate='all',
    validatecommand=(vcmd, '%P', '%s', '%S', '%V', '%i', '%d'),
    invalidcommand=(invcmd, '%P', '%s', '%S', '%V', '%i', '%d')
)
```

4. We're setting up our `validate` and `invalid` methods here. We'll go ahead and pass in all the substitution codes (except `'%w'`, the widget name, since it's fairly useless inside a class context). We're running validation on all conditions, so we can capture both focus and keystroke events.
5. Now, we'll define our error condition handler:

```
    def _toggle_error(self, on=False):
        self.config(foreground=('red' if on else 'black'))
```

6. This will just change the text color to red if there's an error, or black otherwise. We don't set the error in this function, since we'll want to set the actual error text in the validate method as follows:

```
        def _validate(self, proposed, current, char, event, index,
        action):
              self._toggle_error(False)
              self.error.set('')
              valid = True
              if event == 'focusout':
                  valid = self._focusout_validate(event=event)
              elif event == 'key':
                  valid = self._key_validate(proposed=proposed,
                      current=current, char=char, event=event,
                      index=index, action=action)
              return valid

          def _focusout_validate(self, **kwargs):
              return True

          def _key_validate(self, **kwargs):
              return True
```

Our `_validate()` method just handles a few setup chores like toggling off the error and clearing the error message. Then, it runs an event-specific validate method, depending on the event type passed in. We only care about the `key` and `focusout` events right now, so any other event just returns `True`.

Notice that we call the individual methods using keywords; when we create our subclasses, we'll be overriding these methods. By using keyword arguments, our overridden functions can just specify the needed keywords or extract individual arguments from `**kwargs`, rather than having to get all the arguments in the right order. Also notice that all the arguments are passed into `_key_validate()`, but only `event` is passed into `_focusout_validate()`. Focus events don't return anything useful for any of the other arguments, so there's no point in passing them along.

7. The ultimate idea here is that our subclasses only need to override the validation method or methods we care about for that widget. If we don't override them, they just return `True`, so validation passes. Now, we need to handle an invalid event:

```
         def _invalid(self, proposed, current, char, event, index,
         action):
              if event == 'focusout':
                  self._focusout_invalid(event=event)
              elif event == 'key':
                  self._key_invalid(proposed=proposed,
                      current=current, char=char, event=event,
                      index=index, action=action)
```

```
        def _focusout_invalid(self, **kwargs):
            self._toggle_error(True)

        def _key_invalid(self, **kwargs):
            pass
```

8. We take an identical approach to these methods. Unlike the validate methods, though, our invalid data handlers don't need to return anything. For invalid keys, we do nothing by default, and for invalid data on `focusout`, we toggle our error status on.
9. Keystroke validation only really makes sense in the context of entering keys, but there may be times when we want to manually run the `focusout` checks, since it effectively checks a completely entered value. For this reason, we'll implement the following method:

```
       def trigger_focusout_validation(self):
            valid = self._validate('', '', '', 'focusout', '', '')
            if not valid:
                self._focusout_invalid(event='focusout')
            return valid
```

10. We're just duplicating the logic that occurs when a `focusout` event happens: run the validation function, and if it fails, run the invalid handler. This is all we need for `ValidatedMixin`, so let's start applying it to some of our widgets and see how it works.

Building our widgets

Let's think through what classes we need to implement with our new `ValidatedMixin` class, as follows:

- All our fields except `Notes` are required, so we'll need a basic `Entry` widget that registers an error if there's no input.
- We have one `Date` field, so we need an `Entry` widget that enforces a valid date string.
- We have a number of the `Spinbox` widgets for decimal or integer input. We'll need to make sure these only accept valid number strings.
- We have a few `Combobox` widgets that don't behave quite the way we want them to.

Let's get started!

Requiring data

All of our fields are required, so let's start with a basic `Entry` widget that requires data. We can use these for fields: `Technician` and `Seed sample`.

Add the following code under the `ValidatedMixin` class:

```
class RequiredEntry(ValidatedMixin, ttk.Entry):

    def _focusout_validate(self, event):
        valid = True
        if not self.get():
            valid = False
            self.error.set('A value is required')
        return valid
```

There's no keystroke validation to do here, so we just need to create `_focusout_validate()`. If the entered value is empty, we just set an error string and return `False`.

That's all there is to it!

A Date widget

Now, let's apply the mixin class to the `DateEntry` class we made before, keeping the same validation algorithm as follows:

```
class DateEntry(ValidatedMixin, ttk.Entry):

    def _key_validate(self, action, index, char, **kwargs):
        valid = True

        if action == '0':
            valid = True
        elif index in ('0', '1', '2', '3', '5', '6', '8', '9'):
            valid = char.isdigit()
        elif index in ('4', '7'):
            valid = char == '-'
        else:
            valid = False
        return valid

    def _focusout_validate(self, event):
        valid = True
        if not self.get():
            self.error.set('A value is required')
            valid = False
        try:
            datetime.strptime(self.get(), '%Y-%m-%d')
        except ValueError:
            self.error.set('Invalid date')
            valid = False
        return valid
```

Again, pretty simple, all we need to do is specify the validation logic. We've added the logic from our `RequiredEntry` class too, since the `Date` value is required.

Let's move on to something a bit more intricate.

A better Combobox widget

The drop-down widgets in different toolkits behave fairly consistently when it comes to mouse operation, but the response to keystrokes varies, as follows:

- Some do nothing
- Some require the use of arrow keys to select items
- Some move to the first entry that begins with any key pressed, and cycle through entries beginning with that letter on subsequent presses
- Some narrow down the list to entries that match what's typed

We need to think about what behavior our `Combobox` widget should have. Since our users are accustomed to doing data entry with the keyboard, and some have difficulty with the mouse, the widget needs to work with the keyboard. Making them use repeated keystrokes to select options is not very intuitive, either. After talking with the data entry staff, you decide on this behavior:

- If the proposed text matches no entries, it will be ignored
- When the proposed text matches a single entry, the widget is set to that value
- A delete or backspace clears the entire box

Add this code under the `DateEntry` code:

```
class ValidatedCombobox(ValidatedMixin, ttk.Combobox):

    def _key_validate(self, proposed, action, **kwargs):
        valid = True
        # if the user tries to delete, just clear the field
        if action == '0':
            self.set('')
            return True
```

The `_key_validate()` method starts out by setting up a `valid` flag and doing a quick check to see if this is a delete action. If it is, we set the value to a blank string and return `True`.

Now, we'll add the logic to match the proposed text to our values:

```
       # get our values list
        values = self.cget('values')
        # Do a case-insensitive match against the entered text
        matching = [
            x for x in values
            if x.lower().startswith(proposed.lower())
        ]
        if len(matching) == 0:
            valid = False
        elif len(matching) == 1:
            self.set(matching[0])
            self.icursor(tk.END)
            valid = False
        return valid
```

A copy of the widget's list of values is retrieved using its `.cget()` method. Then, we use list comprehension to reduce this list to only the entries that match the proposed text, calling `lower()` on both the values in the list item and the proposed text so that our match is case-insensitive.

Every Tkinter widget supports the `.cget()` method. It can be used to retrieve any of the widget's configuration values by name.

If the length of the matching list is `0`, we reject the keystroke. If it's `1`, we've found our match, so we'll set the variable to that value. If it's anything else, we need to let the user keep typing. As a final touch, we'll send the cursor to the end of the field using the `.icursor()` method if a match is found. This isn't strictly necessary, but it looks better than leaving the cursor in the middle of the text. Now, we'll add the `focusout` validator, as follows:

```
    def _focusout_validate(self, **kwargs):
        valid = True
        if not self.get():
            valid = False
            self.error.set('A value is required')
        return valid
```

We don't have to do much here, because the key validation method ensures that the only possible values are a blank field or an item in the values list, but since all fields are required to have a value, we'll copy the validation from `RequiredEntry`.

That takes care of our `Combobox` widget. Next, we'll deal with the `Spinbox` widget.

A range-limited Spinbox widget

A number entry seems like it shouldn't be too complicated to deal with, but there are a number of subtleties to work through to make it bulletproof. In addition to limiting the field to valid number values, you'll want to enforce the `from`, `to`, and `increment` arguments as the minimum, maximum, and precision of the input, respectively.

The algorithm needs to implement the following rules:

- Deletion is always allowed
- Digits are always allowed
- If `from` is less than `0`, a minus is allowed as the first character
- If `increment` has a decimal component, one dot is allowed
- If the proposed value is greater than the `to` value, ignore the keystroke
- If the proposed value requires more precision than `increment`, ignore the keystroke
- On `focusout`, make sure the value is a valid number string
- Also on `focusout`, make sure the value is greater than the `from` value

Take a look at the following steps:

1. Here's how we'll code, regarding the preceding rules:

```
class ValidatedSpinbox(ValidatedMixin, tk.Spinbox):

    def __init__(self, *args, min_var=None, max_var=None,
                 focus_update_var=None, from_='-Infinity',
                 to='Infinity', **kwargs):
        super().__init__(*args, from_=from_, to=to, **kwargs)
        self.resolution = Decimal(str(kwargs.get('increment',
        '1.0')))
        self.precision = (
            self.resolution
            .normalize()
            .as_tuple()
            .exponent
        )
```

2. We'll start by overriding the `__init__()` method so that we can specify

some defaults and grab the `increment` value from the constructor arguments for processing.

3. The `Spinbox` arguments can be passed in as floats, integers, or strings. Regardless of how you pass them in, Tkinter converts them to floats. Determining the precision of a float is problematic, because of floating-point error, so we want to convert it to a Python `Decimal` before it becomes a float.

*Floats attempt to represent decimal numbers in binary form. Open a Python shell and enter `1.2 / .2`. You might be surprised to find the answer is `5.999999999999999` rather than `6`. This is known as a **floating-point error**, and it's a source of computation error in nearly every programming language. Python offers us the `Decimal` class, which takes a numeric string and stores it in a way that makes mathematical operations safe from floating-point errors.*

4. Before we can use `Decimal`, we need to import it. Add the following code to your imports at the top of the file:

```
from decimal import Decimal, InvalidOperation
```

5. `InvalidOperation` is an exception thrown when `Decimal` is given a string it cannot interpret. We'll be using it later on.

Notice that we cast `increment` to `str` before passing it to `Decimal`. Ideally, we should pass `increment` in as a string to ensure it will be interpreted correctly, but in case we need to pass in a float for some reason, `str` will do some sensible rounding first.

6. We also set defaults for `to` and `from_`: `-Infinity` and `Infinity`. Both `float` and `Decimal` will happily accept these values and treat them as you'd expect them to do. The default `to` and `from_` values for `Tkinter.Spinbox` are `0`; if they're left there, Tkinter treats it as no limit, but this creates a problem if we specify one but not the other.
7. We extract `precision` of the `resolution` value as an exponent of the smallest valid decimal place. We'll use this value in the validation class.
8. Our constructor is settled, so let's write the validate methods. The key validate method is a bit tricky, so we'll walk through it chunk by chunk. First, we start the method:

```
def _key_validate(self, char, index, current,
                  proposed, action, **kwargs):
```

```
                valid = True
                min_val = self.cget('from')
                max_val = self.cget('to')
                no_negative = min_val >= 0
                no_decimal = self.precision >= 0
```

9. To begin, we retrieve the `from` and `to` values, then assign flag variables to indicate if negatives and decimals should be allowed, as follows:

```
        if action == '0':
            return True
```

Deletion should always work, so if it's a deletion, return `True`.

We've broken our no multiple returns guideline here, because the same logic with only one `return` would be nested quite deeply. When trying to write readable, maintainable code, sometimes one has to pick the lesser of two evils.

10. Next, we test if the keystroke is a valid character, as follows:

```
      # First, filter out obviously invalid keystrokes
        if any([
                (char not in ('-1234567890.')),
                (char == '-' and (no_negative or index != '0')),
                (char == '.' and (no_decimal or '.' in current))
        ]):
            return False
```

Valid characters are digits plus `-` and `.`. The minus sign is only valid at index `0`, and the dot can only appear once. Anything else returns `False`.

The built-in `any` function takes a list of expressions and returns `True` if any one of the expressions in the list are true. There's also an `all` function that returns `True` if all the expressions are true. These functions allow you to condense a long chain of boolean expressions.

We're almost guaranteed at this point to have a valid `Decimal` string, but not quite; we might have just `-`, `.`, or `-.` characters.

11. The following are valid partial entries, so we just return `True` for them:

```
        # At this point, proposed is either '-', '.', '-.',
        # or a valid Decimal string
        if proposed in '-.':
            return True
```

12. At this point, the proposed text can only be a valid `Decimal` string, so we'll

make a `Decimal` from it and do some more tests:

```
        # Proposed is a valid Decimal string
        # convert to Decimal and check more:
        proposed = Decimal(proposed)
        proposed_precision = proposed.as_tuple().exponent

        if any([
            (proposed > max_val),
            (proposed_precision < self.precision)
        ]):
            return False

        return valid
```

13. Our last two tests check to see if the proposed text is either greater than our maximum value, or has more precision than the `increment` that we specified (the reason we use a `<` operator here is because `precision` is given as a negative value for decimal places). In case nothing has been returned yet, we return the `valid` value as a safeguard. Our `focusout` validator is much simpler, as follows:

```
    def _focusout_validate(self, **kwargs):
        valid = True
        value = self.get()
        min_val = self.cget('from')

        try:
            value = Decimal(value)
        except InvalidOperation:
            self.error.set('Invalid number string: {}'.format(value))
            return False

        if value < min_val:
            self.error.set('Value is too low (min {})'.format(min_val)
            valid = False
        return valid
```

14. With the entire intended value, we only need to make sure it's a valid `Decimal` string and greater than the minimum value.

With that, our `ValidatedSpinbox` is ready to go.

Dynamically adjusting the Spinbox range

Our `ValidatedSpinbox` method seems adequate for most of our fields. But consider the `Height` fields for a moment. It would not make any sense for the `Mini height` value to be more than the `Max height` value, or for the `Median height` value not to be between them. Is there some way we can work this kind of interdependent behavior into our class?

We can! To do this, we'll rely on the **tracing** feature of Tkinter variables. A trace is essentially a hook into the `.get()` and `.set()` methods of variables that allows you to trigger any Python function or method when a variable is read or changed.

The syntax is as follows:

```
sv = tk.StringVar()
sv.trace('w', some_function_or_method)
```

The first argument to `.trace()` indicates which event we want to trace. Here, `w` indicates a write (`.set()`), `r` indicates a read (`.get()`), and `u` indicates an undefined variable or deletion of the variable.

Our strategy will be to allow optional `min_var` and `max_var` variables into the `ValidatedSpinbox` method and set a trace on these variables to update the `ValidatedSpinbox` method's min or max value whenever this variable is changed. We'll also have a `focus_update_var` variable that will be updated with the `Spinbox` widget value at `focusout` time.

Let's take a look at the following steps:

1. To start, we'll update our `ValidatedSpinbox` constructor as follows:

```
            def __init__(self, *args, min_var=None, max_var=None,
                focus_update_var=None, from_='-Infinity', to='Infinity',
            **kwargs
            ):
                super().__init__(*args, from_=from_, to=to, **kwargs)
                self.resolution = Decimal(str(kwargs.get('increment', '1.0')))
                self.precision = (
                    self.resolution
                    .normalize()
                    .as_tuple()
                    .exponent
                )
                # there should always be a variable,
                # or some of our code will fail
                self.variable = kwargs.get('textvariable') or tk.DoubleVar()

                if min_var:
                    self.min_var = min_var
                    self.min_var.trace('w', self._set_minimum)
                if max_var:
                    self.max_var = max_var
                    self.max_var.trace('w', self._set_maximum)
                self.focus_update_var = focus_update_var
                self.bind('<FocusOut>', self._set_focus_update_var)
```

2. First, note that we've added a line to store our variable in `self.variable`, and we create one if the program doesn't pass one in explicitly. Some of the code we need to write will depend on a text variable existing, so we'll force this, just in case.
3. If we pass in either a `min_var` or `max_var` argument, the value is stored and a trace is configured. The `trace()` method points to an appropriately named method.
4. We also store a reference to the `focus_update_var` argument and bind the `<FocusOut>` event to a method that will be used to update it.

The `bind()` method can be called on any Tkinter widget, and it's used to connect widget events to a Python callable. Events can be keystrokes, mouse movements or clicks, focus events, window management events, and more.

5. Now, we need to add the callback methods for our `trace()` and `bind()` commands. Start with `_set_focus_update_var()`, as follows:

```
        def _set_focus_update_var(self, event):
                value = self.get()
                if self.focus_update_var and not self.error.get():
                    self.focus_update_var.set(value)
```

This method simply gets the widget's current value and, if there is a `focus_update_var` argument present in the instance, sets it to the same value. Note that we don't set the value if there's an error currently present on the widget. It wouldn't make sense to update the value to something invalid.

When Tkinter calls a `bind` callback, it passes in an event object that contains information about the event that triggered the callback. Even if you aren't going to use this information, your function or method needs to be able to take this argument.

6. Now, let's create the callback for setting the minimum, as follows:

```
    def _set_minimum(self, *args):
        current = self.get()
        try:
            new_min = self.min_var.get()
            self.config(from_=new_min)
        except (tk.TclError, ValueError):
            pass
        if not current:
            self.delete(0, tk.END)
        else:
            self.variable.set(current)
        self.trigger_focusout_validation()
```

7. The first thing we do is retrieve the current value. `Tkinter.Spinbox` has the slightly annoying behavior of correcting its value when the `to` or `from` values are changed, moving too-low values to the `from` value and too-high values to the `to` value. This kind of silent auto-correction might slip past the attention of our user and cause bad data to be saved. What we want is to leave the value out of range and mark it as an error; so to work around Tkinter, we're going to save the current value, change the configuration, and then put the original value back in the field.
8. With the current value saved, we attempt to get the value of the `min_var` and set our widget's `from_` value from it. There are several things that could go wrong here, such as a blank or invalid value in whatever field controls our minimum and maximum variables, all of which should throw either a `tk.TclError` or a `ValueError`. In either case, we'll just do nothing.

It's generally a bad idea to just silence exceptions; however, in this case, there's nothing we can reasonably do if the variable is bad except ignore it.

9. Now, we just need to write the current value that we saved back into the field. If it's empty, we just delete the field; otherwise, we set the input's variable. The method ends with a call to the `trigger_focusout_validation()` method to re-check the value in the field against the new minimum.
10. The `_set_maximum()` method will be identical to this method, except that it will update the `to` value using `max_var` instead. You can write it yourself, or see the sample code included with the book.

11. There is one last change we need to make to our `ValidatedSpinbox` class. Since our maximum can potentially change after entry, and we're relying on our `focusout` validation to detect that, we'll need to add some conditions to check the maximum.
12. We need to add this to the `_focusout_validate()` method:

```
        max_val = self.cget('to')
        if value > max_val:
            self.error.set('Value is too high (max {})'.format(max_val))
```

13. Add those lines just before the `return` statement to check the maximum value and set the error, as appropriate.

Updating our form

Now that our widgets are all made, it's time to make the form use them by performing the following steps:

1. Scroll down to the `DataRecordForm` class constructor, and we'll start updating our widgets one row at a time. Line 1 is fairly straightforward:

```
        self.inputs['Date'] = LabelInput(
            recordinfo, "Date",
            input_class=DateEntry,
            input_var=tk.StringVar())
        self.inputs['Date'].grid(row=0, column=0)
        self.inputs['Time'] = LabelInput(
            recordinfo, "Time",
            input_class=ValidatedCombobox,
            input_var=tk.StringVar(),
            input_args={"values": ["8:00", "12:00", "16:00", "20:00"]})
        self.inputs['Time'].grid(row=0, column=1)
        self.inputs['Technician'] = LabelInput(
            recordinfo, "Technician",
            input_class=RequiredEntry,
            input_var=tk.StringVar())
        self.inputs['Technician'].grid(row=0, column=2)
```

2. It's as simple as swapping out the `input_class` value in each `LabelInput` for our new class. Go ahead and run your application and try out the widgets. Try some different valid and invalid dates, and see how the `Combobox` widget works (`RequiredEntry` won't do much at this point, since the only visible indication is red text, and there's no text to mark red if it's empty; we'll address that later on). Now, on to line 2, first add the `Lab` widget, as follows:

```
        self.inputs['Lab'] = LabelInput(
            recordinfo, "Lab",
            input_class=ValidatedCombobox,
            input_var=tk.StringVar(),
            input_args={"values": ["A", "B", "C", "D", "E"]})
```

3. Next, add the `Plot` widget, as follows:

```
        self.inputs['Plot'] = LabelInput(
            recordinfo, "Plot",
            input_class=ValidatedCombobox,
            input_var=tk.IntVar(),
            input_args={"values": list(range(1, 21))})
```

Fairly straightforward again, but if you run it, you'll find there's a problem with `Plot`. It turns out that our `ValidatedComobox` method doesn't work right when the values are integers since the characters the user types are always strings (even if they're digits); we can't compare strings and integers.

4. If you think about it, `Plot` shouldn't really be an integer value. Yes, the values are technically integers, but as we decided back in `Chapter 3`, *Creating Basic Forms with Tkinter and ttk Widgets*, they could as well be letters or symbols; you wouldn't do maths on a plot number. So, we'll change `Plot` to use a `StringVar` variable and make the values of the widget strings as well. Change the `Plot` widget creation, as follows:

```
        self.inputs['Plot'] = LabelInput(
            recordinfo, "Plot",
            input_class=ValidatedCombobox,
            input_var=tk.StringVar(),
            input_args={"values": [str(x) for x in range(1, 21)]})
```

5. Here, we're just changing the `input_var` to a `StringVar` and using a list comprehension to cast every `values` item to a string. Now, `Plot` works as expected.
6. Continue through the form, replacing the default `ttk` widgets with your newly validated versions. For the `Spinbox` widget, make sure you're passing in the `to`, `from_`, and `increment` values as strings rather than integers. For instance, the `Humidity` widget should be as follows:

```
         self.inputs['Humidity'] = LabelInput(
            environmentinfo, "Humidity (g/m³)",
            input_class=ValidatedSpinbox,
            input_var=tk.DoubleVar(),
            input_args={"from_": '0.5', "to": '52.0', "increment":
            '.01'})
```

7. When we get to the `Height` boxes, it's time to put our `min_var` and `max_var` features to the test. First, we need to set up variables to store the minimum and maximum height, as follows:

```
         # Height data
         # create variables to be updated for min/max height
```

```
        # they can be referenced for min/max variables
        min_height_var = tk.DoubleVar(value='-infinity')
        max_height_var = tk.DoubleVar(value='infinity')
```

We create two new `DoubleVar` objects to hold the current minimum and maximum heights, setting them to infinite values to begin with. This ensures there will be effectively no minimum or maximum height to start with.

Note that our widgets won't be affected by these values until they actually change, so they won't nullify the original `to` and `from_` values passed in.

8. Now, we create the `Min Height` widget, as follows:

```
        self.inputs['Min Height'] = LabelInput(
            plantinfo, "Min Height (cm)",
            input_class=ValidatedSpinbox,
            input_var=tk.DoubleVar(),
            input_args={
                "from_": '0', "to": '1000', "increment": '.01',
                "max_var": max_height_var, "focus_update_var":
                 min_height_var})
```

9. We'll use `max_height_var` to set the maximum here, ensuring that our minimum will never go above the maximum value, and set the `focus_update_var` to `min_height_var` values so that it will be updated whenever this field is changed. Now, the `Max Height` widget is as follows:

```
        self.inputs['Max Height'] = LabelInput(
            plantinfo, "Max Height (cm)",
            input_class=ValidatedSpinbox,
            input_var=tk.DoubleVar(),
            input_args={
                "from_": 0, "to": 1000, "increment": .01,
                "min_var": min_height_var, "focus_update_var":
                max_height_var})
```

10. This time, we use our `min_height_var` variable to set the widget's minimum value and update the `max_height_var` from the widget's current value. Finally, the `Median Height` field is as follows:

```
        self.inputs['Median Height'] = LabelInput(
            plantinfo, "Median Height (cm)",
            input_class=ValidatedSpinbox,
            input_var=tk.DoubleVar(),
            input_args={
                "from_": 0, "to": 1000, "increment": .01,
                "min_var": min_height_var, "max_var": max_height_var})
```

11. Here, we're setting the minimum and maximum values for the field from the `min_height_var` and `max_height_var` variables, respectively. We're not updating any variables from the `Median Height` field, although we could add additional variables and code here to make sure that `Min Height` couldn't go above it or `Max Height` below it. In most cases, it won't matter if the user is entering data in order since `Median Height` is last.
12. You might wonder why we don't just use the `input_var` variables from `Min Height` and `Max Height` to hold these values instead. If you try this, you'll discover the reason: the `input_var` updates as you type, which means your partial value instantly becomes the new maximum or minimum value. We'd rather wait until the user has committed the value to assign this, and thus we created a separate variable that is only updated on `focusout`.

Displaying errors

If you run the application, you may notice that while fields with the `focusout` errors turn red, we don't get to see the actual error. We need to fix this by performing the following steps:

1. Locate your `LabelInput` class, and add the following code to the end of the constructor method:

```
        self.error = getattr(self.input, 'error', tk.StringVar())
        self.error_label = ttk.Label(self, textvariable=self.error)
        self.error_label.grid(row=2, column=0, sticky=(tk.W + tk.E))
```

2. Here, we check to see if our input has an error variable, and if not, we create one. We save a reference to it as `self.error`, then create a `Label` with the error as `textvariable`.
3. Finally, we place this under the input widget.
4. Now, when you try the application, you should be able to see the field errors.

Preventing form submission on error

The final step in preventing errors from getting into our CSV file is to stop the application from saving if the form has known errors. Let's perform the following steps to do this:

1. The first step in implementing this is to provide a way for the `Application` object (which handles saving the data) to retrieve the error status from the `DataRecordForm` object.
2. At the end of the `DataRecordForm` class, add the following method:

```
        def get_errors(self):
            """Get a list of field errors in the form"""

            errors = {}
            for key, widget in self.inputs.items():
                if hasattr(widget.input, 'trigger_focusout_validation'):
                    widget.input.trigger_focusout_validation()
                if widget.error.get():
                    errors[key] = widget.error.get()

            return errors
```

3. Similar to how we handled getting the data, we just loop through the `LabelFrame` widgets. We look for inputs that have the `trigger_focusout_validation` method and call it, just to be sure that all values have been checked. Then, if the widget's `error` variable has any value, we add it to an `errors` dictionary. This way, we can retrieve a dictionary of field names and the errors on each field.
4. Now, we need to add this behavior to the `Application` class's save logic.
5. Add the following code to the beginning of `on_save()`, under `docstring`:

```
    # Check for errors first

    errors = self.recordform.get_errors()
    if errors:
        self.status.set(
            "Cannot save, error in fields: {}"
            .format(', '.join(errors.keys()))
        )
```

```
            return False
```

This logic is straightforward: get the errors, if we find any, and alert the user in the status area and return from the function (thus not saving anything).

6. Start the application and try it out by trying to save a blank form. You should get error messages in all fields and a message at the bottom telling you which fields have errors.

Automating input

Preventing users from entering bad data is one way to help users enter better data; another approach is to automate. Using our understanding of how the forms are likely to be filled out, we can insert values that are very likely to be correct for certain fields.

Remember from `Chapter 2`, *Designing GUI Applications with Tkinter*, that the forms are nearly always recorded the same day that they're filled out, and that they're filled out one at a time from `Plot` 1 to `Plot` 20 in order. Also remember that the `Date`, `Lab`, and `Technician` values remain the same for each form which is filled in. Let's automate this for our users.

Inserting a date

Inserting the current date is an easy place to start. The place to do this is in the `DataRecordForm.reset()` method, which sets up the form for entering a new record.

Update that method as follows:

```
    def reset(self):
        """Resets the form entries"""

        # clear all values
        for widget in self.inputs.values():
            widget.set('')

        current_date = datetime.today().strftime('%Y-%m-%d')
        self.inputs['Date'].set(current_date)
```

Just as we do in the `Application.save()` method, we get the current date from `datetime.today()` and format it as an ISO date. Then, we set the `Date` widget's input to that value.

Automating Lab, Time, and Technician

Something which is slightly more complex is our handling of `Lab`, `Time`, and `Technician`. Let's review the logic as follows:

1. Before clearing the data, save the `Lab`, `Time`, and `Technician` values.
2. If `Plot` is less than the last value (`20`), we'll put those values back after clearing all the fields, then increment to the next `Plot` value.
3. If `Plot` is the last value or no value, leave those fields blank. The code is as follows:

```
    def reset(self):
        """Resets the form entries"""

        # gather the values to keep for each lab
        lab = self.inputs['Lab'].get()
        time = self.inputs['Time'].get()
        technician = self.inputs['Technician'].get()
        plot = self.inputs['Plot'].get()
        plot_values = self.inputs['Plot'].input.cget('values')

        # clear all values
        for widget in self.inputs.values():
            widget.set('')

        current_date = datetime.today().strftime('%Y-%m-%d')
        self.inputs['Date'].set(current_date)
        self.inputs['Time'].input.focus()

        # check if we need to put our values back, then do it.
        if plot not in ('', plot_values[-1]):
            self.inputs['Lab'].set(lab)
            self.inputs['Time'].set(time)
            self.inputs['Technician'].set(technician)
            next_plot_index = plot_values.index(plot) + 1
            self.inputs['Plot'].set(plot_values[next_plot_index])
            self.inputs['Seed sample'].input.focus()
```

Because `Plot` looks like an integer, it might be tempting to increment it like one, but it's better to work with it as though it were not. We use the indexes of the values list instead.

4. One last tweak, the focus of the form always starts in the first field, but this means the user has to tab through fields that are already filled in. It would be nice if the next empty inputs were focused at the start instead. Tkinter inputs have a `focus()` method, which gives them keyboard focus. Depending on which fields we've filled in, this will either be `Time` or `Seed sample`. Under the line that sets the `Date` value, add the following code line:

```
|          self.inputs['Time'].input.focus()
```

5. And under the line that sets the `Plot` value, inside the conditional block, add the following line of code:

```
|      self.inputs['Seed sample'].input.focus()
```

Our form is now ready for a trial run with our users. It's definitely an improvement over the CSV entry at this point, and will help data entry to make quick work of those forms.

Summary

The application has really come a long way. In this chapter, we learned about Tkinter validation, created a validation mixin class, and used it to create validated versions of the `Entry`, `Combobox`, and `Spinbox` widgets. We validated different kinds of data on keystrokes and focus events, and created fields that dynamically update their constraints based on the value of related fields.

In the next chapter, we're going to prepare our code base for expansion and learn how to organize a large application for easier maintenance. More specifically, we'll learn about the MVC pattern and how to structure our code in multiple files for simpler maintenance. We'll also learn more about RST and and version control software.

Planning for the Expansion of Our Application

The application is a real hit! After some initial testing and orientation, the data entry staff have been utilizing your new form for a few weeks now. The reduction in errors and data entry time is dramatic, and there's a lot of excited talk about what other problems this program might solve. With even the director joining in on the brainstorming, you have a strong suspicion that you'll be asked to add some new features soon.

There's a problem, though; the application is already a script of several hundred lines, and you're worried about its manageability as it grows. You need to take some time to organize your codebase in preparation for future expansion.

In this chapter, we'll learn about the following topics:

- How to separate the concerns of your application using the **Model-View-Controller** pattern
- How to organize your code into a Python package
- To create the basic files and directories for your package structure
- How to use the Git version control system to track your changes

Separating concerns

Proper architectural design is essential for any project that needs to scale. Anyone can prop up some studs and build a garden shed, but a house or skyscraper takes careful planning and engineering. Software is no different; simple scripts can get away with shortcuts such as global variables or manipulating class properties directly, but as the program grows, our code needs to isolate and encapsulate different functionalities in a way that limits the amount of complexity we need to understand at any given moment.

We call this **separation of concerns**, and it's accomplished through the use of architectural patterns that describe different application components and how they interact.

The MVC pattern

Probably the most enduring of these patterns is the MVC pattern, which was introduced in the 1970s. While this pattern has evolved and spun off variations over the years, the basic gist remains: keep the data, the presentation of the data, and the application logic in separate, independent components.

Let's take a deeper look at these components and understand them in the context of our application as it stands.

What is a model?

The **model** in MVC represents the data. This includes the storage of the data, but also the various ways data can be queried or manipulated. Ideally, the model is not concerned or affected by how data will be presented or what UI controls will be granted, but rather presents a high-level interface that only minimally concerns other components with its inner workings. In theory, if you decided to completely change the UI of the program (say, from a Tkinter application to a web application), the model should be totally unaffected.

Some examples of functionality or information you find in the model include the following:

- Preparation and writing of program data to a persistent medium (data file, database, and so on)
- Retrieval of data from a file or database into a format useful to the program
- An authoritative list of the fields in a set of data, along with their data types and limits
- Validation of data against the data types and limits defined
- Calculations on stored data

We don't have a model class in our application currently; the data layout is defined in the form class, and the `Application.on_save()` method is the only code concerned with data persistence so far. We're going to need to split this logic off into a separate object that will define the data layout and handle all the CSV operations.

What is a view?

A **view** is an interface for presenting data and controls to the user. Applications may have many views, often on the same data. Views don't talk to the model directly, and ideally contain only enough logic to present the UI and communicate user actions back to the controller.

Some examples of code you find in a view include the following:

- GUI layout and widget definitions
- Form automations, such as auto-completion of fields, dynamic toggling of widgets, or display of error dialogs
- Formatting of raw data for presentation

Our `DataRecordForm` class is our main view: it contains most of the code for our application's user interface. It also currently defines the structure of our data records. This logic can stay in the view, because the view does need a way to store the data temporarily before handing it off to the model, but it won't be defining our data record from here on out.

We'll be adding more views to our application as we move forward.

What is a controller?

The **controller** is the Grand Central station for the application. It handles requests from the user and takes care of routing data between the views and the model. Most variations of MVC change the role (and sometimes the name) of the controller, but the important thing is that it acts as the intermediary between the view and the model. Our controller object will need to hold references to the views and models used by our application and be responsible for managing interactions between them.

Examples of code you find in the controller include the following:

- Startup and shutdown logic for the application
- Callbacks for user interface events
- Creation of model and view instances

Our `Application` object is currently acting as the controller for our application, though it has some view and model logic in it as well. As the application evolves, we'll be moving more presentation logic into the views and more data logic into the models, leaving mainly connecting code in our `Application` object.

Why complicate our design?

Initially, it may seem like a lot of needless overhead to split up the application this way. We'll have to shuttle data around between different objects and ultimately write more code to do exactly the same thing. Why would we do this?

Put simply, we're doing it to make expansion manageable. As the application grows, the complexity will also grow. Isolating our components from one another limits the amount of complexity that any one component has to manage; for example, when we restructure the layout of our form view, we shouldn't need to worry about how the model will structure the data in the output file. Those two aspects of the program should be independent of one another.

It also helps us to be consistent about where we put certain types of logic. For example, having a discrete model object helps us to avoid littering our UI code with ad hoc data queries or file access attempts.

The bottom line is, without some guiding architectural strategy, our program is in danger of becoming a hopeless tangle of spaghetti logic. Even without adhering to a strict definition of MVC design, consistently following even a loose MVC pattern will save a lot of headaches as the application becomes more complex.

Structuring our application directory

Just as logically breaking our program into separate concerns helps us manage the logical complexity of each component, physically breaking the code into multiple files helps us keep the complexity of each file manageable. It also reinforces more isolation between components; for example, you can't share global variables, and if your models file imports `tkinter`, you know you're doing something wrong.

Basic directory structure

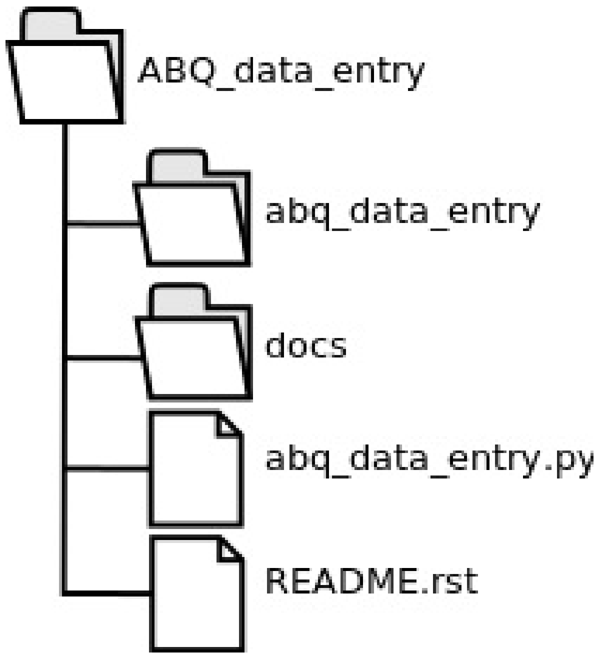
There is no official standard for laying out a Python application directory, but there are some common conventions that will help us keep things tidy and make it easier to package our software later on. Let's set up our directory structure as follows:

1. To begin, create a directory called `ABQ_Data_Entry`. This is the **root directory** of our application, so whenever we refer to the **application root**, this is it.

2. Under the application root, create another directory called `abq_data_entry`. Notice it's in lowercase. This is going to be a Python package that will contain all the code for the application; it should always be given a fairly unique name so that it won't be confused with existing Python packages. Normally, you wouldn't have a different casing between the application root and this main module, but it doesn't hurt anything either; we're doing it here to avoid confusion.

Python modules should always be named using all lowercase names with underscores. This convention is spelled out in PEP 8, Python's official style guide. See `https://www.python.org/dev/peps/pep-0008` *for more information about PEP 8.*

3. Next, create a `docs` folder under the application root. This folder will be for documentation files about the application.
4. Finally, create two empty files in the application root: `README.rst` and `abq_data_entry.py`. Your directory structure should look as follows:


ABQ_data_entry
abq_data_entry
docs
abq_data_entry.py
README.rst

The abq_data_entry.py file

Just as before, `abq_data_entry.py` is the main file that gets executed to start the program. Unlike before, though, it won't contain the bulk of our program. In fact, this file should be as minimal as possible.

Open the file and enter the following code:

```
from abq_data_entry.application import Application

app = Application()
app.mainloop()
```

Save and close the file. The only purpose of this file is to import our `Application` class, make an instance of it, and run it. The remainder of the work will happen inside the `abq_data_entry` package. We haven't created that yet, so this file won't run just yet; before we do, let's deal with our documentation.

The README.rst file

Since as far back as the 1970s, programs have included a short text file called `README` containing a condensed summary of the program's documentation. For small programs, it may be the only documentation; for larger programs, it usually contains essential pre-flight instructions for users or administrators.

There's no prescribed set of contents for a `README` file, but as a basic guideline, consider the following sections:

- **Description**: A brief description of the program and its function. We can reuse the description from our specification, or something like it. This might also contain a brief list of the main features.
- **Author information**: The names of the authors and copyright date. This is especially important if you plan to share your software, but even for something in-house it's useful for future maintainers to know who created the software and when.
- **Requirements**: A list of the software and hardware requirements for the software, if any.
- **Installation**: Instructions for installing the software, its prerequisites, dependencies, and basic setup.
- **Configuration**: How to configure the application and what options are available. This is generally aimed at the command-line or configuration file options, not options set interactively in the program.
- **Usage**: A description of how to launch the application, command-line arguments, and other notes a user would need to know to use the basic functionality of the application.
- **General notes**: A catch-all for notes or critical information users should be aware of.
- **Bugs**: A list of known bugs or limitations in the application.

Not all of these sections will apply to every program; for example, ABQ data entry doesn't currently have any configuration options, so there's no reason to have a configuration section. You might add other sections as well, depending on the situation; for example, publicly distributed software may have a FAQ section, or open source software might have a contributing section with instructions on how to submit patches.

The `README` file is written in plain ASCII or Unicode text, either free-form or using a markup language. Since we're doing a Python project, we'll use reStructuredText, the official markup for Python documentation (which is why our file uses an `rst` file extension).

ReStructuredText

The reStructuredText markup language is part of the Python `docutils` project, and a complete reference can be found at the Docutils website: http://docutils.sourceforge.net. The `docutils` project also provides utilities for converting RST to formats like PDF, ODT, HTML, and LaTeX.

The basics can be grasped fairly quickly, so let's go through them:

- Paragraphs are created by leaving a blank line between blocks of text.
- Headings are created by underlining a single line of text with a non-alphanumeric symbol. The exact symbol doesn't matter; whichever one you use first will be treated as a level one heading for the rest of the document, whichever you use second as a level two, and so on. Conventionally, `=` is usually used for level one, `-` for level two, `~` for level three, and `+` for level four.
- Titles and subtitles are created like headings, except with a line of symbols above and below.
- Bullet lists are created by starting a line with any of `*`, `-`, or `+` and a space. Switching symbols will create a sub-list, and multiline points are created by indenting subsequent lines to where the text starts at the first bullet point.
- Numbered lists are created like bullet lists, but using either digits (which don't need to be correctly ordered) or the `#` symbol as a bullet.
- Code examples can be specified inline by enclosing them in double backtick characters (``` `` ```), or in a block by ending a lead-in line with a double colon and indenting the code block.
- Tables can either be created by surrounding columns of text with `=` symbols, separated by spaces to indicate the column breaks, or by constructing ASCII-art tables from `|`, `-`, and `+`. Tables can be tedious to create in a plain text editor, but some programming tools have plugins to generate the RST tables.

We've used RST already in Chapter 2, *Designing GUI Applications with Tkinter*, to create our program specification; there, you saw the use of titles, headers, bullets, and a table. Let's walk through creating our `README.rst` file:

1. Open the file and start with the title and description, as follows:

```
============================
 ABQ Data Entry Application
============================

Description
===========

This program provides a data entry form for ABQ Agrilabs laborator

Features
--------

* Provides a validated entry form to ensure correct data
* Stores data to ABQ-format CSV files
* Auto-fills form fields whenever possible
```

2. Next, we'll list the authors by adding the following code:

```
Authors
=======

Alan D Moore, 2018
```

   Add yourself, of course. Eventually, other people might work on your application; they should add their names here with the dates they worked on it. Now, add the requirements as follows:

```
Requirements
============

* Python 3
* Tkinter
```

   Right now, we only need Python 3 and Tkinter, but as our application grows we may be expanding this list. Our application doesn't really need to be installed, and has no configuration options, so for now we can skip those sections. Instead, we'll skip to `Usage` as follows:

```
Usage
=====

To start the application, run::

  python3 ABQ_Data_Entry/abq_data_entry.py
```

There really isn't much to know about running the program other than this command; no command-line switches or arguments. We don't know of any bugs, so we'll just leave some general notes at the end as follows:

```
General Notes
=============

The CSV file will be saved to your current directory in the format

This program only appends to the CSV file.  You should have a sprea
```

It seems prudent to tell the user where the file will be saved and what it will be called, since that's hardcoded into the program right now. Also, we should mention the fact that the user should have some kind of spreadsheet, since the program can't edit or view the data. That finishes the `README.rst` file. Save it and let's move on to the `docs` folder.

Populating the docs folder

The `docs` folder is where documentation goes. This can be any kind of documentation: user manuals, program specifications, API references, diagrams, and so on.

For now, you copy in the program specification we wrote in previous chapters, your interface mockups, and a copy of the form used by the technicians.

At some point, you might need to write a user manual, but for now the program is simple enough not to need it.

Making a Python package

Creating your own Python package is surprisingly easy. A Python package consists of the following three things:

- A directory
- One or more Python files in that directory
- A file called `__init__.py` in the directory

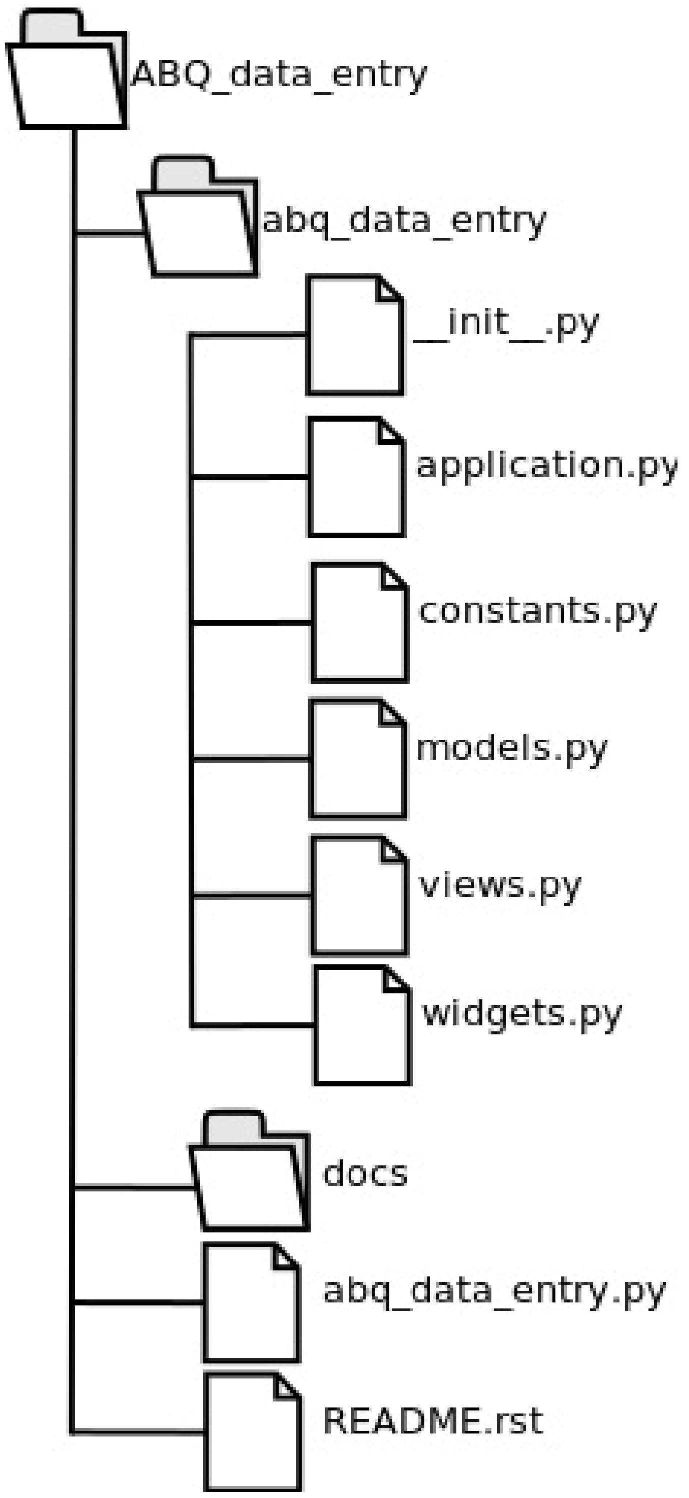
Once you've done this, you can import your package in whole or in part, just like you would import standard library packages, provided your script is in the same parent directory as the package directory.

Note that `__init__.py` in a module is somewhat analogous to what `self.__init__()` is for a class. Code inside it will run whenever the package is imported. The Python community generally discourages putting much code in this file, though, and since no code is actually required, we'll leave this file empty.

Let's start building our application's package. Create the following six empty files under `abq_data_entry`:

- `__init__.py`
- `widgets.py`
- `views.py`
- `models.py`
- `application.py`
- `constants.py`

Each of those Python files is called a **module**. A module is nothing more than a Python file inside a package directory. Your directory structure should now look like this:



At this point, you have a working package, albeit with no actual code in it. To test this, open a Terminal/command-line window, change to your `ABQ_Data_Entry` directory, and start a Python shell.

Now, type the following command:

```
from abq_data_entry import application
```

This should work without error. Of course, it doesn't do anything, but we'll get to that next.

Don't confuse the term package here with the actual distributable Python packages, such as those you download using `pip`. We will learn how to make distributable Python packages in `Chapter 15`, Packaging with setuptools and cx_Freeze. In this context, a package is just a collection of Python modules.

Splitting our application into multiple files

Now that our directory structure is in order, we need to start dissecting our application script and splitting it up into our module files. We'll also need to create our model class. Open up your `abq_data_entry.py` file from `Chapter 4`, *Reducing User Error with Validation and Automation*, and let's begin!

Creating the models module

When your application is all about data, it's good to begin with the model. Remember that the job of a model is to manage the storage, retrieval, and processing of our application's data, usually with respect to its persistent storage format (in this case, CSV). To accomplish this, our model should contain all the knowledge about our data.

Currently, our application has nothing like a model; knowledge about the application's data is scattered into the form fields, and the `Application` object simply takes whatever data the form contains and stuffs it directly into a CSV file when a save operation is requested. Since we aren't yet retrieving or updating information, our application has no actual knowledge about what's inside the CSV file.

To move our application to an MVC architecture, we'll need to create a model class that both manages data storage and retrieval, and represents the authoritative source of knowledge about our data. In other words, we have to encode the knowledge contained in our data dictionary here in our model. We don't really know what we'll *do* with this knowledge yet, but this is where it belongs.

There are a few ways we could store this data, such as creating a custom field class or a `namedtuple` object, but we'll keep it simple for now and just use a dictionary, mapping field names to field metadata.

The field metadata will likewise be stored as a dictionary of attributes about the field, which will include:

- Whether or not the field is required
- The type of data stored in the field
- The list of possible values, if applicable
- The minimum, maximum, and increment of values, if applicable

To store the data type for each field, let's define some data types. Open the `constants.py` file and add the following code:

```
class FieldTypes:
    string = 1
    string_list = 2
    iso_date_string = 3
    long_string = 4
    decimal = 5
    integer = 6
    boolean = 7
```

We've created a class called `FieldTypes` that simply stores some named integer values, which will describe the different types of data we're going to store. We could just use Python types here, but it's useful to differentiate between certain types of data that are likely to be the same Python type (such as `long`, `short`, and `date` strings). Note that the integer values here are basically meaningless; they just need to be different from one another.

TIP *Python 3 has an `Enum` class, which we could have used here, but it adds very little that we actually need in this case. You may want to investigate this class if you're creating a lot of constants such as our `FieldTypes` class and need additional features.*

Now, open `models.py`, where we'll import `FieldTypes` and create our model class and field definitions as follows:

```
import csv
import os
from .constants import FieldTypes as FT

class CSVModel:
    """CSV file storage"""
    fields = {
        "Date": {'req': True, 'type': FT.iso_date_string},
        "Time": {'req': True, 'type': FT.string_list,
                 'values': ['8:00', '12:00', '16:00', '20:00']},
        "Technician": {'req': True, 'type':  FT.string},
        "Lab": {'req': True, 'type': FT.string_list,
                'values': ['A', 'B', 'C', 'D', 'E']},
        "Plot": {'req': True, 'type': FT.string_list,
                 'values': [str(x) for x in range(1, 21)]},
        "Seed sample":  {'req': True, 'type': FT.string},
        "Humidity": {'req': True, 'type': FT.decimal,
                     'min': 0.5, 'max': 52.0, 'inc': .01},
        "Light": {'req': True, 'type': FT.decimal,
                  'min': 0, 'max': 100.0, 'inc': .01},
        "Temperature": {'req': True, 'type': FT.decimal,
                        'min': 4, 'max': 40, 'inc': .01},
        "Equipment Fault": {'req': False, 'type': FT.boolean},
        "Plants": {'req': True, 'type': FT.integer,
                   'min': 0, 'max': 20},
        "Blossoms": {'req': True, 'type': FT.integer,
                     'min': 0, 'max': 1000},
        "Fruit": {'req': True, 'type': FT.integer,
                  'min': 0, 'max': 1000},
        "Min Height": {'req': True, 'type': FT.decimal,
                       'min': 0, 'max': 1000, 'inc': .01},
        "Max Height": {'req': True, 'type': FT.decimal,
                       'min': 0, 'max': 1000, 'inc': .01},
        "Median Height": {'req': True, 'type': FT.decimal,
                          'min': 0, 'max': 1000, 'inc': .01},
        "Notes": {'req': False, 'type': FT.long_string}
    }
```

Notice the way we import `FieldTypes`: `from .constants import FieldTypes`. The dot in front of `constants` makes this a **relative import**. Relative imports can be used inside a Python package to locate other modules in the same package. In this case, we're in the `models` module, and we need to access the `constants` module inside the `abq_data_entry` package. The single dot represents our current parent module (`abq_data_entry`), and thus `.constants` means the `constants` module of the `abq_data_entry` package.

Relative imports also distinguish our custom modules from modules in `PYTHONPATH`. Thus, we don't have to worry about any third-party or standard library packages conflicting with our module names.

In addition to field attributes, we're also documenting the order of fields here. In Python 3.6 and later, dictionaries retain the order they were defined by; if you're using an older version of Python 3, you'd need to use the `OrderedDict` class from the `collections` standard library module to preserve the field order.

Now that we have a class that understands which fields need to be stored, we need to migrate our save logic from the application class into the model.

The code in our current script is as follows:

```
datestring = datetime.today().strftime("%Y-%m-%d")
filename = "abq_data_record_{}.csv".format(datestring)
newfile = not os.path.exists(filename)

data = self.recordform.get()

with open(filename, 'a') as fh:
    csvwriter = csv.DictWriter(fh, fieldnames=data.keys())
    if newfile:
        csvwriter.writeheader()
    csvwriter.writerow(data)
```

Let's go through this code and determine what goes to the model and what stays in the controller (that is, the `Application` class):

- The first two lines define the filename we're going to use. This could go into the model, but thinking ahead, it seems that the users may want to be able to open arbitrary files or define the filename manually. This means the application will need to be able to tell the model which filename to work with, so it's better to leave the logic that determines the name in the controller.
- The `newfile` line determines whether the file exists or not. As an implementation detail of the data storage medium, this is clearly the model's problem, not the application's.
- `data = self.recordform.get()` pulls data from the form. Since our model has no knowledge of the form's existence, this needs to stay in the controller.
- The last block opens the file, creates a `csv.DictWriter` object, and appends the data. This is definitely the model's concern.

Now, let's begin moving code into the `CSVModel` class:

1. To start the process, let's create a constructor for `CSVModel` that allows us to pass in a filename:

```
    def __init__(self, filename):
        self.filename = filename
```

   The constructor is pretty simple; it just takes a `filename` parameter and stores it as a property. Now, we'll migrate the save logic as follows:

```
    def save_record(self, data):
        """Save a dict of data to the CSV file"""

        newfile = not os.path.exists(self.filename)

        with open(self.filename, 'a') as fh:
            csvwriter = csv.DictWriter(fh,
                fieldnames=self.fields.keys())
            if newfile:
                csvwriter.writeheader()
            csvwriter.writerow(data)
```

   This is essentially the logic we chose to copy from

`Application.on_save()`, but with one difference; in the call to `csv.DictWriter()`, the `fieldnames` parameter is defined by the model's `fields` list rather than the keys of the `data` dict. This allows our model to manage the format of the CSV file itself, and not depend on what the form gives it.

2. Before we're done, we need to take care of our module imports. The `save_record()` method uses the `os` and `csv` libraries, so we need to import them. Add this to the top of the file as follows:

```
import csv
import os
```

With the model in place, let's start working on our view components.

Moving the widgets

While we could put all of our UI-related code in one `views` file, we have a lot of widget classes that should really be put in their own file to limit the complexity of the `views` file.

So instead, we're going to move all of the code for our widget classes into the `widgets.py` file. Widgets include all the classes that implement reusable GUI components, including compound widgets like `LabelInput`. As we develop more of these, we'll add them to this file.

Open `widgets.py` and copy in all of the code for `ValidatedMixin`, `DateInput`, `RequiredEntry`, `ValidatedCombobox`, `ValidatedSpinbox`, and `LabelInput`. These are our widgets.

The `widgets.py` file will need to import any module dependencies used by the code being copied in. We'll need to look through our code and find what libraries we use and import them. Obviously, we need `tkinter` and `ttk`, so add those at the top as follows:

```
import tkinter as tk
from tkinter import ttk
```

Our `DateInput` class uses the `datetime` class from the `datetime` library, so import that too, as follows:

```
from datetime import datetime
```

Finally, our `ValidatedSpinbox` class makes use of the `Decimal` class and `InvalidOperation` exception from the `decimal` library as follows:

```
from decimal import Decimal, InvalidOperation
```

This is all we need in `widgets.py` for now, but we'll revisit this file as we refactor our view logic.

Moving the views

Next, we need to create the `views.py` file. Views are larger GUI components, like our `DataRecordForm` class. Currently it's our only view, but we'll be creating more views in later chapters, and they'll be added here.

Open the `views.py` file and copy in the `DataRecordForm` class, then go back to the top to deal with the module imports. Again, we'll need `tkinter` and `ttk`, and our file saving logic relies on `datetime` for the filename.

Add them to the top of the file as follows:

```
import tkinter as tk
from tkinter import ttk
from datetime import datetime
```

We aren't done, though; our actual widgets aren't here and we'll need to import them. Since we're going to be doing a lot of importing of objects between our files, let's pause for a moment to consider the best way to handle these imports.

There are three ways we could import objects:

- Use a wildcard import to bring in all the classes from `widgets.py`
- Explicitly import all the needed classes from `widgets.py` using the `from ... import ...` format
- Import `widgets` and keep our widgets in their own namespace

Let's consider the relative merits of those ways:

- The first option is by far the easiest, but it can cause us headaches as the application expands. A wildcard import will bring in every name defined at the global scope within the module. That includes not just the classes we defined, but any imported modules, aliases, and defined variables or functions. This can lead to unintended consequences and subtle bugs as the application expands in complexity.

- The second option is cleaner, but means we'll need to maintain the list of imports as we add new classes and use them in different files, and this leads to a long and ugly imports section that is hard for humans to parse.
- The third option is by far the best, as it keeps all names within a namespace and keeps the code elegantly simple. The only downside is that we'll need to update our code so that all references to widget classes include the module name as well. To keep this from being unwieldy, let's alias the `widgets` module to something short, like `w`.

Add the following code to your imports:

```
from . import widgets as w
```

Now, we just need to go through the code and prepend `w.` to all instances of `LabelInput`, `RequiredEntry`, `DateEntry`, `ValidatedCombobox`, and `ValidatedSpinbox`. This should be easy enough to do in IDLE or any other text editor using a series of search and replace actions.

For example, `line 1` of the form is as follows:

```
# line 1
self.inputs['Date'] = w.LabelInput(
    recordinfo, "Date",
    input_class=w.DateEntry,
    input_var=tk.StringVar()
)
self.inputs['Date'].grid(row=0, column=0)
self.inputs['Time'] = w.LabelInput(
    recordinfo, "Time",
    input_class=w.ValidatedCombobox,
    input_var=tk.StringVar(),
    input_args={"values": ["8:00", "12:00", "16:00", "20:00"]}
)
self.inputs['Time'].grid(row=0, column=1)
self.inputs['Technician'] = w.LabelInput(
    recordinfo, "Technician",
    input_class=w.RequiredEntry,
    input_var=tk.StringVar()
)
self.inputs['Technician'].grid(row=0, column=2)
```

Before you go through and change that everywhere, though, let's stop and take a moment to refactor some of the redundancy out of this code.

Removing redundancy in our view logic

Look at the field definitions in the view logic: they contain a lot of information that is also in our model. Minimums, maximums, increments, and possible values are defined both here and in our model code. Even the type of the input widget is related directly to the type of data being stored. Ideally, this should only be defined one place, and that place should be the model. If we needed to update the model for some reason, our form would be out of sync.

What we need to do is to pass the field specification from our model into the view class and let the widgets' details be defined from that specification.

Since our widget instances are being defined inside the `LabelInput` class, we're going to enhance that class with the ability to automatically work out the `input` class and arguments from our model's field specification format. Open up the `widgets.py` file and import the `FieldTypes` class, just as you did in `model.py`.

Now, locate the `LabelInput` class and add the following code before the `__init__()` method:

```
    field_types = {
        FT.string: (RequiredEntry, tk.StringVar),
        FT.string_list: (ValidatedCombobox, tk.StringVar),
        FT.iso_date_string: (DateEntry, tk.StringVar),
        FT.long_string: (tk.Text, lambda: None),
        FT.decimal: (ValidatedSpinbox, tk.DoubleVar),

        FT.integer: (ValidatedSpinbox, tk.IntVar),
        FT.boolean: (ttk.Checkbutton, tk.BooleanVar)
    }
```

This code acts as a key to translate our model's field types into a widget type and variable type appropriate for the field type.

Now, we need to update `__init__()` to take a `field_spec` parameter and, if given, use it to define the input widget as follows:

```
    def __init__(self, parent, label='', input_class=None,
         input_var=None, input_args=None, label_args=None,
         field_spec=None, **kwargs):
        super().__init__(parent, **kwargs)
        input_args = input_args or {}
        label_args = label_args or {}
        if field_spec:
            field_type = field_spec.get('type', FT.string)
            input_class = input_class or
            self.field_types.get(field_type)[0]
            var_type = self.field_types.get(field_type)[1]
            self.variable = input_var if input_var else var_type()
            # min, max, increment
            if 'min' in field_spec and 'from_' not in input_args:
                input_args['from_'] = field_spec.get('min')
            if 'max' in field_spec and 'to' not in input_args:
                input_args['to'] = field_spec.get('max')
            if 'inc' in field_spec and 'increment' not in input_args:
                input_args['increment'] = field_spec.get('inc')
            # values
            if 'values' in field_spec and 'values' not in input_args:
                input_args['values'] = field_spec.get('values')
        else:
            self.variable = input_var
        if input_class in (ttk.Checkbutton, ttk.Button, ttk.Radiobutton):
            input_args["text"] = label
            input_args["variable"] = self.variable
        else:
            self.label = ttk.Label(self, text=label, **label_args)
            self.label.grid(row=0, column=0, sticky=(tk.W + tk.E))
            input_args["textvariable"] = self.variable
        # ... Remainder of __init__() is the same
```

Let's break down the changes:

1. First, we've added `field_spec` as a keyword argument with `None` as a default. We might want to use this class in a situation where there isn't a field specification, so we keep this parameter optional.
2. If there is `field_spec` given, we're going to do the following things:
    - We'll grab the `type` value and use that with our class's field key to get `input_class`. In case we want to override this, an explicitly passed `input_class` will override the detected one.
    - We'll determine the appropriate variable type in the same way. Once again, if `input_var` is explicitly passed, we'll prefer that, otherwise we'll use the one determined from the field type. We'll create an instance either way and store it in `self.variable`.
    - For `min`, `max`, `inc`, and `values`, if the key exists in the field

specification, and the corresponding `from_`, `to`, `increment`, or `values` argument has not been passed in explicitly, we'll set up the `input_args` variable with the `field_spec` value.
3. If `field_spec` wasn't passed in, we need to assign `self.variable` from the `input_var` argument.
4. We're using `self.variable` now instead of `input_var` for assigning the input's variable, since those values might not necessarily be the same anymore and `self.variable` will contain the correct reference.

Now, we can update our view code to take advantage of this new ability. Our `DataRecordForm` class will need access to the model's `fields` dictionary, which it can then use to send a field specification to the `LabelInput` class.

Back in the `views.py` file, edit the method signature so that we can pass in a dictionary of field specifications:

```
    def __init__(self, parent, fields, *args, **kwargs):
```

With access to the `fields` dictionary, we can just get the field specification from it and pass that into the `LabelInput` class instead of specifying the input class, input variable, and input arguments.

Now, the first line looks like this:

```
        self.inputs['Date'] = w.LabelInput(
            recordinfo, "Date",
            field_spec=fields['Date'])
        self.inputs['Date'].grid(row=0, column=0)
        self.inputs['Time'] = w.LabelInput(
            recordinfo, "Time",
            field_spec=fields['Time'])
        self.inputs['Time'].grid(row=0, column=1)
        self.inputs['Technician'] = w.LabelInput(
            recordinfo, "Technician",
            field_spec=fields['Technician'])
        self.inputs['Technician'].grid(row=0, column=2)
```

Go ahead and update the rest of the widgets the same way, replacing `input_class`, `input_var`, and `input_args` with `field_spec`. Note that when you get to the height fields, you'll need to keep the part of `input_args` that defines `min_var`, `max_var`, and `focus_update_var`.

For example, the following is the `Min Height` input definition:

```
        self.inputs['Min Height'] = w.LabelInput(
            plantinfo, "Min Height (cm)",
            field_spec=fields['Min Height'],
            input_args={"max_var": max_height_var,
                        "focus_update_var": min_height_var})
```

That does it. Now, any changes to our field specification can be made solely in the model, and the form will simply do the correct thing.

Creating the application file

Finally, let's create our controller class, `Application`, by following these steps:

1. Open the `application.py` file and copy in the `Application` class definition from the script.

2. The first thing we'll fix is our imports. At the top of the file, add the following code:

```
import tkinter as tk
from tkinter import ttk
from datetime import datetime
from . import views as v
from . import models as m
```

   We need `tkinter` and `ttk`, of course, and `datetime` to define our filename. Although we only need one class each from `views` and `models`, we're going to keep them in their own namespaces anyway. It's likely we're going to have many more views as the application expands, and possibly more models.

3. We need to update the call to `DataRecordForm` in `__init__()` for the new namespace and make sure we pass in the required field specification dictionary as follows:

```
        self.recordform = v.DataRecordForm(self, m.CSVModel.fields)
```

4. Finally, we need to update `Application.on_save()` to use the model, as follows:

```
def on_save(self):
    """Handles save button clicks"""

    errors = self.recordform.get_errors()
    if errors:
        self.status.set(
            "Cannot save, error in fields: {}"
```

```
                .format(', '.join(errors.keys())))
            return False

        # For now, we save to a hardcoded filename
        with a datestring.
        datestring = datetime.today().strftime("%Y-%m-%d")
        filename = "abq_data_record_{}.csv".format(datestring)
        model = m.CSVModel(filename)
        data = self.recordform.get()
        model.save_record(data)
        self.records_saved += 1
        self.status.set(
            "{} records saved this session".
            format(self.records_saved)
        )
        self.recordform.reset()
```

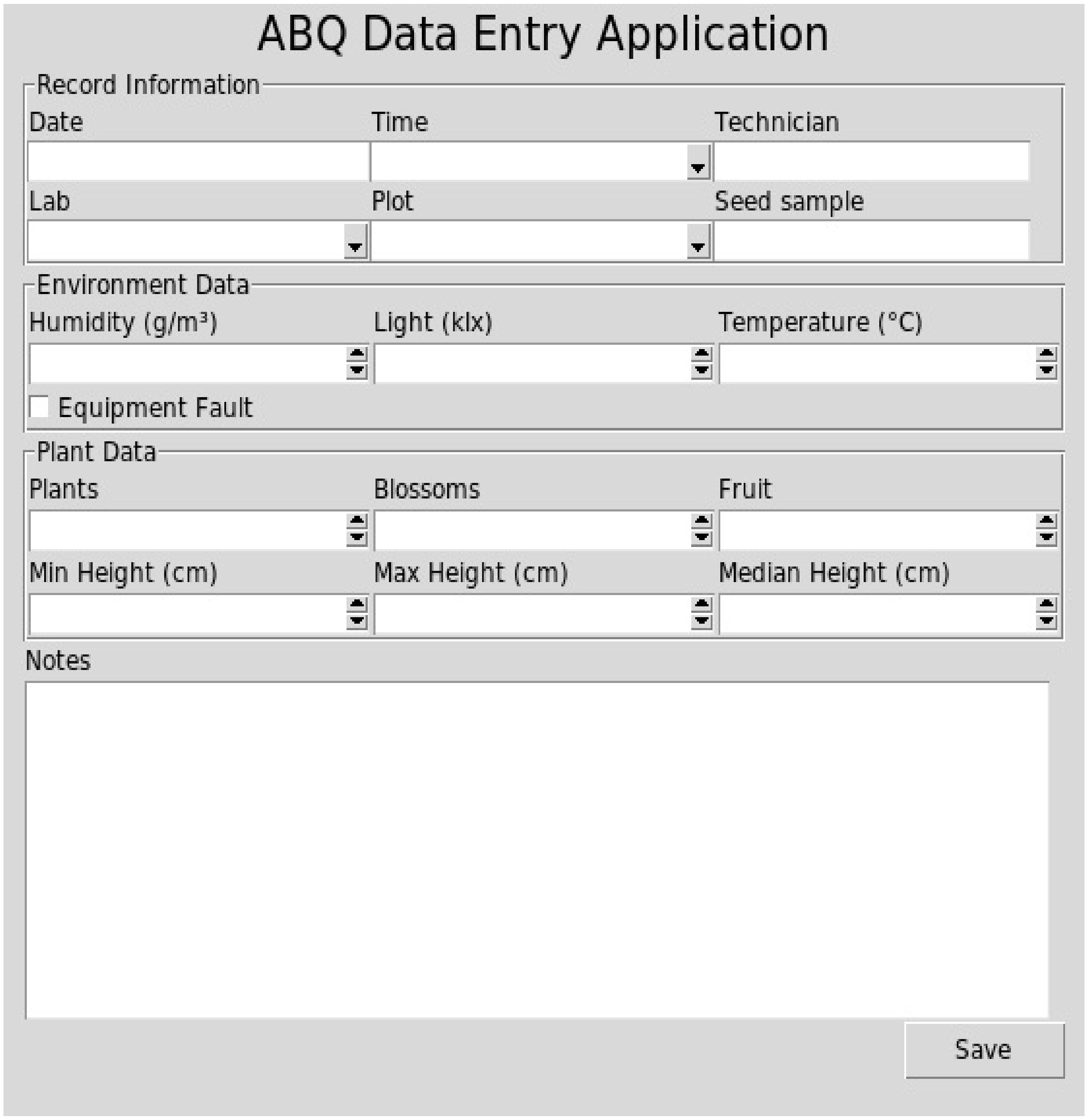
As you can see, using our model is pretty seamless; we just created a `CSVModel` class by passing in the filename, and then passed the form's data to `save_record()`.

Running the application

The application is now completely migrated to the new data format. To test it, navigate to the application root folder, `ABQ_Data_Entry`, and execute the following command:

```
python3 abq_data_entry.py
```

It should look and act just like the single script from Chapter 4, *Reducing User Error with Validation and Automation,* and run without errors, as shown in the following screenshot:


ABQ Data Entry Application
Record Information
Date
Time
Technician
Lab
Plot
Seed sample
Environment Data
Humidity (g/m³)
Light (klx)
Temperature (°C)
Equipment Fault
Plant Data
Plants
Blossoms
Fruit
Min Height (cm)
Max Height (cm)
Median Height (cm)
Notes
Save

Success!

Using version control software

Our code is nicely structured for expansion, but there's one more critical item we should address: **version control**. You may already be familiar with a **version control system** (**VCS**), sometimes called **revision control** or **source code management**, but if not, it's an indispensable tool for dealing with a large and changing codebase.

When working on an application, we sometimes think we know what needs to be changed, but it turns out we're wrong. Sometimes we don't know exactly how to code something, and it takes several attempts to find the correct approach. Sometimes we need to revert to code that was changed a long time back. Sometimes we have multiple people working on the same piece of code, and we need to merge their changes together. Version control systems were created to address these issues and more.

There are dozens of different version control systems, but most of them work essentially the same:

- You have a working copy of the code that you make changes to
- You periodically select changes to commit back to the master copy
- You can checkout older versions of the code at any point, then revert back to the master copy
- You can create branches of the code to experiment with different approaches, new features, or large refactors
- You can later merge these branches back into the master copy

VCS provides a safety net that gives you the freedom to change your code without the fear that you'll hopelessly ruin it: reverting to a known working state is just a few quick commands away. It also helps us to document changes to our code, and collaborate with others if the opportunity arises.

There are dozens of VC systems available, but by far the most popular for many years now is **Git**.

A super-quick guide to using Git

Git was created by Linus Torvalds to be the version control software for the Linux kernel project, and has since grown to be the most popular VC software in the world. It is utilized by source sharing sites like GitHub, Bitbucket, SourceForge, and GitLab. Git is extremely powerful, and mastering it can take months or years; fortunately, the basics can be grasped in a few minutes.

First, you'll need to install Git; visit `https://git-scm.com/downloads` for instructions on how to install Git on macOS, Windows, Linux, or other Unix operating systems.

Initializing and configuring a Git repository

Once Git is installed, we need to initialize and configure our project directory as a Git repository by following these steps:

1. Run the following command in the application's root directory (`ABQ_Data_Entry`):

   ```
   git init
   ```

   This command creates a hidden directory under our project root called `.git` and initializes it with the basic files that make up the repository. The `.git` directory will contain all the data and metadata about our saved revisions.

2. Before we add any files to the repository, we need to instruct Git to ignore certain kinds of files. For example, Python creates bytecode (`.pyc`) files whenever it executes a file, and we don't want to save these as part of our code. To do this, create a file in your project root called `.gitignore` and put the following lines in it:

   ```
   *.pyc
   __pycache__/
   ```

Adding and committing code

Now that our repository is initialized, we can add files and directories to our Git repository using the following commands:

```
git add abq_data_entry
git add abq_data_entry.py
git add docs
git add README.rst
```

At this point, our files are staged, but not yet committed to the repository. You can check the status of your repository and the files in it at any time by entering `git status`.

You should get the following output:

```
On branch master

No commits yet

Changes to be committed:
  (use "git rm --cached <file>..." to unstage)

    new file:   README.rst
    new file:   abq_data_entry.py
    new file:   abq_data_entry/__init__.py
    new file:   abq_data_entry/application.py
    new file:   abq_data_entry/models.py
    new file:   abq_data_entry/views.py
    new file:   abq_data_entry/widgets.py
    new file:   docs/Application_layout.png
    new file:   docs/abq_data_entry_spec.rst
    new file:   docs/lab-tech-paper-form.png

Untracked files:
  (use "git add <file>..." to include in what will be committed)

    .gitignore
```

This shows you that all the files under `abq_data_entry` and `docs`, as well as the files you specified directly, are staged to be committed to the repository.

Let's go ahead and commit the changes as follows:

```
git commit -m "Initial commit"
```

The `-m` flag here passes in a commit message, which is stored with the commit. Each time you commit code to the repository, you will be required to write a message. You should always make these messages as meaningful as possible, detailing what changes you made and the rationale behind them.

Viewing and using our commits

To view your repository's history, run the `git log` command as follows:

```
alanm@alanm-laptop:~/ABQ_Data_Entry$ git log
commit df48707422875ff545dc30f4395f82ad2d25f103 (HEAD -> master)
Author: Alan Moore <alan@example.com>
Date:   Thu Dec 21 18:12:17 2017 -0600

    Initial commit
```

As you can see, the `Author`, `Date`, and `commit` message is displayed for our last commit. If we had more commits, they would be listed here as well, from newest to oldest. The long hexadecimal value you see in the first line of output is the **commit hash**, a unique value that identifies the commit. This value can be used to refer to the commit in other operations.

For example, we can use it to reset our repository to a past state, as follows:

1. Delete the `README.rst` file, and verify that it's completely gone.
2. Now, enter the command `git reset --hard df48707`, replacing `df48707` with the first seven characters of your commit's hash.
3. Check your file listing again: the `README.rst` file is back.

What happened here is that we altered our repository, then told Git to hard reset the state of the repository to our first commit. If you don't want to reset your repository, you can also checkout an old commit temporarily, or create a branch using a particular commit as the base. As you can see already, this gives us a powerful safety net for experimentation; no matter how much you tinker with the code, any commit is just a command away!

Git has many more features that are beyond the scope of this book. If you'd like to learn more, the Git project provides a free online manual at `https://git-scm.com/book` where you can learn about advanced features like branching and setting up remote repositories. For now, the important thing is to commit changes as you go, so that you maintain your safety net and document the history of changes.

Summary

In this chapter, you learned to prepare your simple script for some serious expansion. You learned how to divide your application's areas of responsibility into separate components, and how to split your code into separate modules. You learned how to document your code using reStructuredText and track all your changes with version control.

In the next chapter, we're going to put our new project layout to the test by implementing some new features. You'll learn how to work with Tkinter's application menu widgets, how to implement file opening and saving, and how to use message popups to alert users or confirm actions.

Creating Menus with Menu and Tkinter Dialogs

> As an application grows, organizing access to its features becomes increasingly important. Traditionally, applications have addressed this with a **menu system**, which is typically located at the top of the application window or (on some platforms) in a global desktop menu. While these menus are application-specific, certain organizational conventions have been developed that we should follow in order to make our software user-friendly.

In this chapter, we're going to cover the following topics:

- Analyzing some reported problems and deciding on a solution
- Exploring some of Tkinter's dialog classes, and using them for implementing common menu functionality
- Learning how to work with Tkinter's Menu widget and using it to create a menu for our application
- Creating some options for our application and saving them to disk

Solving problems in our application

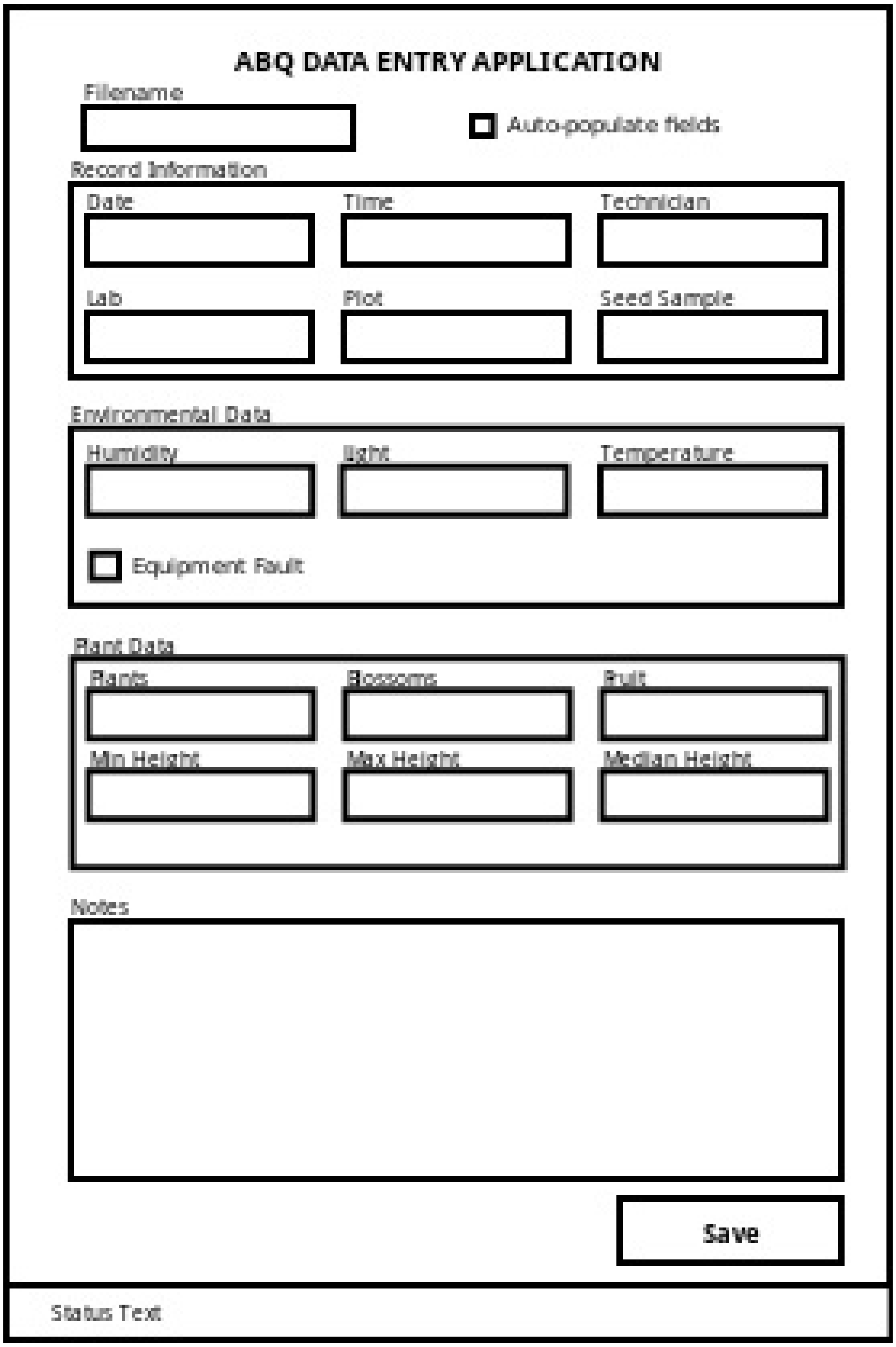
Your boss has brought you the first set of problems that need to be addressed in your application. First, in situations where the last reports of the day aren't able to be entered until the following day, the hardcoded date string in the filename is a problem. The data entry staff need a way to manually choose which file they'll be appending to.

Also, the data entry staff have mixed feelings about the auto-populate features in the form. Some find it very helpful, but others would really like to see it disabled. You'll need a way to allow users to turn this feature on and off.

Finally, some users have a hard time noticing the status bar text at the bottom, and would like the application to be more conspicuous when it fails to save data due to errors.

Deciding how to address these problems

It's clear you need to implement a way to select a file and toggle the auto-populate features of the form. First, you consider just adding controls to the main application for both of these, and make this quick mock-up:



It doesn't take long for you to realize that this is not a great design, and certainly not one that will accommodate growth. Your users don't want to have to type a file path and filename blindly into the box, nor do they want a lot of extra fields cluttering up the UI.

Fortunately, Tkinter offers some tools that will help us to solve these problems:

- **File dialogs**: Tkinter's `filedialog` library will help make file selection simple
- **Error dialogs**: Tkinter's `messagebox` library will let us display error messages more noticeably
- **Main menu**: Tkinter's `Menu` class can help us organize common functionality for easy access

Implementing simple Tkinter dialogs

The status bar is fine for incidental information that shouldn't interrupt a user's workflow, but for errors that prevent work from continuing as expected, users should be alerted in a more assertive way. An **error dialog** that halts the program until it's acknowledged with a mouse click is fairly assertive and seems like a good way to address the issue of users not seeing errors. In order to implement these, you'll need to learn about Tkinter's `messagebox` library.

Tkinter messagebox

The best way to display simple dialog boxes in Tkinter is by using the `tkinter.messagebox` library, which contains several convenient functions that allow you to quickly create common dialog types. Each function displays a preset icon and a selection of buttons with a message and detail text that you specify, and returns a value depending on which button the user clicked.

The following table shows some of the `messagebox` functions with their icons and return values:

Function	**Icon**	**Button / return value**
`askokcancel`	Question	Ok (`True`), Cancel (`False`)
`askretrycancel`	Warning	Retry (`True`), Cancel (`False`)
`askyesno`	Question	Yes (`True`), No (`False`)
`askyesnocancel`	Question	Yes (`True`), No (`False`), Cancel (`None`)
`showerror`	Error	Ok (`ok`)
`showinfo`	Information	Ok (`ok`)
`showwarning`	Warning	Ok (`ok`)

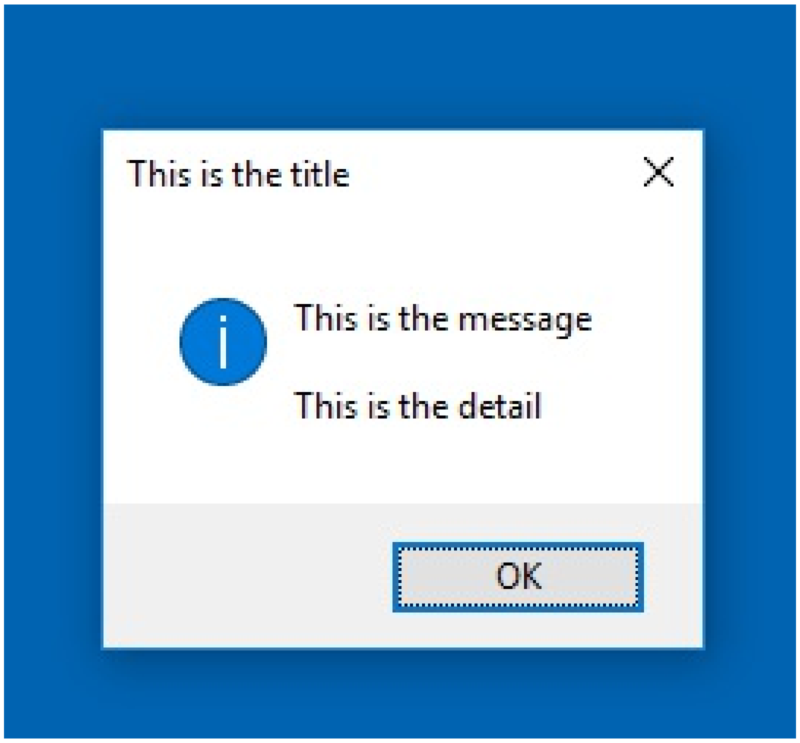
We can pass the following three text arguments into any `messagebox` function:

- `title`: This argument sets the title of the window, which is displayed in the title bar and/or task bar in your desktop environment.
- `message`: This argument sets the main message of the dialog. It's usually in a heading font and should be kept fairly short.
- `detail`: This argument sets the body text of the dialog, which is usually displayed in the standard window font.

Here is a basic call to `showinfo()`:

```
messagebox.showinfo(
    title='This is the title',
    message="This is the message",
    detail='This is the detail')
```

In Windows 10, it results in a dialog box (on other platforms, it may look a bit different), as shown in the following screenshot:


This is the title

This is the message

This is the detail

Tkinter `messagebox` dialog boxes are **modal**, which means that the program execution pauses and the rest of the UI is unresponsive while the dialog box is open. There is no way to change this, so only use them in situations where it's acceptable for the program to pause execution while the box is open.

Let's create a small example to show the use of the `messagebox` functions:

```
import tkinter as tk
from tkinter import messagebox
```

To use `messagebox`, we need to import it from Tkinter; you can't simply use `tk.messagebox` because it's a submodule and must be explicitly imported.

Let's create a yes-no message box as follows:

```
see_more = messagebox.askyesno(title='See more?',
    message='Would you like to see another box?',
    detail='Click NO to quit')
if not see_more:
    exit()
```

This creates a dialog with Yes and No buttons; if Yes is clicked, the function returns `True`. If No is clicked, the function returns `False` and the application exits.

In case our user wants to see more boxes, let's display an information box:

```
messagebox.showinfo(title='You got it',
    message="Ok, here's another dialog.",
    detail='Hope you like it!')
```

Note the difference between the way `message` and `detail` are displayed on your platform. On some platforms, there is no difference; on others, `message` is large and bold, which is appropriate for short texts. For cross-platform software, it's best to use `detail` for extended output.

Showing the error dialogs

Now that you understand how to use `messagebox`, error dialogs should be easy to implement. The `Application.on_save()` method already displays errors in the status bar; we just need to make this error display in an error message box as well by performing the following steps:

1. First, we'll need to import it in `application.py` as follows:

```
      from tkinter import messagebox
```

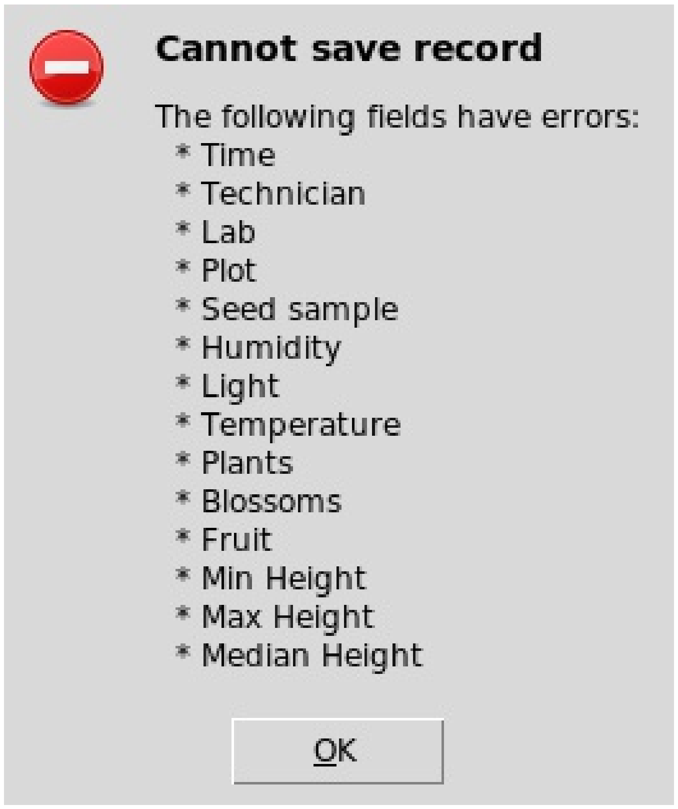
2. Now, in the `on_save()` method after the check for errors, we'll set up the message for the error dialog. We'll make a bullet list of the fields with errors by joining them with `"\n *"`. Unfortunately, `messagebox` doesn't support any sort of markup, so constructs like bullet lists need to be built manually using regular characters, as in the following:

```
        message = "Cannot save record"
        detail = "The following fields have errors: \n  * {}".format(
            '\n  * '.join(errors.keys()))
```

3. Now, we can call `showerror()`, just after the call to `status()` as follows:

```
        messagebox.showerror(title='Error', message=message, detail=detail)
```

4. Now, open the program and hit Save; you'll see a dialog box alerting you to the errors in the application, as shown in the following screenshot:



Cannot save record

The following fields have errors:
  * Time
  * Technician
  * Lab
  * Plot
  * Seed sample
  * Humidity
  * Light
  * Temperature
  * Plants
  * Blossoms
  * Fruit
  * Min Height
  * Max Height
  * Median Height

This error should be hard for anyone to miss!

One shortcoming of the `messagebox` dialogs is that they don't scroll; a long error message will create a dialog that may fill (or extend beyond) the screen. If this is a potential problem, you'll want to create a custom dialog containing a scrollable widget. We'll make a custom dialog in `Chapter 11`, Improving Data Storage with SQL.

Designing our menu

Most applications organize functionality into a hierarchical **menu system**, typically displayed at the top of the application or screen (depending on the OS). While the organization of this menu varies between operating systems, certain items are fairly common across platforms.

Of these common items, our application will need the following:

- A file menu containing file operations such as open/save/export, and often an option to quit the application. Our users will need this menu to select a file and quit the program.
- An options, preferences, or settings menu where users can configure the application. We'll need this menu for our toggle settings; we'll call it options for now.
- A help menu, which contains links to help documentation, or, at the very least, an about message giving the basic information about the application. We'll implement this menu for the about dialog.

Apple, Microsoft, and the Gnome Project publish guidelines for macOS, Windows, and Gnome desktops (used on Linux and BSD), respectively; each set of guidelines addresses the layout of menu items specific to that platform. We'll explore this in more detail in `Chapter 9`*, Maintaining Cross-Platform Compatibility.*

Before we can implement our menu, we'll need to understand how menus work in Tkinter.

Creating menus in Tkinter

The `tkinter.Menu` widget is used to implement menus in Tkinter applications; it's a fairly simple widget that acts as a container for any number of menu items.

The menu items can be one of the following five types:

- `command`: These items are labeled buttons that, when clicked, run a callback.
- `checkbutton`: These items are just like `Checkbutton` in our forms, and can be used to toggle `BooleanVar`.
- `radiobutton`: These items are similar to `Checkbutton`, but can be used to switch any kind of Tkinter variable between several mutually exclusive options.
- `separator`: These items are used to segment the menu into sections.
- `cascade`: These items allow you to add a submenu to the menu. The submenu is just another `tkinter.Menu` object.

Let's write the following small program to demonstrate the use of Tkinter menus:

```
import tkinter as tk

root = tk.Tk()
main_text = tk.StringVar(value='Hi')
label = tk.Label(root, textvariable=main_text)
label.pack()

root.mainloop()
```

This application sets up a label whose text is controlled by a string variable, `main_text`. If you run this application, you'll see a simple window that says Hi. Let's start adding the menu components.

Right above `root.mainloop()`, add the following code:

```
main_menu = tk.Menu(root)
root.config(menu=main_menu)
```

This creates a main menu and then sets it as the main menu of our application.

Currently, that menu is empty, so let's add an item by adding the following code:

```
main_menu.add('command', label='Quit', command=root.quit)
```

We've added a command to quit the application. The `add` method allows us to specify an item type and any number of attributes to create a new menu item. In the case of a command, we need to at least have a `label` argument specifying the text that will show in the menu and a `command` argument pointing to a Python callback.

Some platforms, such as macOS, don't allow a command in the top-level menu. We'll cover the differences between menus on different platforms in more detail in `Chapter 9`, Maintaining Cross-Platform Compatibility.

Let's try creating a submenu as follows:

```
text_menu = tk.Menu(main_menu, tearoff=False)
```

Creating a submenu is just like creating a menu, except that we specify the `parent` menu as the widget's `parent`. Notice the `tearoff` argument; by default, submenus in Tkinter are tearable, which means they can be pulled off and moved around as independent windows. You don't have to disable this option, but it is a rather archaic UI feature that is rarely used on modern platforms. Users will likely just find it confusing, so it's best to disable it whenever you create submenus.

Add some commands to the menu as follows:

```
text_menu.add_command(label='Set to "Hi"',
                  command=lambda: main_text.set('Hi'))
text_menu.add_command(label='Set to "There"',
                  command=lambda: main_text.set('There'))
```

We're using the `lambda` functions here for convenience, but you can pass any Python callable. The `add_command` method used here is simply a shortcut for `add('command')`. There are analogous methods for adding other items as well (cascade, separator, and so on).

Let's use the `add_cascade` method to add our menu back to its `parent` widget as follows:

```
main_menu.add_cascade(label="Text", menu=text_menu)
```

When adding a submenu to its `parent` menu, we simply have to provide the label for the menu and the menu itself.

We can add the `Checkbutton` and `Radiobutton` widgets to the menu as well. To demonstrate this, let's create another submenu to alter the label's appearance.

First, we need the following setup code:

```
font_bold = tk.BooleanVar()
font_size = tk.IntVar()

def set_font(*args):
    font_spec = 'TkDefaultFont {size} {bold}'.format(
        size=font_size.get(),
        bold='bold' if font_bold.get() else '')
    label.config(font=font_spec)

font_bold.trace('w', set_font)
font_size.trace('w', set_font)
```

Here, we're just creating variables to store the state of the bold option and font size, then a callback method that actually sets the label's font from these variables when called. Then, we set up a trace on both variables to call the callback whenever their values are changed.

Now, we just need to create the menu options to change the variables by adding the following code:

```
# appearance menu
appearance_menu = tk.Menu(main_menu, tearoff=False)
main_menu.add_cascade(label="Appearance", menu=appearance_menu)

# bold text button
appearance_menu.add_checkbutton(label="Bold", variable=font_bold)
```

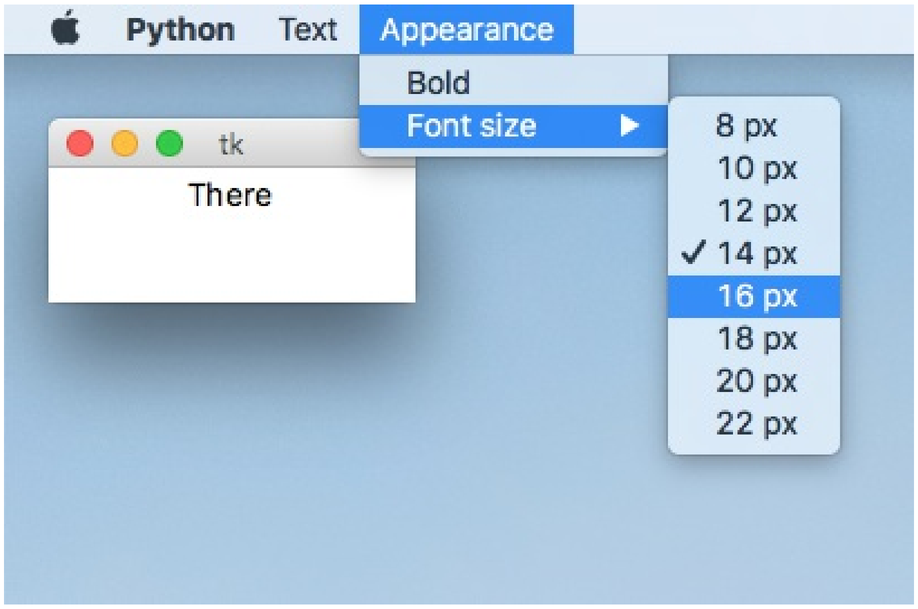
Like a regular `Checkbutton` widget, the `add_checkbutton` method takes `BooleanVar`, which is passed to the `variable` argument that will be bound to its checked status. Unlike a regular `Checkbutton` widget, use the `label` argument, rather than the `text` argument, to assign the label text.

To demonstrate the radio buttons, let's add a submenu to our submenu, like so:

```
size_menu = tk.Menu(appearance_menu, tearoff=False)
appearance_menu.add_cascade(label='Font size', menu=size_menu)
for size in range(8, 24, 2):
    size_menu.add_radiobutton(label="{} px".format(size),
        value=size, variable=font_size)
```

Just as we added a submenu to our main menu, we can add submenus to submenus. In theory, you could nest submenus indefinitely, but most UI guidelines discourage more than two levels. To create the items for our size menu, we're just iterating a generated list of even numbers between 8 and 24; for each one, we add a `radiobutton` item with a value equal to that size. Just like with regular `Radiobutton` widgets, the variable given in the `variable` argument will be updated with the value given in the `value` argument when the button is selected.

Launch the application and try it out, as shown in the following screenshot:



Now that you understand the `Menu` widget, let's add one to our application.

Implementing our application menu

As a major component of the GUI, our menu is clearly a view, and should be implemented in the `views.py` file. However, it's also going to need to set options that affect other views (such as the form options we're implementing now) and run functions that affect the application (like quitting). We need to implement it in such a way that we keep controller functions in the `Application` class but still keep the UI code in `views.py`. Let's take a look at the following steps:

1. Let's start out by opening `views.py` and creating a `MainMenu` class that subclasses `tkinter.Menu`:

```
class MainMenu(tk.Menu):
"""The Application's main menu"""
```

   Our overridden `__init__()` method will take two dictionaries, a `settings` dictionary and a `callbacks` dictionary, as follows:

```
    def __init__(self, parent, settings, callbacks, **kwargs):
        super().__init__(parent, **kwargs)
```

   We'll use these dictionaries to communicate with the controller: `settings` will contain Tkinter variables that can be bound to our menu controls, and `callbacks` will be controller methods that we can bind to menu commands. Naturally, we'll need to make sure to populate these dictionaries with the expected variables and callables in our `Application` object.

2. Now, let's start creating our submenus, starting with the file menu as follows:

```
file_menu = tk.Menu(self, tearoff=False)
file_menu.add_command(
    label="Select file…",
    command=callbacks['file->open'])
```

   Our first command in the file menu is `Select file...`. Notice the ellipses in the label: this indicates to the user that the option will open another window that will require further input. We're setting `command` to a reference from our `callbacks` dictionary using the `file->open` key. This function doesn't exist yet; we'll implement it shortly. Let's add our next file menu command, `file->quit`:

```
        file_menu.add_separator()
        file_menu.add_command(label="Quit",
                command=callbacks['file->quit'])
```

Once again, we've pointed this command to an as yet undefined function in our `callbacks` dictionary. We've also added a separator; since quitting the program is a fundamentally different sort of operation from selecting a target file, it makes sense to separate them, and you'll see this in most application menus.

3. This completes the file menu, so we need to add it to the main `menu` object as follows:

```
        self.add_cascade(label='File', menu=file_menu)
```

4. The next submenu we need to create is our `options` menu. Since we only have two menu options, we'll just add them directly to the submenu as `Checkbutton`. The option menu looks as follows:

```
        options_menu = tk.Menu(self, tearoff=False)
        options_menu.add_checkbutton(label='Autofill Date',
            variable=settings['autofill date'])
        options_menu.add_checkbutton(label='Autofill Sheet data',
            variable=settings['autofill sheet data'])
        self.add_cascade(label='Options', menu=options_menu)
```

The variables bound to these `Checkbutton` widgets are in the `settings` dictionary, so our `Application` class will populate `settings` with two `BooleanVar` variables: `autofill date` and `autofill sheet data`.

5. Last of all, we'll create a `help` menu, featuring an option to show an `About` dialog:

```
        help_menu = tk.Menu(self, tearoff=False)
        help_menu.add_command(label='About…', command=self.show_about)
        self.add_cascade(label='Help', menu=help_menu)
```

Our `About` command points to an internal `MainMenu` method called `show_about`, which we'll implement next. The `About` dialog is going to be pure UI code with no actual application functionality in it, so we can implement it entirely within the view.

Showing an About dialog

We've already seen how to use `messagebox` to create error dialogs. Now, we can apply that knowledge to create our `About` box by performing the following steps:

1. Start a new method definition after `__init__()`:

```
    def show_about(self):
        """Show the about dialog"""
```

2. The `About` dialog can show any information you feel is relevant, including your contact information, support information, version information, or even the entire `README` file. In our case, we'll keep it fairly short. Let's specify the `message` header text and `detail` body text:

```
        about_message = 'ABQ Data Entry'
        about_detail = ('by Alan D Moore\n'
            'For assistance please contact the author.')
```

   We're just using the application name for the header, and a short message about our name and who to contact for support for the detail. Feel free to put whatever text you wish in your `About` box.

There are several ways you can deal with long, multiline strings in Python code; the approach used here is to place multiple strings between parenthesis with only whitespace between them. Python automatically concatenates strings separated by only whitespace, so to Python this looks like a single long string inside a set of parentheses. In contrast to other methods, such as triple-quoting, this allows you to maintain clean indents and control new lines explicitly.

3. Finally, we need to display our `About` box as follows:

```
    messagebox.showinfo(title='About', message=about_message,
        detail=about_detail)
```

   In the preceding code, the `showinfo()` function is clearly the most appropriate, since we are in fact showing information. This finishes our `show_about()` method and our `MainMenu` class. Next, we need to make the necessary modifications to `Application` to make it work.

Adding the menu functionality in the controller

Now that our menu class is defined, our `Application` object needs to create an instance and add it into the main window. Before we can do that, we'll need to define some things that our `MainMenu` class needs.

Remember the following things from the previous section:

- We need a `settings` dictionary that contains Tkinter variables for our two settings options
- We need a `callbacks` dictionary that points to callbacks for `file->select` and `file->quit`
- We need the actual functions that implement file selection and quitting

Let's define some things that our `MainMenu` class needs.

Open `application.py` and let's start adding code just before the creation of `self.recordform`:

```
        self.settings = {
            'autofill date': tk.BooleanVar(),
            'autofill sheet data': tk.BooleanVar()
        }
```

This will be our global settings dictionary that stores the boolean variables for our two configuration options. Next, we'll create the `callbacks` dictionary:

```
        self.callbacks = {
            'file->select': self.on_file_select,
            'file->quit': self.quit
        }
```

Here, we're pointing our two callbacks to the methods of the `Application` class that will implement the functionality. Fortunately for us, Tkinter already implements `self.quit`, which does exactly what you'd expect it to do, so we only need to implement `on_file_select` ourselves. We will finish up here by creating our `menu` object and add it to the application as follows:

```
        menu = v.MainMenu(self, self.settings, self.callbacks)
        self.config(menu=menu)
```

Handling file selection

When a user needs to enter a file or directory path, the preferred way to do this is to display a dialog containing a miniature file browser, commonly called a file dialog. Like most toolkits, Tkinter provides us with dialogs for opening files, saving files, and selecting a directory. These are all part of the `filedialog` module.

Just like `messagebox`, `filedialog` is a Tkinter submodule that needs to be explicitly imported to be used. Also like `messagebox`, it contains a set of convenience functions that create file dialogs that are appropriate for different scenarios.

The following table lists the functions, what they return, and their UI features:

Function	Return value	Features
`askdirectory`	Directory path as string	Only shows directories, no files
`askopenfile`	File handle object	Only allows selection of existing files
`askopenfilename`	File path as string	Only allows selection of existing files
`askopenfilenames`	File paths as list of strings	Like `askopenfilename`, but allows multiple selections
`askopenfiles`	List of file handle objects	Like `askopenfile`, but allows multiple selections
`asksaveasfile`	File handle object	Allows creation of new files, prompts for confirmation on existing files

`asksaveasfilename`	File path as string	Allows creation of new files, prompts for confirmation on existing files

As you can see, each file selection dialog comes in two versions: one that returns a path as a string, and one that returns an open file object.

Each function can take the following common arguments:

- `title`: This argument specifies the dialog window title.
- `parent`: This argument specifies the (optional) `parent` widget. The file dialog will appear over this widget.
- `initialdir`: This argument is the directory in which the file browser should start.
- `filetypes`: This argument is a list of tuples, each with a label and matching pattern, which will be used to create files of the filter drop-down type typically seen under the filename entry. This is used to filter the visible files to only those supported by the application.

The `asksaveasfile` and `asksaveasfilename` methods take the following two additional options:

- `initialfile`: This option is a default file path to select
- `defaultextension`: This option is a file extension string that will be automatically appended to the filename if the user doesn't do it

Finally, the methods that return a file object take a `mode` argument that specifies the file-open mode; these are the same one- or two-character strings used by Python's `open` built-in function.

Which dialog do we need to use in our application? Let's consider our needs:

- We need a dialog that allows us to select an existing file
- We also need to be able to create a new file
- Since opening the file is the responsibility of the model, we just want to get a filename to pass to the model

These requirements clearly point to the `asksaveasfilename` function. Let's take a look at the following steps:

1. Start a new method on the `Application` object:

```
        def on_file_select(self):
        """Handle the file->select action from the menu"""

        filename = filedialog.asksaveasfilename(
            title='Select the target file for saving records',
            defaultextension='.csv',
            filetypes=[('Comma-Separated Values', '*.csv *.CSV')])
```

   The method first asks the user to select a file with a `.csv` extension; using the `filetypes` argument, the selection of existing files will be limited to those ending in `.csv` or CSV. When the dialog exits, the function will return the path to the selected file as a string to `filename`. Somehow, we have to get this path to our model.

2. Currently, the filename is generated in the `Application` object's `on_save` method and passed into the model. We need to move `filename` to a property of the `Application` object so that we can override it from our `on_file_select()` method.
3. Back in the `__init__()` method, add the following code line before the `settings` and `callbacks` definitions:

```
                self.filename = tk.StringVar()
```

4. The `self.filename` property will keep track of the currently selected save file. Previously, we set up our hardcoded filename inside the `on_save()` method; there's no good reason to keep doing this every time `on_save()` is called, particularly since we're only using it if the user hasn't selected a file otherwise. Instead, move those lines from `on_save()` to just above the `self.filename` definition:

```
                datestring = datetime.today().strftime("%Y-%m-%d")
                default_filename = "abq_data_record_{}.csv".
                format(datestring)
                self.filename = tk.StringVar(value=default_filename)
```

5. With the default filename defined, we can supply it as a default value for `StringVar`. The value will be updated by `on_file_select()` whenever the

user selects a filename. This is accomplished by the following lines at the end of `on_file_select()`:

```
        if filename:
            self.filename.set(filename)
```

6. The reason for the `if` statement is that we only want to set a value if a file was actually selected by the user. Remember that the file dialogs will return `None` if the user cancels the operation; in this case, a user would expect that the currently set filename will remain the target.
7. Lastly, we need to make our `on_save()` method use this value when it's set instead of the hardcoded default.
8. Down in the `on_save()` method, locate the line where `filename` is defined and change it to the following line:

```
        filename = self.filename.get()
```

9. That completes the code changes to make filename selection work. At this point, you should be able to run the application and test out the file selection functionality. Save a few records and note that they indeed save to the file you selected.

Making our settings work

While the file saving works, the settings do not. The `settings` menu items should work as expected, remaining checked or unchecked, but they don't yet change the behavior of the data entry form. Let's make this work.

Recall that both autofill features are implemented in the `DataRecordForm` class's `reset()` method. To use our new settings, we need to give our form access to the `settings` dictionary by performing the following steps:

1. Open `views.py` and update the `DataRecordForm.__init__()` method as follows:

```
    def __init__(self, parent, fields, settings, *args, **kwargs):
        super().__init__(parent, *args, **kwargs)
        self.settings = settings
```

2. We've added an additional positional argument, `settings`, and then set that to `self.settings` so that all of the methods in the class can access it. Now, look at the `reset()` method; currently, the date autofill code is as follows:

```
        current_date = datetime.today().strftime('%Y-%m-%d')
        self.inputs['Date'].set(current_date)
        self.inputs['Time'].input.focus()
```

3. We just need to make sure this happens only when `settings['autofill date']` is `True`:

```
        if self.settings['autofill date'].get():
            current_date = datetime.today().strftime('%Y-%m-%d')
            self.inputs['Date'].set(current_date)
            self.inputs['Time'].input.focus()
```

   Autofilling the sheet data is already under a conditional statement, as you can see here:

```
        if plot not in ('', plot_values[-1]):
            self.inputs['Lab'].set(lab)
            self.inputs['Time'].set(time)
           ...
```

4. To make the setting effective, we just need to add another condition to the `if` statement:

```
        if (self.settings['autofill sheet data'].get() and
            plot not in ('', plot_values[-1])):
            ...
```

   The last piece of the puzzle is to make sure we're sending our `settings` dictionary to `DataRecordForm` when it's created.

5. Back in the `Application` code, update our call to `DataRecordForm()` to include `self.settings` as follows:

```
        self.recordform = v.DataRecordForm(self,
            m.CSVModel.fields, self.settings)
```

6. Now, if you run the program, you should find that the settings are respected; try checking and unchecking them and see what happens after you save a record.

Persisting settings

Our settings work, but there's a major annoyance: they don't persist between sessions. Shut down the application and start it up again, and you'll see that the settings are back to their defaults. It's not a major problem, but it's a rough edge we shouldn't leave for our users.

Python gives us a variety of ways to persist data in files. We've already experienced CSV, which is designed for tabular data; there are other formats designed with different capabilities in mind.

The following table shows just a few of the options for storing data available in the Python standard library:

Library	Data type	Suitable	Benefits	Drawbacks
`pickle`	Binary	Any kind of object	Fast, easy, small files	Not safe, files aren't human-readable, whole file has to be read
`configparser`	Text	`key->value` pairs	Fast, easy, human-readable files	Can't handle sequences or complex objects, limited heirarchy
`json`	Text	Simple values and sequences	Widely used, easy, human-readable files	Can't serialize complex objects without modification
`xml`	Text	Any kind of Python object	Powerful, flexible, mostly human-	Not safe, complex to use, verbose file syntax

			readable files	
`sqlite`	Binary	Relational data	Fast and powerful files	Requires SQL knowledge, objects must be translated to tables

If this weren't enough, there are even more options available in the third-party libraries. Almost any of them would be suitable for storing a couple of boolean values, so how do we choose?

- SQL and XML are powerful, but far too complex for our simple needs here.
- We'd like to stick to a text format in case we need to debug a corrupt settings file, so `pickle` is out.
- `configparser` would work now, but its inability to handle lists, tuples, and dictionaries may be limiting in the future.
- That leaves `json`, which is a good option. While it can't handle every kind of Python object, it can handle strings, numbers, and booleans, as well as lists and dictionaries. That should cover our configuration needs just fine.

What does it mean when we say that a library is "not safe"? Some data formats are designed with powerful capabilities, such as extensibility, linking, or aliasing, which parser libraries must implement. Unfortunately, those capabilities can be exploited for malicious purposes. For example, the billion laughs XML vulnerability combines three XML capabilities to craft a file that, when parsed, expands to a massive size (usually causing the program or, in some cases, the system, to crash).

Building a model for settings persistence

As with any kind of data persistence, we need to start by implementing a model. As with our `CSVModel` class, the settings model needs to save and load the data, as well as define the layout of the settings data.

In the `models.py` file, let's start a new class as follows:

```
class SettingsModel:
    """A model for saving settings"""
```

Just as we did with our `CSVModel` class, we'll need to define our model's schema:

```
    variables = {
        'autofill date': {'type': 'bool', 'value': True},
        'autofill sheet data': {'type': 'bool', 'value': True}
     }
```

The `variables` dictionary will store both the schema and the values for each item. Each setting has a dictionary listing the data type and default value (we could list other attributes here if they are needed, such as minimum, maximum, or possible values). The `variables` dictionary will be the data structure we save to disk and load from disk to persist the program's settings.

The model needs a location to save the configuration file too, so our constructor will take the filename and path as arguments. For now, we'll just provide and use reasonable defaults, but in the future we may want to change these.

We can't just provide a single file path, though; we have different users on the same computer who will want to save different settings. We need to make sure that the settings are saved in the individual user's home directory rather than a single common location.

Therefore, our `__init__()` method is as follows:

```
    def __init__(self, filename='abq_settings.json', path='~'):
        # determine the file path
        self.filepath = os.path.join(
            os.path.expanduser(path), filename)
```

As users of the Linux or macOS Terminal will know, the `~` symbol is a Unix shortcut that points to the user's home directory. Python's `os.path.expanduser()` function translates this character into an absolute path (even on Windows), so that the file will be saved in the home directory of the user running the program. `os.path.join()` appends the filename to the expanded path, giving us a full path to a user-specific configuration file.

As soon as the model is created, we'll want to load the user's saved options from disk. Loading data from disk is a pretty basic model operation that we should be able to control outside the class, so we'll make this a public method.

We'll call this method `load()`, and call it here:

```
        self.load()
```

`load()` will expect to find a JSON file containing a dictionary in the same format as the `variables` dictionary. It will need to load that data from the file and replace its own copy of `variables` from the file copy.

A simplistic implementation is as follows:

```
    def load(self):
        """Load the settings from the file"""

        with open(self.filepath, 'r') as fh:
            self.variables = json.loads(fh.read())
```

The `json.loads()` function reads in a JSON string and converts it to a Python object, which we're saving directly to our `variables` dictionary. Of course, there are some problems with this method. First of all, what happens if the settings file doesn't exist? In that case, `open` will throw an exception and the program will crash. Not good!

So, before we try to open the file, let's test to see if it exists as follows:

```
        # if the file doesn't exist, return
        if not os.path.exists(self.filepath):
            return
```

If the file doesn't exist, the method simply returns and does nothing. It's perfectly reasonable for the file not to exist, especially if the user has never run the program or edited any of the settings. In this case, the method would leave `self.variables` alone and the user would end up with the defaults.

The second problem is that our settings file might exist, but contain no data or invalid data (such as keys not present in the `variables` dictionary), resulting in a crash. To prevent this, we'll pull in the JSON data to a local variable; we'll then update `variables` by asking `raw_values` for only those keys that exist in `variables`, providing a default value if they aren't present.

The new, safer code is as follows:

```
        # open the file and read in the raw values
        with open(self.filepath, 'r') as fh:
            raw_values = json.loads(fh.read())

        # don't implicitly trust the raw values,
        # but only get known keys
        for key in self.variables:
            if key in raw_values and 'value' in raw_values[key]:
                raw_value = raw_values[key]['value']
                self.variables[key]['value'] = raw_value
```

Since `variables` is created with default values already in place, we just need to ignore `raw_values` if it doesn't have a given key or if the dictionary in that key doesn't contain a `values` item.

Now that `load()` is written, let's write a `save()` method to write our values to the file:

```
    def save(self, settings=None):
        json_string = json.dumps(self.variables)
        with open(self.filepath, 'w') as fh:
            fh.write(json_string)
```

The `json.dumps()` function is the inverse of `loads()`: it takes a Python object and returns a JSON string. Saving our `settings` data is as simple as converting the `variables` dictionary to a string and writing it to the specified text file.

The final method our model needs is a way for external code to set values; they could manipulate `variables` directly, but in the interest of protecting our data integrity, we'll do it through a method call. Keeping with Tkinter convention, we'll call this method `set()`.

A basic implementation of the `set()` method is as follows:

```
    def set(self, key, value):
        self.variables[key]['value'] = value
```

This simple method just takes a key and value and writes them to the `variables` dictionary. Once again, though, this opens up some potential problems; what if the value provided isn't valid for the data type? What if the key isn't in our `variables` dictionary? This could create a situation that would be hard to debug, so our `set()` method should safeguard against this.

Change the code as follows:

```
            if (
                key in self.variables and
                type(value).__name__ == self.variables[key]['type']
            ):
                self.variables[key]['value'] = value
```

By using the `type` strings that correspond to the names of actual Python types, we can match it against the value's type name using `type(value).__name__` (we could have used the actual type objects themselves in our `variables` dictionary, but those can't be serialized to JSON). Now, an attempt to write an unknown key or incorrect variable type will fail.

However, we shouldn't let it fail silently; we should immediately raise `ValueError` to alert us to the problem as follows:

```
            else:
                raise ValueError("Bad key or wrong variable type")
```

Why raise an exception? If the test fails, it can only mean a bug in the calling code. With an exception, we'll know immediately if calling code is sending bad requests to our model. Without it, requests would fail silently, leaving a hard-to-find bug.

The idea of raising an exception on purpose often seems strange to beginners; after all, exceptions are something we're trying to avoid, right? This is true in the case of small scripts where we're mainly users of existing modules; when writing your own module, however, exceptions are the correct way for your module to communicate problems to the code using it. Trying to handle—or worse, silence—bad behavior by external calling code will, at best, break modularity; at worst, it will create subtle bugs that are difficult to track down.

Using the settings model in our application

Our application needs to load in the settings when it starts, then save them automatically whenever they are changed. Currently, the application's `settings` dictionary is created manually, but our model should really be telling it what kind of variables to create. Let's perform the following steps for using the `settings` model in our application:

1. Replace the code that defines `Application.settings` with the following code:

   ```
                   self.settings_model = m.SettingsModel()
                   self.load_settings()
   ```

   First, we create a `settings` model and save it to our `Application` object. Then, we're going to run a `load_settings()` method. This method will be responsible for setting up the `Application.settings` dictionary based on `settings_model`.

2. Now, let's create `Application.load_settings()`:

   ```
       def load_settings(self):
           """Load settings into our self.settings dict."""
   ```

3. Our model stores the type and value for each variable, but our application needs Tkinter variables. We need a way to translate the model's representation of the data into a structure that `Application` can use. A dictionary provides a handy way to do this as follows:

   ```
               vartypes = {
                   'bool': tk.BooleanVar,
                   'str': tk.StringVar,
                   'int': tk.IntVar,
                  'float': tk.DoubleVar
               }
   ```

   Notice that each name matches the type name of a Python built-in function. We could add more entries here, but this should cover most of our future needs. Now, we can combine this dictionary with the model's `variables` dictionary to construct the `settings` dictionary:

```
        self.settings = {}
        for key, data in self.settings_model.variables.items():
            vartype = vartypes.get(data['type'], tk.StringVar)
            self.settings[key] = vartype(value=data['value'])
```

4. The main reason for using Tkinter variables here is so that we can trace any changes the user makes to the values via the UI and respond immediately. Specifically, we want to save our settings whenever the user makes a change as follows:

```
        for var in self.settings.values():
            var.trace('w', self.save_settings)
```

5. Of course, this means we need to write a method called `Application.save_settings()`, which will run whenever the values are changed. `Application.load_settings()` is complete, so let's do that next:

```
    def save_settings(self, *args):
        """Save the current settings to a preferences file"""
```

6. The `save_settings()` method just needs to get the data back from `Application.settings` to the model and then save it:

```
        for key, variable in self.settings.items():
            self.settings_model.set(key, variable.get())
        self.settings_model.save()
```

   It's as simple as looping through `self.settings` and calling our model's `set()` method to pull in the values one at a time. Then, we call the model's `save()` method.

7. Now, you should be able to run the program and observe that the settings are saved, even when you close and re-open the application. You'll also find a file in your home directory called `abq_settings.json` (this isn't the ideal place to keep a `settings` file, but we'll address that in `Chapter 9`, *Maintaining Cross-Platform Compatibility*).

Summary

In this chapter, our simple form has taken a big step forward towards being a fully-blown application. We've implemented a main menu, option settings that are persisted between executions, and an `About` dialog. We've added the ability to select a file where records are saved, and improved the visibility of form errors with an error dialog. Along the way, you learned about Tkinter menus, file dialogs, and message boxes, as well as the various options for persisting data in the standard library.

In the next chapter, we're going to be asked to make the program read and write. We'll learn about Tkinter's tree widget, how to switch between main views, and how to make our `CSVModel` and `DataRecordForm` classes capable of reading and updating existing data.

Navigating Records with Treeview

You've received another request for features in the application. Now that your users can open arbitrary files, they'd like to be able to see what's in those files and correct old records using the data entry form they've grown accustomed to, rather than having to switch over to a spreadsheet. In a nutshell, it's finally time to implement read and update capabilities in our application.

In this chapter, we're going to cover the following topics:

- Modifying our CSV model for read and update capabilities
- Discovering the ttk `Treeview` widget, and building a list of records with it
- Implementing record loading and updating in our data record form
- Redesigning the menu and application with read and update in mind

Implementing read and update in the model

Our entire design up to this point has been centered around a form that only appends data to a file; adding read and update capabilities is a fundamental change that will touch nearly every portion of the application. It may seem like a daunting task, but by taking it one component at a time, we'll see that the changes are not so overwhelming.

The first thing we should do is update our documentation, starting with the `Requirements` section:

```
The program must:

* Provide a UI for reading, updating, and appending data to the CSV file
* ...
```

And, of course, also update the part that is not required that follows:

```
The program does not need to:

* Allow deletion of data.
```

Now, it's a simple matter of making the code match with the documentation.

Adding read and update to our model

Open `models.py` and consider what's missing from the `CSVModel` class:

- We'll need a method that can retrieve all records in a file so we can display them. We'll call it `get_all_records()`.
- We'll need a method to fetch individual records from the file by row number. We can call this `get_record()`.
- We'll need to save records in a way that can not only append new records, but update existing records as well. We can update our `save_record()` method to accommodate this.

Implementing get_all_records()

Start a new method called `get_all_records()`:

```
    def get_all_records(self):
        if not os.path.exists(self.filename):
            return []
```

The first thing we've done is check if the model's file exists yet. Remember that when our application starts, it generates a default filename pointing to a file that likely doesn't exist yet, so `get_all_records()` will need to handle this situation gracefully. It makes sense to return an empty list in this case, since there's no data if the file doesn't exist.

If the file does exist, let's open it in read-only mode and get all the records:

```
        with open(self.filename, 'r') as fh:
            csvreader = csv.DictReader(fh)
            records = list(csvreader)
```

While not terribly efficient, pulling the entire file into memory and converting it into a list is acceptable in our case, since we know that our largest files should be limited to a mere 401 rows: 20 plots times 5 labs plus a header row. This code is just a little too trusting, however. We should at least do some sanity checks to make sure that the user has actually opened a CSV file containing the proper fields and not some other arbitrary file.

Let's check that the file has the correct field structure:

```
        csvreader = csv.DictReader(fh)
        missing_fields = (set(self.fields.keys()) -
                          set(csvreader.fieldnames))
        if len(missing_fields) > 0:
            raise Exception(
                "File is missing fields: {}"
                .format(', '.join(missing_fields))
            )
        else:
            records = list(csvreader)
```

Here, we first find any missing fields by converting a list of our `fields` dictionary `keys` and the CSV file's `fieldnames` to Python `set` objects. We can subtract the `fieldnames` set from `keys` and determine which fields, if any, are missing in the file. If there are any, we'll raise an exception; otherwise, we convert the CSV data to `list`.

Python `set` objects are very useful for comparing the content of the `list`, `tuple`, and other sequence objects. They provide an easy way to get information such as the difference (items in `x` that are not in `y`) or intersection (items in both `x` and `y`) between two sets, or allow you to compare sequences without respect to order.

Before we can return the `records` list, we need to correct one issue; all data in a CSV file is stored as text, and read by Python as a string. Most of this is not a problem, since Tkinter will take care of converting strings to `float` or `int` as necessary, but `bool` values are stored in the CSV file as the strings `True` and `False`, and coercing these values directly back to `bool` doesn't work. `False` is a non-empty string, and all non-empty strings evaluate to `True` in Python.

To fix this, let's first define a list of strings that should be interpreted as `True`:

```
        trues = ('true', 'yes', '1')
```

Any values not in this list will be considered `False`. We'll do a case-insensitive comparison, so there are only lowercase values in our list.

Next, we create a list of fields that are `boolean` fields using a list comprehension as follows:

```
        bool_fields = [
            key for key, meta
            in self.fields.items()
            if meta['type'] == FT.boolean]
```

We know that `Equipment Fault` is our only boolean field, so technically we could just hardcode that here, but it's a good idea to design your model so that any changes to the schema will be automatically handled appropriately by the logic portions.

Now, let's check these boolean fields in each row by adding the following code:

```
        for record in records:
            for key in bool_fields:
                record[key] = record[key].lower() in trues
```

For every record, we iterate through our list of the boolean fields and check its value against our list of truthy strings, setting the value of the item accordingly.

With the boolean values fixed, we can return our `records` list as follows:

```
        return records
```

Implementing get_record()

Our `get_record()` method needs to take a row number and return a single dictionary containing the data for that row.

This is pretty simple if we leverage our `get_all_records()` method as follows:

```
    def get_record(self, rownum):
        return self.get_all_records()[rownum]
```

Since our files are small and there's very little overhead to pulling all the records, we can simply do that and then dereference the record we need.

Keep in mind that it's possible to pass `rownum` that doesn't exist in our records list; in this case, we'd get `IndexError`; our calling code will need to catch this error and deal with it appropriately.

Adding update to save_record()

To convert our `save_record()` method so that we can update records, the first thing we'll need to do is provide the ability to pass in a row number to update. The default will be `None`, which will indicate that the data is a new row that should be appended.

The new method signature looks like this:

```
    def save_record(self, data, rownum=None):
        """Save a dict of data to the CSV file"""
```

Our existing logic doesn't need to change, but it should only be run if `rownum` is `None`.

So, the first thing to do in the method is check `rownum`:

```
        if rownum is not None:
            # This is an update, new code here
        else:
            # Old code goes here, indented one more level
```

For relatively small files, the simplest way to update a single row is to load the entire file into a list, change the row in the list, and then write the entire list back to a clean file.

Under the `if` block, we'll add the following code:

```
            records = self.get_all_records()
            records[rownum] = data
            with open(self.filename, 'w') as fh:
                csvwriter = csv.DictWriter(fh,
                    fieldnames=self.fields.keys())
                csvwriter.writeheader()
                csvwriter.writerows(records)
```

Once again, we leverage our `get_all_records()` method to fetch the CSV file's content into a list. We then replace the dictionary in the requested row with the `data` dictionary provided. Finally, we open the file in write mode (`w`), which will clear its content and replace it with whatever we write to the file, and write the header and all records back to the file.

The approach we're taking makes it unsafe for two users to work in the save CSV file simultaneously. Creating software that allows for multiple users editing a single file is notoriously difficult, and many programs simply opt to prevent it in the first place using lock files or other protection mechanisms.

This method is finished, and that's all we need to change in our model to enable updating and viewing. Now, it's time to add the necessary features to our GUI.

Implementing a record list view

The record list view will allow our users to browse the content of the file and open records for viewing or editing. Our users are accustomed to seeing this data in a spreadsheet, laid out in a table-like format, so it makes sense to design our view in a similar fashion. Since our view mainly exists for finding and selecting individual records, we don't need to display all the information; just enough for the users to distinguish one record from another.

A quick analysis shows that we need CSV row number, `Date`, `Time`, `Lab`, and `Plot`.

For building table-like views with selectable rows, Tkinter gives us the ttk `Treeview` widget. To build our record list view, we'll need to learn about `Treeview`.

The ttk Treeview

The `Treeview` is a ttk widget designed to show columns of data in a hierarchical structure.

Perhaps the best example of this kind of data is a filesystem tree:

- Each row can represent a file or directory
- Each directory can contain additional files or directories
- Each row can have additional data properties, such as permissions, size, or ownership information

To explore how `Treeview` works, we'll create a simple file browser with some help from `pathlib`.

In previous chapters, we used `os.path` to work with file paths. `pathlib` is a new addition to the Python 3 standard library that provides a more object-oriented approach to paths.

Open a new file called `treeview_demo.py` and start with this template:

```
import tkinter as tk
from tkinter import ttk
from pathlib import Path

root = tk.Tk()
# Code will go here

root.mainloop()
```

We'll start by getting a list of all the file paths under the current working directory. `Path` has a method called `glob` that will give us such a list as follows:

```
paths = Path('.').glob('**/*')
```

`glob()` expands wildcard characters like `*` and `?` against a filesystem tree. The name goes back to a very early Unix command, though the same wildcard syntax is now used across most modern operating systems.

`Path('.')` creates a path object referencing the current working directory, and `**/*` is a special wildcard syntax that recursively grabs all objects under the path. The result is a list of the `Path` objects that include every directory and file under our current directory.

With that done, we can create and configure our `Treeview` widget by executing the following code:

```
tv = ttk.Treeview(root, columns=['size', 'modified'],
                  selectmode='None')
```

Like any Tkinter widget, the first argument to `Treeview` is its `parent` widget. Each column in the `Treeview` widget is given an identifying string; by default, there is always one column named `"#0"`. This column represents the basic identifying information about each item in the tree, such as a name or ID number. To add more columns, we specify them using the `columns` argument. This list contains any number of strings that will be used to identify the subsequent columns.

Finally, we set `selectmode`, which determines how users can select items in the tree.

The following table shows the options for `selectmode`:

Value	Behavior
`selectmode`	Selections can be made
`none` (as a string, not the `None` object)	No selections can be made
`browse`	User can select one item only
`extended`	User can select multiple items

In this case, we're preventing selection, so we set it to `none`.

To show how we use the column names, we'll set some headings for the columns:

```
tv.heading('#0', text='Name')
tv.heading('size', text='Size', anchor='center')
tv.heading('modified', text='Modified', anchor='e')
```

The `Treeview` heading method is for manipulating the column `heading` widget; it takes the column name, and then any number of attributes you want to assign to the column's `heading` widget.

Those attributes can include:

- `text`: The text displayed for the heading. By default, it's blank.
- `anchor`: The alignment of the text; it can be any of eight cardinal directions or `center`, specified as strings or Tkinter constants.
- `command`: A command to run when the heading is clicked. This might be used to order the rows by that column, or select all the values in the column, for example.
- `image`: An image to display in the heading.

Finally, we pack the column into the `root` widget and expand it to fill the widget:

```
tv.pack(expand=True, fill='both')
```

In addition to configuring the headers, we can configure some attributes of the column itself using the `Treeview.column` method.

For example, we can add the following code:

```
tv.column('#0', stretch=True)
tv.column('size', width=200)
```

In this example, we've set `stretch` to `True` in the first column, which will cause it to expand to fill available; and we've set the `width` value on the `size` column to `200` pixels.

The column parameters that can be set include:

- `stretch`: Whether or not to expand this column to fill the available space.
- `width`: The width of the column in pixels.
- `minwidth`: The minimum width to which the column can be resized, in pixels.
- `anchor`: The alignment of the text in the column. Can be any of eight

cardinal directions or center, specified as strings or Tkinter constants.

With the tree view configured, it now needs to be filled with data. Populating a `Treeview` with data is done one row at a time using the `insert` method.

The `insert` method looks like this:

```
mytreeview.insert(parent, 'end', iid='item1',
          text='My Item 1', values=['12', '42'])
```

The first argument specifies the `parent` item for the inserted row. This is not the `parent` widget, but rather the `parent` row under which the inserted row belongs in the hierarchical structure. The value is a string that refers to the `iid` of the `parent` item. For top-level items, this value should be an empty string.

The next argument specifies where the item should be inserted. It's either a numerical index or `end`, which places the item at the end of the list.

After this, we specify keyword arguments, which can include:

- `text`: This is the value to be shown in the first column.
- `values`: This is a list of values for the remaining columns.
- `image`: This is an image object to display in the far left of the column.
- `iid`: The item ID string. This will be automatically assigned if you don't specify it.
- `open`: Whether or not the row is open (displaying child items) at the start.
- `tags`: A list of tag strings. We'll learn more about tags when we discuss styling in `Chapter 8`, *Improving the Look with Styles and Themes*.

To insert our paths into the `Treeview`, let's iterate our `paths` list as follows:

```
for path in paths:
    meta = path.stat()
    parent = str(path.parent)
    if parent == '.':
        parent = ''
```

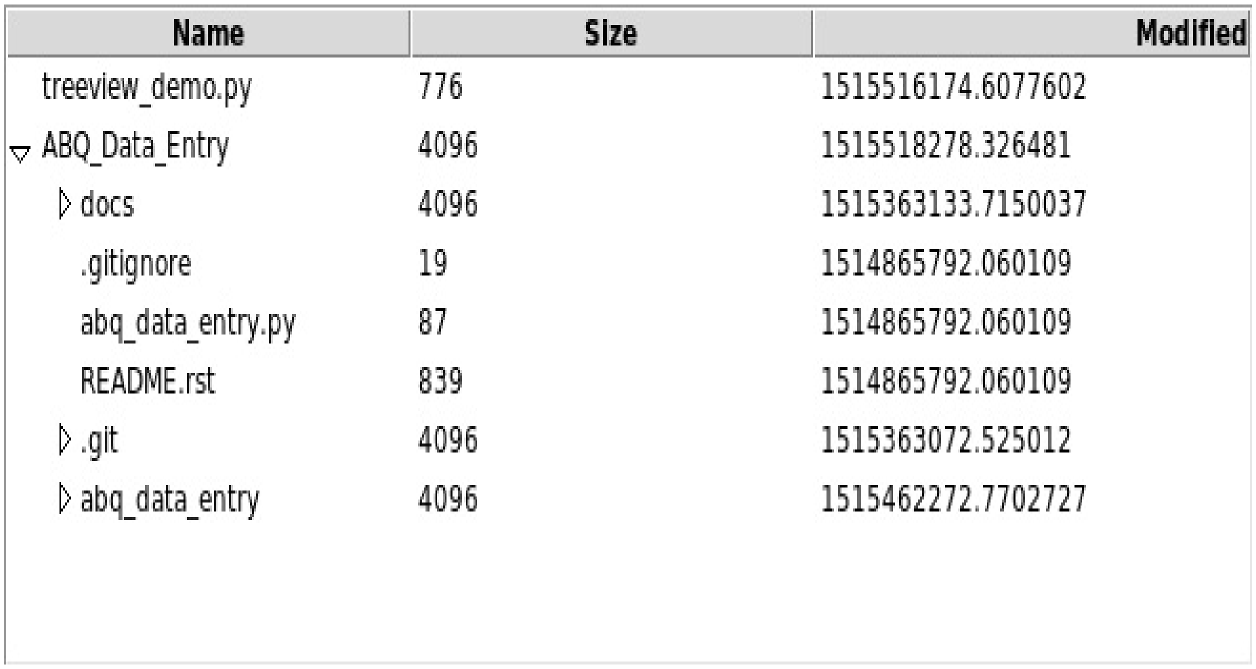
Before calling `insert`, we need to extract and prepare some data from the path object. `path.stat()` will give us an object containing various file information. `path.parent` provides us the containing path; however, we need to change the name of the `root` path (currently a single dot) to an empty string, which is how `Treeview` represents the `root` node.

Now, we add the `insert` call as follows:

```
    tv.insert(parent, 'end', iid=str(path),
        text=str(path.name), values=[meta.st_size, meta.st_mtime])
```

By using the path string as the item ID, we can then specify it as a parent for its child objects. We use only the object `name` (without the containing path) as our display value, then `st_size` and `st_mtime` for populating the size and modification time columns.

Run this script and you should see a simple file tree browser that looks something like this:



Name	Size	Modified
treeview_demo.py	776	1515516174.6077602
▽ ABQ_Data_Entry	4096	1515518278.326481
▷ docs	4096	1515363133.7150037
.gitignore	19	1514865792.060109
abq_data_entry.py	87	1514865792.060109
README.rst	839	1514865792.060109
▷ .git	4096	1515363072.525012
▷ abq_data_entry	4096	1515462272.7702727

The `Treeview` widgets doesn't offer any kind of sorting functionality by default, but we can add it fairly easily.

First, let's create a sorting function by adding the following code:

```
def sort(tv, col):
    itemlist = list(tv.get_children(''))
    itemlist.sort(key=lambda x: tv.set(x, col))
    for index, iid in enumerate(itemlist):
        tv.move(iid, tv.parent(iid), index)
```

In the preceding code snippet, the `sort` function takes a `Treeview` widget and the ID of a column in which we'll sort. It starts by getting a list of all the `iid` values using the `get_children()` method of `Treeview`. Next, it sorts the various `iid` values using the value of `col` for each item as a key; rather confusingly, the `set()` method of `Treeview` is used to retrieve the value of the column (there is no `get()` method). Finally, we iterate the list and use the `move()` method to move each item to a new index under its parent (which is retrieved using the `parent()` method).

To make our columns sortable, add this function as a callback to the headers using the `command` argument as follows:

```
tv.heading('#0', text='Name', command=lambda: sort(tv, '#0'))
tv.heading('size', text='Size', anchor='center',
           command=lambda: sort(tv, 'size'))
tv.heading('modified', text='Modified', anchor='e',
           command=lambda: sort(tv, 'modified'))
```

Implementing our record list with Treeview

Now that we understand how to use the `Treeview` widget, let's start building our record list widget.

We'll begin by subclassing `tkinter.Frame`, just as we did with our record form:

```
class RecordList(tk.Frame):
    """Display for CSV file contents"""
```

To save ourselves from some repetitious code, we'll define our column properties and defaults in class constants. This also makes it easier to tweak them to suit our needs.

Start out your class with the following properties:

```
    column_defs = {
        '#0': {'label': 'Row', 'anchor': tk.W},
        'Date': {'label': 'Date', 'width': 150, 'stretch': True},
        'Time': {'label': 'Time'},
        'Lab': {'label': 'Lab', 'width': 40},
        'Plot': {'label': 'Plot', 'width': 80}
        }
    default_width = 100
    default_minwidth = 10
    default_anchor = tk.CENTER
```

Recall that we're going to be displaying `Date`, `Time`, `Lab`, and `Plot`. For the first default column, we'll show the CSV row number. We've also set the `width` and `anchor` values for some columns, and configured the `Date` field to stretch. We'll use these values when configuring the `Treeview` widget in `__init__()`.

Let's start our `__init__()` definition as follows:

```
    def __init__(self, parent, callbacks, *args, **kwargs):
        super().__init__(parent, *args, **kwargs)
        self.callbacks = callbacks
```

As with other views, we're going to accept a dictionary of callback methods from the `Application` object, and save it as an instance property.

Configuring a Treeview widget

Now, let's create our `Treeview` widget by executing the following code snippet:

```
        self.treeview = ttk.Treeview(self,
            columns=list(self.column_defs.keys())[1:],
            selectmode='browse')
```

Note that we're excluding the `#0` column from our `columns` list; it should never be specified here since it's automatically created. We're also choosing the `browse` select mode, so that users can select individual rows of the CSV file.

Let's go ahead and add our `Treeview` widget to `RecordList` and make it fill the widget:

```
        self.columnconfigure(0, weight=1)
        self.rowconfigure(0, weight=1)
        self.treeview.grid(row=0, column=0, sticky='NSEW')
```

Now, configure the columns and headings of `Treeview` by iterating through the `column_defs` dictionary:

```
        for name, definition in self.column_defs.items():
```

For each set of items, let's extract the configuration values we need as follows:

```
            label = definition.get('label', '')
            anchor = definition.get('anchor', self.default_anchor)
            minwidth = definition.get(
                'minwidth', self.default_minwidth)
            width = definition.get('width', self.default_width)
            stretch = definition.get('stretch', False)
```

Finally, we'll use those values to configure the heading and columns:

```
            self.treeview.heading(name, text=label, anchor=anchor)
            self.treeview.column(name, anchor=anchor,
                minwidth=minwidth, width=width, stretch=stretch)
```

Adding a scrollbar

The ttk `Treeview` does not have a scrollbar by default; it *can* be scrolled, using the keyboard or mouse-wheel controls, but users would reasonably expect a scrollbar on a scrollable area to help them visualize the size of the list and their current position in it.

Fortunately, ttk provides us with a `Scrollbar` object that can be connected to our `Treeview` widget:

```
        self.scrollbar = ttk.Scrollbar(self,
            orient=tk.VERTICAL, command=self.treeview.yview)
```

Here, `Scrollbar` takes the following two important arguments:

- `orient`: This argument determines whether it is a horizontal or vertical scroll
- `command`: This argument provides a callback for scrollbar move events

In this case, we set the callback to the tree view's `yview` method, which is used to make the `Treeview` scroll up and down. The other option would be `xview`, which would be used for horizontal scrolling.

We also need to connect our `Treeview` back to the scrollbar:

```
        self.treeview.configure(yscrollcommand=self.scrollbar.set)
```

If we don't do this, our `Scrollbar` won't know how far down the list we've scrolled or how long the list is, and can't set the size or location of the bar widget appropriately.

With our `Scrollbar` configured, we need to place it on the widget—conventionally, just to the right of the widget being scrolled.

We can use our `grid` layout manager for this:

```
        self.scrollbar.grid(row=0, column=1, sticky='NSW')
```

Notice we set `sticky` to north, south, and west. North and south make sure the scrollbar stretches the entire height of the widget, and west makes sure it's snug against the `Treeview` widget to the left of it.

Populating the Treeview

Now that we have our `Treeview` widget, we'll create a `populate()` method to populate it with data:

```
    def populate(self, rows):
        """Clear the treeview & write the supplied data rows to it."""
```

The `rows` argument will take a list of the `dict` data types, such as what is returned from `model`. The idea is that the controller will fetch a list from the model and then pass it to this method.

Before refilling `Treeview`, we need to empty it:

```
        for row in self.treeview.get_children():
            self.treeview.delete(row)
```

The `get_children()` method of `Treeview` returns a list of every row's `iid`. We're iterating this list, passing each `iid` to the `Treeview.delete()` method, which, as you'd expect, deletes the row.

With the `Treeview` cleared, we can iterate through the `rows` list and populate the table:

```
        valuekeys = list(self.column_defs.keys())[1:]
        for rownum, rowdata in enumerate(rows):
            values = [rowdata[key] for key in valuekeys]
            self.treeview.insert('', 'end', iid=str(rownum),
                                 text=str(rownum), values=values)
```

The first thing we do here is create a list of all the keys we actually want to fetch from each row; this is just the list of keys from `self.column_defs` minus the `"#0"` column.

Next, we iterate through the rows using the `enumerate()` function to generate a row number. For each row, we'll create a list of values in the proper order using a list comprehension, then insert the list to the end of the `Treeview` widget with the `insert()` method. Notice that we're just using the row number (converted to a string) as both `iid` and `text` for the row.

The last thing we need to do in this function is a small usability tweak. To make our `Treeview` keyboard friendly, we need to focus the first item so that keyboard users can immediately start to navigate it via the arrow keys.

Doing this in a `Treeview` widget actually takes three method calls as follows:

```
        if len(rows) > 0:
            self.treeview.focus_set()
            self.treeview.selection_set(0)
            self.treeview.focus('0')
```

First, `focus_set` moves focus to `Treeview`. Next, `selection_set(0)` selects the first record in the list. Finally, `focus('0')` focuses the row with `iid` of `0`. And, of course, we only do this if there are any rows at all.

Responding to record selection

The purpose of this widget is for users to select and open records; therefore, we need a way to do that. It would be nice to be able to trigger this from an event like a double-click or keyboard selection.

The `Treeview` widget has three special events which we can use to trigger a callback as shown in the following table:

Event string	Triggered when
`<<TreeviewSelect>>`	A row is selected, such as by clicking it with a mouse
`<<TreeviewOpen>>`	A row is opened by a double-click or by selecting it and hitting *Enter*
`<<TreeviewClose>>`	An open row is closed

`<<TreeviewOpen>>` sounds like the event we want; even though we're not using a hierarchical list, the user is still conceptually opening the record, and the triggering action (double-click) seems intuitive. We'll bind this event to a method that will open the selected record.

Add this code at the end of `__init__()`:

```
        self.treeview.bind('<<TreeviewOpen>>', self.on_open_record)
```

The `on_open_record()` method is quite simple; add this code to the class:

```
    def on_open_record(self, *args):
        selected_id = self.treeview.selection()[0]
        self.callbacks['on_open_record'](selected_id)
```

It's as simple as retrieving the selected ID from `Treeview`, then calling a function provided by our controller in the `callbacks` dictionary with the selected ID. It will be up to the controller to do something appropriate here.

The `RecordList` class is now complete, but some of our other view classes need attention.

Modifying the record form for read and update

As long as we're editing views, we'll need to look at our `DataRecordForm` view and adjust it to make it capable of updating records.

Take a moment and consider the following changes we'll need to make:

- The form will need some way to load in a record provided by the controller.
- The form will need to keep track of what record it's editing, or if it's a new record.
- Our user will need some visual indication of what record is being edited.
- Our Save button is currently in the application. It doesn't really make sense in any context other than the form, so it should probably be part of the form.
- This means our form will need a callback to call when the save button is clicked. We'll need to provide it with a `callbacks` dictionary like we did with our other views.

Updating __init__()

Let's start working through these with our `__init__()` method:

```
    def __init__(self, parent, fields,
                 settings, callbacks, *args, **kwargs):
        self.callbacks = callbacks
```

We're adding a new argument, `callbacks`, and storing it as an instance property. This will give the controller a way to provide methods for the view to call.

Next, our `__init__()` method should set up a variable in which to store the current record:

```
        self.current_record = None
```

We'll use `None` to indicate that no record is loaded and the form is being used to create a new record. Otherwise, this value will be an integer referencing a row in the CSV data.

We could use a Tkinter variable here, but there's no real advantage in this case, and we wouldn't be able to use `None` as a value.

At the top of the form, before the first form fields, let's add a label that will keep track of which record we're editing:

```
        self.record_label = ttk.Label()
        self.record_label.grid(row=0, column=0)
```

We're placing this in row `0`, column `0`, but the first `LabelFrame` is also in that location. You'll need to go through each `LabelFrame` and increment the `row` value in its call to `grid`.

We'll make sure this label gets updated whenever a record is loaded into the form.

At the very end of the widget, after the `Notes` field, let's add our new Save button as follows:

```
        self.savebutton = ttk.Button(self,
            text="Save", command=self.callbacks["on_save"])
        self.savebutton.grid(sticky="e", row=5, padx=10)
```

The button will call an `on_save()` method from the `callbacks` dictionary when clicked. We'll need to make sure to provide this method when creating `DataRecordForm` in `Application`.

Adding a load_record() method

The last thing to add in our view is a method for loading in a new record. This method will need to set up our form with a given row number and data dictionary from the controller.

Let's call it `load_record()` as follows:

```
    def load_record(self, rownum, data=None):
```

The first thing we should do is set the form's `current_record` value from the `rownum` provided:

```
        self.current_record = rownum
```

Recall that `rownum` could be `None`, indicating that this is a new record.

Let's check for that by executing the following code:

```
        if rownum is None:
            self.reset()
            self.record_label.config(text='New Record')
```

If we're going to be inserting a new record, we simply want to reset the form, then set the label to indicate that this is a new record.

Note that our `if` condition here checks specifically whether `rownum` is `None`; we can't just check the truth value of `rownum`, since `0` is a valid `rownum` for updating!

If we do have a valid `rownum`, we'll need it to act differently:

```
        else:
            self.record_label.config(text='Record #{}'.format(rownum))
            for key, widget in self.inputs.items():
                self.inputs[key].set(data.get(key, ''))
                try:
                    widget.input.trigger_focusout_validation()
                except AttributeError:
                    pass
```

In this block, we first set the label appropriately with the row number we're editing.

Then, we cycle through the keys and widgets of our `inputs` dictionary and pull in the matching values from the `data` dictionary. We also attempt to call the `trigger_focusout_validation()` method on each widget's input, since it's possible that the CSV file contains invalid data. If the input has no such method (that is, if we used a regular Tkinter widget rather than one of our custom ones, such as with `Checkbutton`), we just do nothing.

Updating the rest of the application

Before our changes to the form can take effect, we need to update the remaining portions of our application for the new functionality. Our main menu needs some navigation items so that users can switch between the record list and the form, and controller methods need to be created or updated in `Application` to bring together our new model and view functionality.

Main menu changes

Since we're already in the `views.py` file, let's start by updating our main menu view with some commands to switch between the record list and record form. We'll add a `Go` menu containing two more options to our menu that will allow switching between the record list and a blank record form.

Add the following lines between the `Options` and `Help` menus:

```
        go_menu = tk.Menu(self, tearoff=False)
        go_menu.add_command(label="Record List",
                         command=callbacks['show_recordlist'])
        go_menu.add_command(label="New Record",
                         command=callbacks['new_record'])
        self.add_cascade(label='Go', menu=go_menu)
```

As before, we're binding these menu commands to functions in the `callbacks` dictionary, which we'll need to add in our `Application` class.

Connecting the pieces in Application

Let's quickly take stock of the following changes we're going to need to make in our `Application` class:

- We need to add an instance of our `RecordList` view
- We'll need to update our use of `CSVModel` so that we can access data from it
- We'll need to implement or refactor several callback methods used by our views

Adding the RecordList view

We'll create the `RecordList` object in `__init__()`, just after `DataRecordForm`, by executing the following code snippet:

```
        self.recordlist = v.RecordList(self, self.callbacks)
        self.recordlist.grid(row=1, padx=10, sticky='NSEW')
```

Notice that when we call `grid()`, we're adding the `RecordList` view to the grid cell that already contains `DataRecordForm`. **This is intentional**. When we do this, Tkinter just stacks the second widget on top of the first, like laying one piece of paper on top of another; we'll add code in a moment to control which view is visible by raising one or the other to the top of the stack. Notice that we also stick the widget to all sides of the cell. Without this code, bits of one widget might be visible behind the other.

Similarly, we need to update the `grid` call for the record form as follows:

```
        self.recordform.grid(row=1, padx=10, sticky='NSEW')
```

Moving the model

Currently, our data model object is only created in the `on_save()` method, and is recreated every time the user saves. Some of the other callbacks we're going to write will need access to the model as well, so instead we'll create a single data model instance that can be shared by all the methods when the `Application` class is started or whenever a new filename is chosen. Let's take a look at the following steps:

1. First, edit the `Application.__init__()` method right after the `default_filename` is created:

```
        self.filename = tk.StringVar(value=default_filename)
        self.data_model = m.CSVModel(filename=self.filename.get())
```

2. Next, the `on_file_select()` method needs to recreate the `data_model` object whenever the filename is changed.
3. Change the end of `on_file_select()` to the following code:

```
        if filename:
            self.filename.set(filename)
            self.data_model = m.CSVModel(filename=self.filename.get())
```

Now, `self.data_model` will always point to a current data model and all our methods can use it for saving or reading data.

Populating the record list

The `Treeview` widget is added to our application, but we need a way to fill it with data.

We'll create a method called `populate_recordlist()` by executing the following code:

```
    def populate_recordlist(self):
```

The logic is simple enough: just get all the rows from the model and send them to the record list's `populate()` method.

We could write it as simply as this:

```
        rows = self.data_model.get_all_records()
        self.recordlist.populate(rows)
```

Remember, though, that in the event of a problem with the file, `get_all_records()` will raise an `Exception`; we need to catch that exception and let the user know things are wrong.

Update the code with the `try` and `except` blocks as follows:

```
        try:
            rows = self.data_model.get_all_records()
        except Exception as e:
            messagebox.showerror(title='Error',
                message='Problem reading file',
                detail=str(e))
        else:
            self.recordlist.populate(rows)
```

In this case, if we get an exception from `get_all_records()`, we'll display an error dialog showing the `Exception` text.

The `RecordList` view should be repopulated any time a new model gets created; currently, that happens in `Application.__init__()` and `Application.on_file_select()`.

Update `__init__()` just after the record list is created:

```
        self.recordlist = v.RecordList(self, self.callbacks)
        self.recordlist.grid(row=1, padx=10, sticky='NSEW')
        self.populate_recordlist()
```

Update `on_file_select()` at the very end, inside the `if filename:` block as follows:

```
        if filename:
            self.filename.set(filename)
            self.data_model = m.CSVModel(filename=self.filename.get())
            self.populate_recordlist()
```

Adding the new callbacks

Looking over our view code, the following callback functions need to be added to our `callbacks` dictionary:

- `show_recordlist()`: This function is called when the user clicks the Record List option in the menu, it should cause the record list to be visible
- `new_record()`: This function is called when the user clicks New Record in the menu, it should show a reset `DataRecordForm`
- `on_open_record()`: This function is called when a record list item is opened, it should show `DataRecordForm` which is populated with the ID and data of the record
- `on_save()`: This function is called when the Save button (now part of `DataRecordForm`) is clicked, it should cause the data in the record form to be updated or inserted in the model

We'll start with `show_recordlist()`:

```
    def show_recordlist(self):
        """Show the recordform"""
        self.recordlist.tkraise()
```

Remember that when we laid out the main application, we stacked `recordlist` on top of the data entry form, so that one obscured the other. The `tkraise()` method can be called on any Tkinter widget to raise it to the top of a stack of widgets. Calling it here will raise our `RecordList` widget to the top and obscure the data entry form.

Don't forget to add the following content to the `callbacks` dictionary:

```
        self.callbacks = {
             'show_recordlist': self.show_recordlist,
             ...
```

Both the `new_record()` and `on_open_record()` callbacks cause `recordform` to be displayed; one is called without a row number, and the other is called with a row number. We can easily answer both of these in a single method.

Let's call that method `open_record()`:

```
    def open_record(self, rownum=None):
```

Remember that our `DataRecordForm.load_record()` method takes a row number and a `data` dictionary, and that if the row number is `None`, it resets the form for a new record. So, all we need to do is set the row number and record accordingly and pass them into the `load_record()` method.

First, we'll handle `rownum` being `None`:

```
        if rownum is None:
            record = None
```

Without a row number, there is no record. Easy enough.

Now, if there is a row number, we need to attempt to fetch that row from the model and use that for `record`:

```
        else:
            rownum = int(rownum)
            record = self.data_model.get_record(rownum)
```

Note that Tkinter may be passing in `rownum` as a string, since the `iid` values of `Treeview` are strings. We'll do a safety cast to `int`, since that's what our model expects.

Remember that in the event of a problem reading the file, the model throws an `Exception`, so we should catch this.

Place the call to `get_record()` inside a `try` block:

```
        try:
            record = self.data_model.get_record(rownum)
        except Exception as e:
            messagebox.showerror(title='Error',
                message='Problem reading file',
                detail=str(e))
            return
```

In the event of an `Exception`, we'll display an error dialog and return from the function without changing anything.

With `rownum` and `record` set correctly, we can now pass them to `DataRecordForm`:

```
        self.recordform.load_record(rownum, record)
```

Finally, we need to raise the `form` widget so that it's on top of the record list:

```
        self.recordform.tkraise()
```

Now, we can update our `callbacks` dictionary to point those keys to the new method:

```
        self.callbacks = {
            'new_record': self.open_record,
            'on_open_record': self.open_record,
            ...
```

You could argue that we shouldn't have the same method in here twice, and just have our views pull the same key; however, it makes sense to let the views refer to callbacks semantically—that is, in terms of what they intend to accomplish, rather than how it's accomplished—and then letting the controller determine which piece of code best meets that semantic need. If, at some point, we need to separate these into two methods, we'll only need to do that in `Application`.

We already have a method for `on_save()`, so that's simple enough to add to our callbacks:

```
        self.callbacks = {
            ...
            'on_save': self.on_save
        }
```

However, our current `on_save()` method only handles inserting new records. We'll need to fix that.

First, we can remove the two lines that fetch the filename and create the model, since we can just use the `Application` object's `data_model` property.

Now, replace the next couple of lines with this:

```
        data = self.recordform.get()
        rownum = self.recordform.current_record
        try:
            self.data_model.save_record(data, rownum)
```

We simply need to get the data and current record from `DataRecordForm`, then pass them to the model's `save_record()` method. Remember that if we send `rownum` of `None`, the model will insert a new record; otherwise it will update the record at that row number.

Because `save_record()` can throw a couple of different exceptions, it's under a `try` block here.

First, if we try to update a row number that doesn't exist, we'll get `IndexError`, so let's catch that:

```
        except IndexError as e:
            messagebox.showerror(title='Error',
                message='Invalid row specified', detail=str(e))
            self.status.set('Tried to update invalid row')
```

In the event of the problem, we're going to show an error dialog and update the status text.

The `save_record()` method can also throw a generic `Exception`, since it calls the model's `get_all_records()` method.

We'll catch this as well and show an appropriate error:

```
        except Exception as e:
            messagebox.showerror(title='Error',
                message='Problem saving record', detail=str(e))
            self.status.set('Problem saving record')
```

The remaining code in this method should only be run if no exceptions were thrown, so move it under an `else` block:

```
    else:
        self.records_saved += 1
        self.status.set(
            "{} records saved this session".format(self.records_saved)
        )
        self.recordform.reset()
```

Since inserting or updating records will usually cause a change in the record list, we should also repopulate the record list after a successful file save.

Add the following line under the `if` block:

```
            self.populate_recordlist()
```

Finally, we only want to reset the record form if we're inserting new files; if not, we should do nothing.

Put the call to `recordform.reset()` under an `if` block:

```
            if self.recordform.current_record is None:
                self.recordform.reset()
```

Cleaning up

Before coming out of `application.py`, make sure to remove the Save button code, since we've moved that piece of UI to the `DataRecordForm`.

Look for these lines in `__init__()` to remove them:

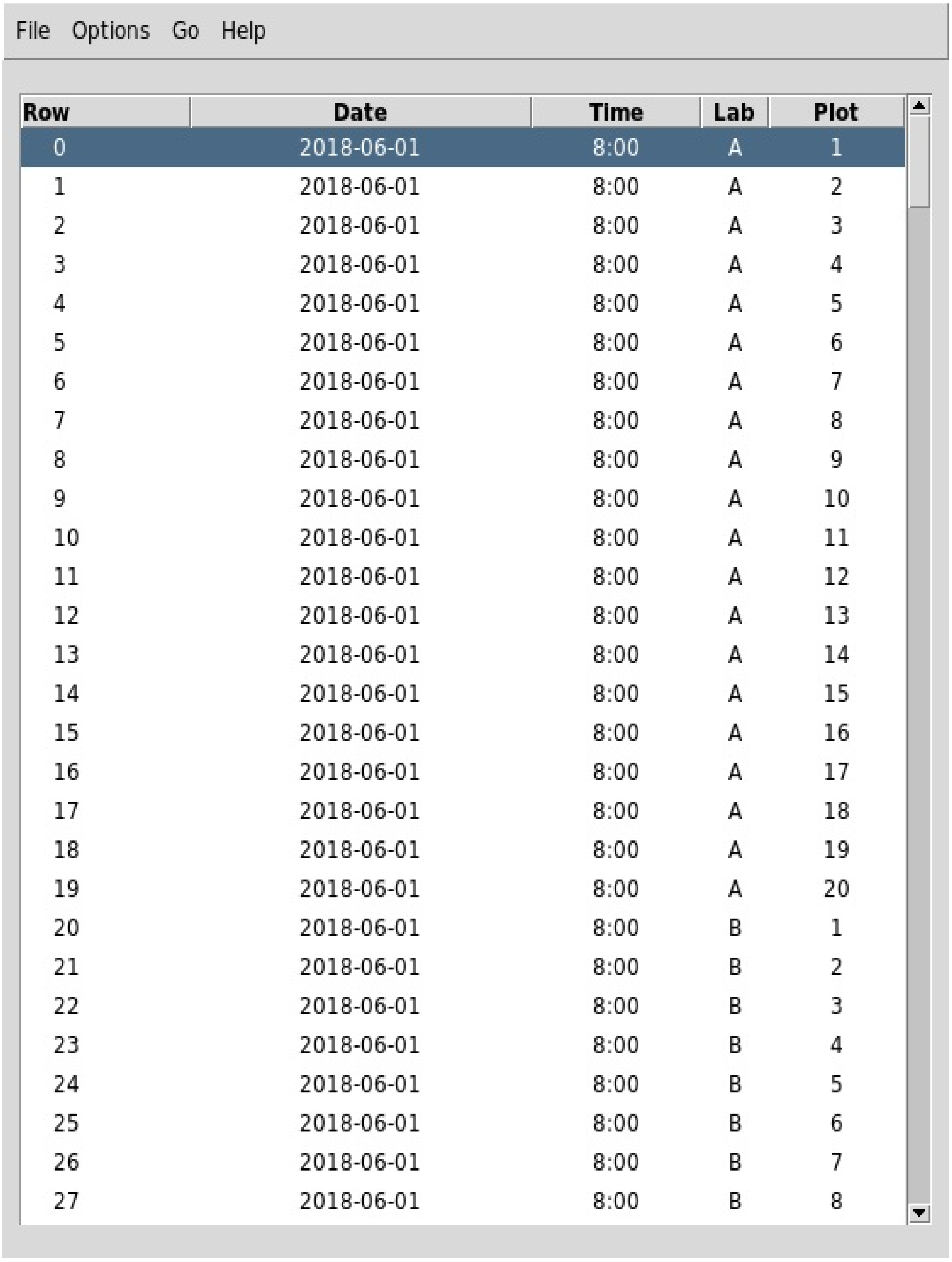
```
        self.savebutton = ttk.Button(self, text="Save",
                                     command=self.on_save)
        self.savebutton.grid(sticky="e", row=2, padx=10)
```

You can also move the `statusbar` position up one row:

```
        self.statusbar.grid(sticky="we", row=2, padx=10)
```

Testing our program

At this point, you should be able to run the application and load in a sample CSV file as shown in the following screenshot:



Row	Date	Time	Lab	Plot
0	2018-06-01	8:00	A	1
1	2018-06-01	8:00	A	2
2	2018-06-01	8:00	A	3
3	2018-06-01	8:00	A	4
4	2018-06-01	8:00	A	5
5	2018-06-01	8:00	A	6
6	2018-06-01	8:00	A	7
7	2018-06-01	8:00	A	8
8	2018-06-01	8:00	A	9
9	2018-06-01	8:00	A	10
10	2018-06-01	8:00	A	11
11	2018-06-01	8:00	A	12
12	2018-06-01	8:00	A	13
13	2018-06-01	8:00	A	14
14	2018-06-01	8:00	A	15
15	2018-06-01	8:00	A	16
16	2018-06-01	8:00	A	17
17	2018-06-01	8:00	A	18
18	2018-06-01	8:00	A	19
19	2018-06-01	8:00	A	20
20	2018-06-01	8:00	B	1
21	2018-06-01	8:00	B	2
22	2018-06-01	8:00	B	3
23	2018-06-01	8:00	B	4
24	2018-06-01	8:00	B	5
25	2018-06-01	8:00	B	6
26	2018-06-01	8:00	B	7
27	2018-06-01	8:00	B	8

Make sure to try opening a record, editing and saving it, as well as inserting new records and opening different files.

You should also test the following error conditions:

- Try opening a file that isn't a CSV file, or a CSV with incorrect fields. What happens?
- Open a valid CSV file, select a record for editing, then, before clicking Save, select a different or empty file. What happens?
- Open two copies of the program and point them to the saved CSV file. Try alternating edit or update actions between the programs. Note what happens.

Summary

We have changed our program from being an append-only form to an application capable of loading, viewing, and updating data from existing files. You learned how to make a read-write model, work with the ttk `Treeview`, and modify the existing views and controller to read and update records.

In our next chapter, we'll be learning how to modify the look and feel of our application. We'll learn about using widget attributes, styles, and themes, as well as working with bitmapped graphics.

Improving the Look with Styles and Themes

While programs can be perfectly functional with plain text in shades of black, white, and gray, the subtle use of colors, fonts, and images can enhance the visual appeal and usability of even the most utilitarian applications. Your data entry application is no exception. Your boss and your users have brought several issues to your attention, which seem to require the use of Tkinter's styling capabilities. Your boss has informed you that corporate HQ requires all in-house software to prominently display the company logo, while the data entry staff have mentioned a variety of issues with the readability and overall look of the application.

In this chapter, we're going to learn about some features of Tkinter that will help us to solve these issues:

- We'll learn how to add images to our Tkinter GUI
- We'll learn how to adjust the fonts and colors in our Tkinter widgets, both directly and with tags
- We'll learn how to adjust the look of Ttk widgets using styles and themes

Working with images in Tkinter

The first requirement we're going to handle is adding the company logo. As a result of corporate policy, your application is supposed to have the company logo embedded in it, and you've been asked to make your application comply if possible.

To add this image to our application, you'll need to learn about Tkinter's `PhotoImage` class.

Tkinter PhotoImage

Several Tkinter widgets, including `Label` and `Button`, can take an `image` argument, which allows them to display an image. We can't simply put a path to an image file in those cases; instead, we have to create a `PhotoImage` object.

Making a `PhotoImage` object is fairly simple:

```
myimage = tk.PhotoImage(file='my_image.png')
```

`PhotoImage` is typically called with the keyword argument `file`, which is pointed to a file path. Alternatively, you can use the `data` argument to point to a `bytes` object containing image data.

A `PhotoImage` can be used wherever an `image` argument is accepted, such as a `Label`:

```
mylabel = tk.Label(root, image=myimage)
```

It's critical to note that your application must retain a reference to the `PhotoImage` object that will stay in scope for as long as the image is shown; otherwise, the image will not appear.

Consider the following example:

```
import tkinter as tk
class App(tk.Tk):
    def __init__(self):
        super().__init__()
        smile = tk.PhotoImage(file='smile.gif')
        tk.Label(self, image=smile).pack()
App().mainloop()
```

If you run this example, you'll notice that no image gets displayed. That's because the `smile` variable is destroyed as soon as `__init__()` exits; with no reference to the `PhotoImage` object, the image vanishes, even though we've packed it into the layout. To fix this, you would need to store the `image` object in an instance variable such as `self.smile`, which will continue to exist after the method returns.

Image support in Tkinter is limited to GIF, PGM, PPM, and (as of version 8.6) PNG files. To use other file formats, such as JPEG or BMP, you'll need to use an image manipulation library such as Pillow to convert them into a format that Tkinter understands.

At the time of writing, Python 3 for macOS ships with Tkinter 8.5. To use PNG on macOS, you'll need to upgrade to Tkinter 8.6 or later, or use Pillow. Please see `https://www.python.org/download/mac/tcltk/` *for more information about Tcl/Tk and macOS. Pillow is not in the Python standard library. To install it, follow the instructions at* `http://python-pillow.org`.

Adding the company logo

With our knowledge of `PhotoImage`, adding the company logo to our program should be simple; however, we have to solve the problem of how to determine the image file's path. The path can be either absolute or relative to the working directory, but we don't know what those will be on another system. Fortunately, there's a way to figure it out.

Under the `abq_data_entry` directory, create a new directory called `images`, and within it place an appropriately-sized PNG file that we can use in our application (the image has an 8x5 aspect ratio, so in this case, we're using `32x20`). To get an absolute path to the image, we're going to rely on a built-in variable in Python called `__file__`. In any Python script, the `__file__` variable will contain the absolute path to the current script file, which we can use to locate our image files.

For example, from our `application.py` file, we could find our image using this code:

```
from os import path
image_path = path.join(path.dirname(__file__),
                       'images/abq_logo_32x20.png')
```

In this example, we first find the directory that contains the `application.py` file by calling `path.dirname(__file__)`. This gives us an absolute path to `abq_data_entry`, from which we know the relative path to the image. We can join these two paths and have an absolute path to the image, no matter where the program is installed on the filesystem.

This approach works fine, but consider that we may want to access images from a variety of modules in our application, and having to import `path` and repeat this logic in multiple files is less than optimal. A cleaner approach is to treat our `images` folder like a Python package and create constants in it that point to image paths.

Start by creating an `__init__.py` file inside the `images` folder and add the following code:

```
from os import path

IMAGE_DIRECTORY = path.dirname(__file__)

ABQ_LOGO_32 = path.join(IMAGE_DIRECTORY, 'abq_logo-32x20.png')
ABQ_LOGO_64 = path.join(IMAGE_DIRECTORY, 'abq_logo-64x40.png')
```

Now, our `application.py` module can simply do this:

```
from .images import ABQ_LOGO_32
```

`Application.__init__()` can then create a `PhotoImage` object using the path in `ABQ_LOGO_32`:

```
        self.logo = tk.PhotoImage(file=ABQ_LOGO_32)
        tk.Label(self, image=self.logo).grid(row=0)
```

After creating the `PhotoImage` object, we display it using a `Label`. If you run the application, you should see the logo show up at the top.

Setting our Window icon

We can also add the logo as our Window icon, which makes more sense than leaving the default Tkinter logo. This way, the logo will show up in both the window decorations and in the operating system's taskbar.

As a subclass of Tk, our `Application` object has a method called `iconbitmap` which should, given a path to an icon file, set the icon appropriately. Unfortunately, this method is fairly finicky about the type of file it's given and does not work well across platforms. We can work around this using `PhotoImage` and the special Tk `call()` method.

The `call` method allows us to directly call Tcl/Tk commands, and can be useful to access Tk capabilities that Tkinter wraps poorly or not at all.

The code looks like this:

```
        self.taskbar_icon = tk.PhotoImage(file=ABQ_LOGO_64)
        self.call('wm', 'iconphoto', self._w, self.taskbar_icon)
```

The first line creates another `PhotoImage` object, referencing a larger version of the logo. Next, we execute `self.call()`, passing in the individual tokens of the Tcl/Tk command. In this case, we're calling the `wm iconphoto` command. `self._w` returns the Tcl/Tk name for our `Application` object; and, last of all, we pass in the `PhotoImage` object we created.

Hopefully, you won't need to use `call` often, but if you do, you can find documentation about Tcl/Tk commands at: `https://www.tcl.tk/doc/` .

Run your application and notice how the icon has changed.

Styling Tkinter widgets

Tkinter has essentially two styling systems: the old Tkinter widgets system, and the newer Ttk system. Since we still need to work with both Tkinter and Ttk widgets, we'll have to look at both systems. Let's take a look first at the older Tkinter system and apply some styling to the Tkinter widgets in our application.

Widget color properties

Basic Tkinter widgets allow you to change two colors: **foreground**, meaning mainly the text and borders, and **background**, meaning the rest of the widget. These can be set using the `foreground` and `background` arguments, or their aliases `fg` and `bg`.

This example shows the use of colors on a `Label`:

```
l = tk.Label(text='Hot Dog!', fg='yellow', bg='red')
```

The values for the colors can be color name strings or CSS-style RGB hex strings.

For example, this code produces the same effect:

```
l2 = tk.Label(text='Also Hot Dog!',
              foreground='#FFFF00',
              background='#FF0000')
```

There are over 700 named colors recognized by Tkinter, roughly corresponding to those recognized by the X11 display server used on Linux and Unix, or the CSS named colors used by web designers. For a complete list, see `https://www.tcl.tk/man/tcl8.6/TkCmd/colors.htm`.

Using widget properties on our form

One request you received from the data entry staff is to increase the visual separation between the sections on the data entry form. Our `LabelFrame` widgets are simple Tkinter widgets (not Ttk), so we can accomplish this fairly simply by giving the sections colored backgrounds.

After some thought and discussion, you decide to color-code the sections as follows:

- Record information will use `khaki`, suggesting the classic manila folders used for paper records
- Environment information will use `lightblue`, symbolic of water and air
- Plant information will have a `lightgreen` background, symbolic of plants
- `Notes` are distinctive enough, so it will remain the same

Open up `views.py` and edit the `LabelFrame` calls in `DataRecordForm.__init__()`:

```
        recordinfo = tk.LabelFrame(
            self, text="Record Information",
            bg="khaki", padx=10, pady=10)
...
        environmentinfo = tk.LabelFrame(
            self, text="Environment Data",
            bg='lightblue', padx=10, pady=10)
...
        plantinfo = tk.LabelFrame(
            self, text="Plant Data",
            bg="lightgreen", padx=10, pady=10)
```

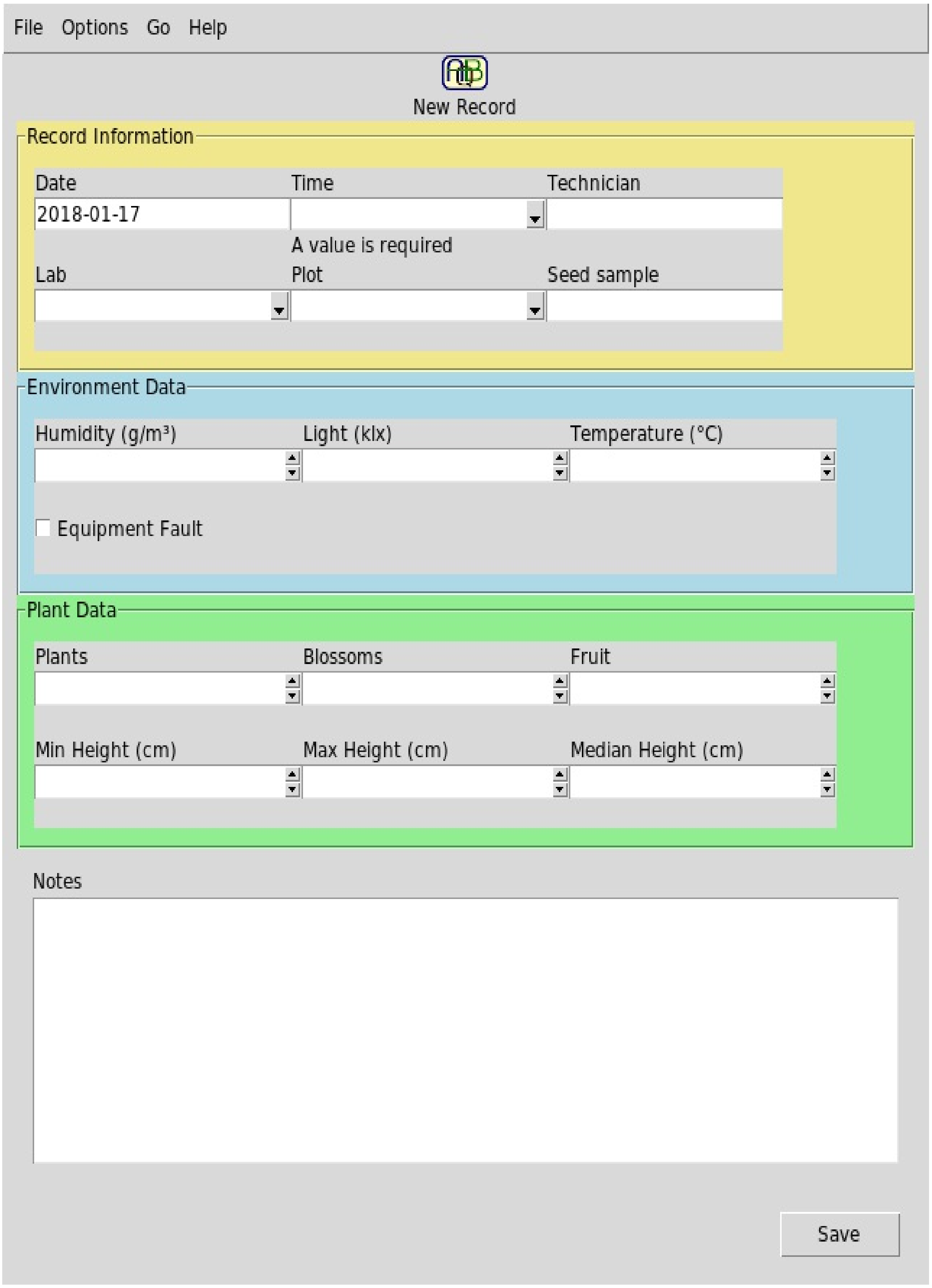
Notice that we've added a bit of padding here as well, to make the color more visible around the widgets and to also create more separation in the form.

We should add similar padding around the `Notes` widget:

```
   self.inputs['Notes'].grid(sticky="w", row=4, column=0,
                             padx=10, pady=10)
```

In this case, we add the padding to the `grid` call, so that the entire `LabelInput` gets shifted over.

The result, at least on Debian Linux, looks something like this:



Record Information

Date	Time	Technician
2018-01-17		
	A value is required	
Lab	Plot	Seed sample

Environment Data

Humidity (g/m³)	Light (klx)	Temperature (°C)

☐ Equipment Fault

Plant Data

Plants	Blossoms	Fruit
Min Height (cm)	Max Height (cm)	Median Height (cm)

Notes

Hardly a visual masterpiece yet, but we have some separation and color coding between form sections.

Using tags

Foreground and background are sufficient for simple widgets such as buttons, but more complex Tkinter widgets like the `Text` widget or the Ttk `Treeview` rely on a system of **tags**. A tag in Tkinter is a named region of a widget's content to which color and font settings can be applied. To see how this works, let's build a crude, but pretty, Python shell.

We'll start by creating a `Text` widget:

```
import tkinter as tk
text = tk.Text(width=50, height=20, bg='black', fg='lightgreen')
text.pack()
```

Here, we've used the `fg` and `bg` arguments to set up a green-on-black theme, popular with programmers. Rather than have only green text, though, let's configure different colors for our prompt and our interpreter output.

To do this, we'll define some tags:

```
text.tag_configure('prompt', foreground='magenta')
text.tag_configure('output', foreground='yellow')
```

The `tag_configure` method allows us to create and configure tags on the `Text` widget. We've created one called `'prompt'` for our shell prompt, and another called `'output'` for the Python output.

To `insert` text with a given tag applied, we do the following:

```
text.insert('end', '>>> ', ('prompt',))
```

As you may remember, the `Text.insert` method takes an index and string as its first two arguments. Notice the third argument: this is a tuple of the tags with which we want to mark the inserted text. This value must be a tuple, even if you're only using one tag.

If you add `text.mainloop()` to the end of the code and run it, you'll see that we have a black text entry window with a magenta prompt, but if you type your text, it will show up in green. So far so good; now, let's make it execute some Python.

Create a function just before the `mainloop()` call:

```
def on_return(*args):
    cmd = text.get('prompt.last', 'end').strip()
```

When retrieving text from a `Text` widget, we're required to supply start and end indices for the text we want to retrieve. Notice that we've used our tag name in the index. `prompt.last` tells Tkinter to fetch the text starting after the end of the region tagged `prompt`.

Next, let's execute `cmd`:

```
     if cmd:
        try:
            output = str(eval(cmd))
        except Exception as e:
            output = str(e)
```

If our `cmd` actually contains anything, we'll try to execute it with `eval`, then store a string of the response value as `output`. If it throws an exception, we'll get our exception as a string and set that as the `output`.

Then, we'll just show our `output`:

```
   text.insert('end', '\n' + output, ('output',))
```

We insert our `output` text, prepended with a newline and tagged as `output`.

We'll finish off the function by giving the user back a `prompt`:

```
    text.insert('end', '\n>>> ', ('prompt',))
    return 'break'
```

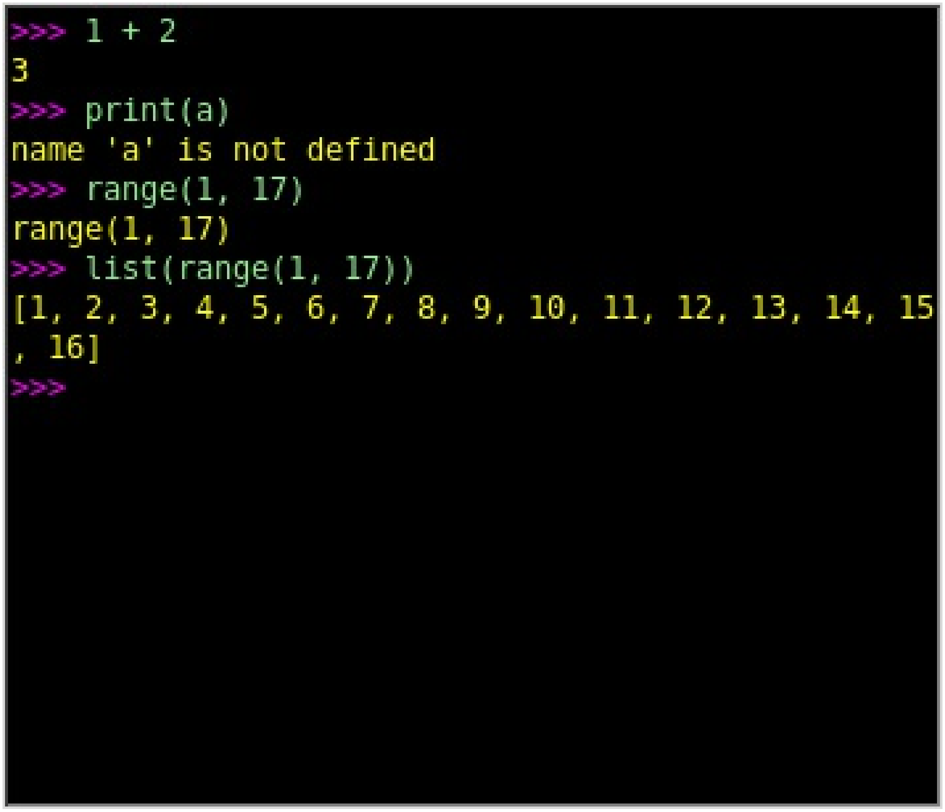
We also return the string `break` here to tell Tkinter to ignore the original event that triggered the callback. Since we're going to trigger this from a `Return`/`Enter` keystroke, we want to ignore that keystroke after we're finished. If we don't, the keystroke will be executed after our function returns and the user will be on the line under the prompt.

Finally, we need to bind our function to the `Return` key:

```
text.bind('<Return>', on_return)
```

Note that the event for the `Enter`/`Return` key is always `<Return>`, even on non-Apple hardware (where the key is more commonly labeled `Enter`).

Your application should look something like this:



```
>>> 1 + 2
3
>>> print(a)
name 'a' is not defined
>>> range(1, 17)
range(1, 17)
>>> list(range(1, 17))
[1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15
, 16]
>>>
```

While this shell won't be supplanting IDLE any time soon, it does look rather nice, don't you think?

Styling our record list with tags

Although `Treeview` is a Ttk widget, it uses tags to control the styling of individual rows. We can use this to answer another of the requests you've gotten from the data entry staff: they'd like the record list to highlight records updated and inserted during the current session.

The first thing we'll need to do is have our `Application` object keep track of which rows have been updated or inserted during the session.

In `Application.__init__()`, we'll create the following instance variables:

```
        self.inserted_rows = []
        self.updated_rows = []
```

When a record is saved, we'll need to update one or the other of these lists with its row number. We'll do this in `Application.on_save()`, after the record is saved, but before we repopulate the record list.

First, we'll check for an updated record:

```
        if rownum is not None:
            self.updated_rows.append(rownum)
```

Updates have `rownum` which do not have a `None` value, so if this is the case, we'll append it to the list. If a record is continually updated, there will be duplicates in our list, but that's not really of any consequence in the scale at which we're operating.

Now, we need to deal with inserts:

```
        else:
            rownum = len(self.data_model.get_all_records()) - 1
            self.inserted_rows.append(rownum)
```

Inserted records are a little more troublesome in that we don't have a row number readily available to record. We do know that inserts are always appended to the end of the file, though, so it should be one less than the number of rows in the file.

Our inserted and updated records will be kept until the end of the program session (when the user exits the program), but we need to manually delete them in the case where a user selects a new file.

We can handle that by clearing the lists in `on_file_select()`:

```
        if filename:
            ...
            self.inserted_rows = []
            self.updated_rows = []
```

Now, our controller knows about inserted and updated records. Our record list does not, however; we need to fix that.

Find the `RecordList` call in `Application.__init__()` and add the variables to its arguments:

```
        self.recordlist = v.RecordList(
            self, self.callbacks,
            self.inserted_rows,
            self.updated_rows)
```

Now, we'll need to go back into `views.py` and tell the `RecordList` what to do with this information.

We'll start by updating its argument list and saving the lists to instance variables:

```
    def __init__(self, parent, callbacks,
                 inserted, updated,
                 *args, **kwargs):
        self.inserted = inserted
        self.updated = updated
```

Next, we'll need to configure tags with appropriate colors. Our data entry staff feels that `lightgreen` would be a sensible color for inserted records, and `lightblue` for updated.

Add this code in `__init__()` after the `self.treeview` configuration:

```
        self.treeview.tag_configure('inserted', background='lightgreen')
        self.treeview.tag_configure('updated', background='lightblue')
```

Just as we did with the `Text` widget earlier, we call `tag_configure` to connect background color settings with our tag names. Note that you aren't restricted to just one configuration setting here; we could conceivably add `foreground`, `font`, or other configuration settings to the same call.

To add the tags to our `TreeView` rows, we'll need to update the `populate` method.

Inside the `for` loop, just before inserting the row, we'll add this code:

```
            if self.inserted and rownum in self.inserted:
                tag = 'inserted'
             elif self.updated and rownum in self.updated:
                tag = 'updated'
             else:
                tag = ''
```

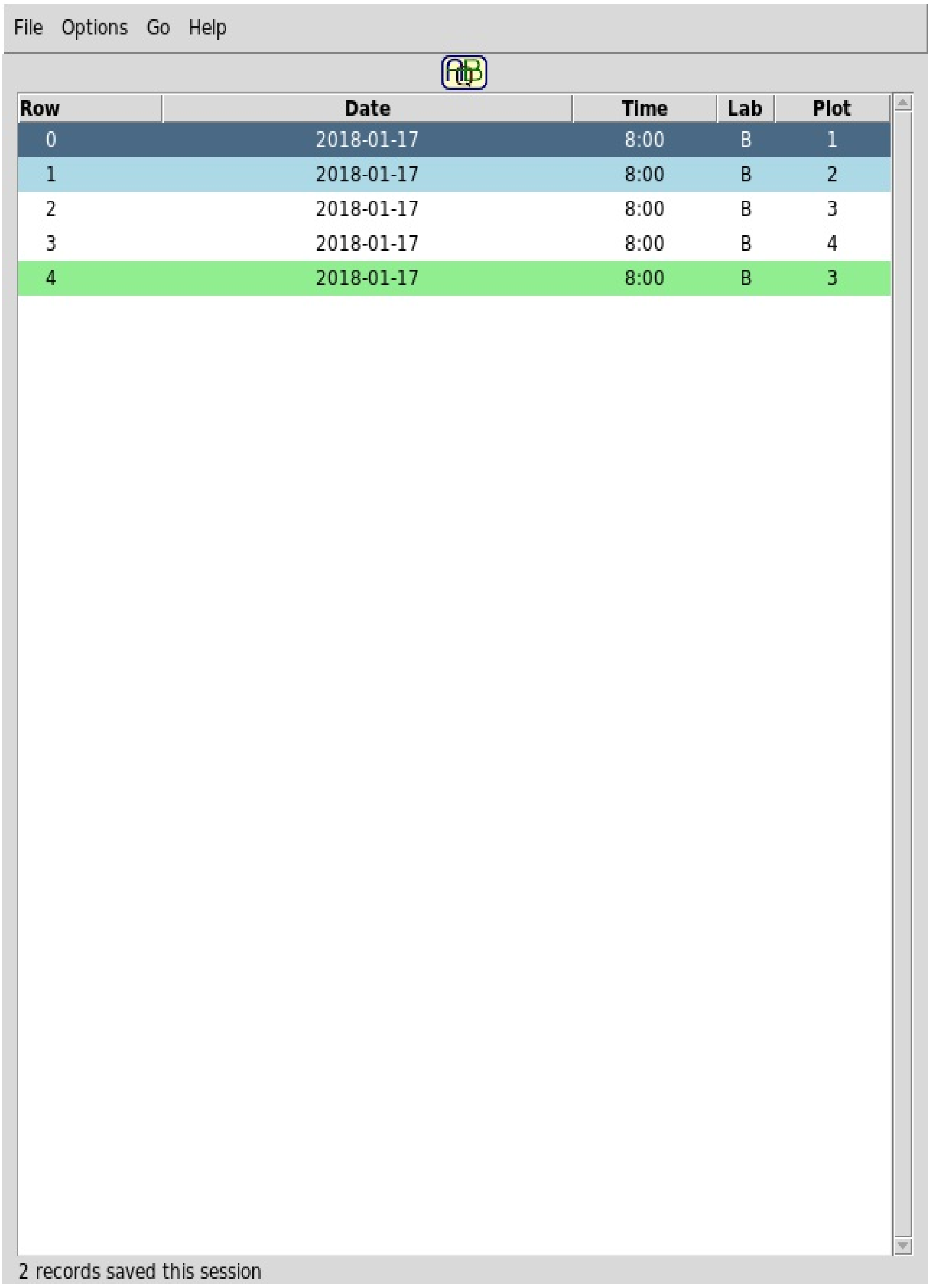
We want `tag` to equal `'inserted'` if the `inserted` list exists and our `rownum` is in it; we want it to be `'updated'` if the `updated` list exists and our `rownum` is in it. Otherwise, we leave it blank.

Now, our `treeview.insert` call just needs to be amended with this `tag` value:

```
             self.treeview.insert('', 'end', iid=str(rownum),
                                  text=str(rownum), values=values,
                                  tag=tag)
```

Run the application and try inserting and updating some records.

You should get something like this:



Row	Date	Time	Lab	Plot
0	2018-01-17	8:00	B	1
1	2018-01-17	8:00	B	2
2	2018-01-17	8:00	B	3
3	2018-01-17	8:00	B	4
4	2018-01-17	8:00	B	3

2 records saved this session

Tkinter fonts

There are three ways of specifying a widget's font in Tkinter.

The simplest way is to just use a string format:

```
tk.Label(text="Direct font format",
         font="Times 20 italic bold")
```

The string takes the format `Font-family size styles`, where `styles` can be any valid combination of text style keywords.

Those words include:

- `bold` for boldface text, or `normal` for normal weight
- `italic` for italized text, or `roman` for regular slant
- `underline` for underlined text
- `overstrike` for struck-out text

Everything but the font family is optional, though you need to specify a `size` if you want to specify any of the styling keywords. The ordering of style keywords doesn't matter, but the weight and slant keywords are mutually exclusive (that is, you can't have `bold normal` or `italic roman`).

One shortcoming of the string approach is that it cannot handle fonts with spaces in the name.

To handle these, you can use the tuple format for fonts:

```
tk.Label(
    text="Tuple font format",
    font=('Droid sans', 15, 'overstrike'))
```

This format is exactly like the string format except that the different components are written as items in a tuple. The `size` component can be an integer or a string containing digits, which provides some flexibility depending on where the value comes from.

This approach works fine for setting up a handful of font changes at launch time, but for situations that need to dynamically manipulate font settings, Tkinter has a feature called **named fonts.** This approach uses a `Font` class that can be assigned to widgets and then dynamically changed.

To use `Font`, it must be imported from the `tkinter.font` module:

```
from tkinter.font import Font
```

Now, we can create a custom `Font` object and assign it to widgets:

```
labelfont = Font(family='Courier', size=30,
                 weight='bold', slant='roman',
                 underline=False, overstrike=False)
tk.Label(text='Using the Font class', font=labelfont).pack()
```

As you can see, the `Font` constructor arguments correlate the keywords used in string and tuple font specifications.

Once this font is assigned, we can dynamically alter aspects of it at runtime:

```
def toggle_overstrike():
    labelfont['overstrike'] = not labelfont['overstrike']

tk.Button(text='Toggle Overstrike', command=toggle_overstrike).pack()
```

In this example, we're providing a `Button` that will toggle the `overstrike` attribute on and off.

Tk comes with several named fonts already configured; we can create Python `Font` objects from them using the `nametofont` function from the `tkinter.font` module.

This table shows some of the named fonts included in Tkinter:

Font name	**Defaults to**	**Used for**
`TkCaptionFont`	System title font	Window and dialog caption bars
`TkDefaultFont`	System default font	Items not otherwise specified

`TkFixedFont`	System fixed-width font	Nothing
`TkHeadingFont`	System heading font	Column headings in lists and tables
`TkIconFont`	System icon font	Icon captions
`TkMenuFont`	System menu font	Menu labels
`TkSmallCaptionFont`	System title	Subwindows, tool dialogs
`TkTextFont`	System input font	Input widgets: Entry, Spinbox, and so on
`TkTooltipFont`	System tooltip font	Tooltips

If you're curious as to what fonts Tkinter is using on your operating system, you can use the `tkinter.font.names()` function to retrieve a list of them.

To change the overall look of the application, we can override these named fonts and the changes will get applied across all widgets that don't otherwise have a font set.

For example:

```
import tkinter as tk
from tkinter.font import nametofont

default_font = nametofont('TkDefaultFont')
default_font.config(family='Helvetica', size=32)

tk.Label(text='Feeling Groovy').pack()
```

In this example, we use the `nametofont` function to retrieve an object for `TkDefaultFont`, the default named font class for Tkinter applications. After retrieving it, we can set its font `family` and `size`, changing those values for all widgets using `TkDefaultFont`.

The `Label` then shows the result of this adjustment:

Feeling Groovy

Giving users font options

Some of our data entry users have complained that the font of the application is just a little too small to read easily, but others dislike the idea of you increasing it because it makes the application too big for the screen. To accommodate all the users, we can add a configuration option that allows them to set a preferred font size.

We need to begin by adding a `'font size'` option to our settings model.

Open `models.py` and append the `SettingsModel.variables` dictionary as follows:

```
    variables = {
        ...
        'font size': {'type': 'int', 'value': 9}
```

Next, we'll add a set of radio buttons to our options menu so that the user can set the value.

Open `views.py` and let's start creating a menu just before the options menu gets added to the main menu:

```
        font_size_menu = tk.Menu(self, tearoff=False)
        for size in range(6, 17, 1):
            font_size_menu.add_radiobutton(
                label=size, value=size,
                variable=settings['font size'])
        options_menu.add_cascade(label='Font size',
                                 menu=font_size_menu)
```

This should look familiar, since we created a nearly identical font size menu when learning about the Tkinter `Menu` widget. We're allowing fonts from `6` to `16`, which should provide plenty of range for our users.

In the `Application` class, let's create a method that will apply the font setting to our application's fonts:

```
    def set_font(self, *args):
```

We include `*args` because `set_font` will be called as a `trace` callback, so we need to capture any arguments being sent in, even though we won't use them.

Next, we'll get the current `'font size'` value:

```
    font_size = self.settings['font size'].get()
```

There are several named fonts we're going to need to change, not just `TkDefaultFont`. For our application, `TkDefaultFont`, `TkTextFont`, and `TkMenuFont` should be sufficient.

We'll just loop through these, retrieving the classes and setting the size on each one:

```
        font_names = ('TkDefaultFont', 'TkMenuFont', 'TkTextFont')
        for font_name in font_names:
            tk_font = nametofont(font_name)
            tk_font.config(size=font_size)
```

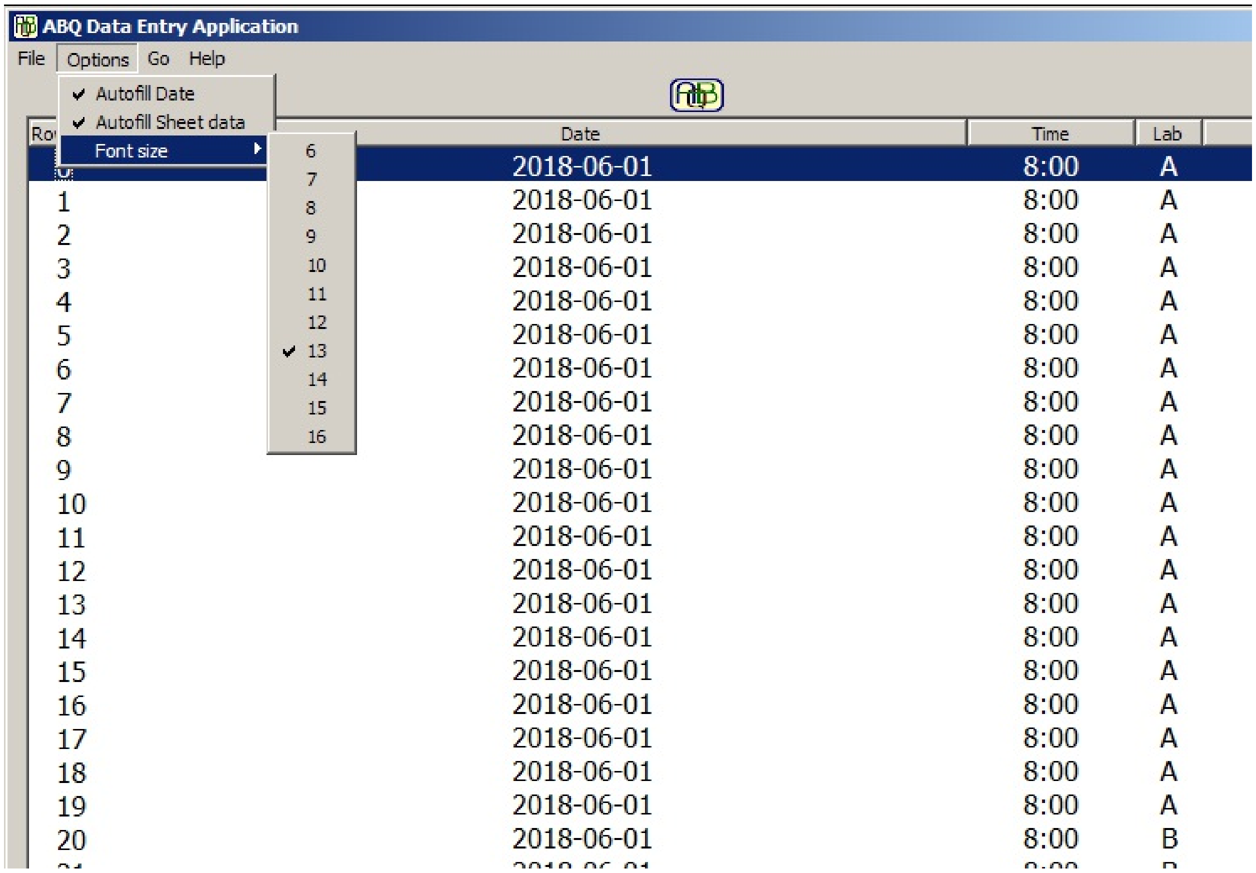
The last thing we need to do is to make sure this callback gets called.

Just after the `load_settings()` call in `Application.__init__()`, add this:

```
        self.set_font()
        self.settings['font size'].trace('w', self.set_font)
```

We call `set_font()` once to activate any saved `font size` settings and then set a `trace` to run it whenever the value is changed.

Run the application and try out the font menu. It should look something like this:



✓ Autofill Date
✓ Autofill Sheet data
Font size: ✓ 13

Row	Date	Time	Lab
0	2018-06-01	8:00	A
1	2018-06-01	8:00	A
2	2018-06-01	8:00	A
3	2018-06-01	8:00	A
4	2018-06-01	8:00	A
5	2018-06-01	8:00	A
6	2018-06-01	8:00	A
7	2018-06-01	8:00	A
8	2018-06-01	8:00	A
9	2018-06-01	8:00	A
10	2018-06-01	8:00	A
11	2018-06-01	8:00	A
12	2018-06-01	8:00	A
13	2018-06-01	8:00	A
14	2018-06-01	8:00	A
15	2018-06-01	8:00	A
16	2018-06-01	8:00	A
17	2018-06-01	8:00	A
18	2018-06-01	8:00	A
19	2018-06-01	8:00	A
20	2018-06-01	8:00	B

Styling Ttk widgets

Ttk widgets represent a major improvement over standard Tkinter widgets in terms of the power and flexibility with which they can be styled. This flexibility is what gives Ttk widgets the ability to mimic native UI controls across platforms, but it comes at a cost: Ttk styling is confusing, poorly documented, and occasionally inconsistent.

To understand Ttk styling, let's start with some vocabulary, from the most basic elements to the most complex:

- Ttk starts with **elements**. An element is one piece of a widget, such as a border, an arrow, or a field where text can be typed.
- Elements are composed using **layouts** into a complete widget (a `Combobox` or `Treeview`, for example).
- **Styles** are collections of properties that define color and font settings:
  - Each style has a name, usually T, plus the name of the widget, such as `TButton` or `TEntry`. There are some exceptions to this.
  - Each element in a layout references one or more style properties to define its appearance.
- Widgets have a number of **states**, which are flags that can be turned on or off:
  - Styles can be configured with a **map** that connects property values to states or combinations of states
- A collection of styles is called a **theme**. Tkinter ships with different themes on different platforms.:
  - A theme might define not only different styles, but different layouts as well. For example, a `ttk.Button` on the default macOS theme may contain a different set of elements, applying style settings differently compared to a `ttk.Button` using the default theme in Windows.

If you're confused at this point, that's okay. Let's take a deep dive into the anatomy of a `ttk.Combobox` to get a better feel for these ideas.

Exploring a Ttk widget

To get a better picture of how a Ttk widget is built, open a shell in IDLE and import `tkinter`, `ttk`, and `pprint`:

```
>>> import tkinter as tk
>>> from tkinter import ttk
>>> from pprint import pprint
```

Now, create a root window, `Combobox`, and `Style` object:

```
>>> root = tk.Tk()
>>> cb = ttk.Combobox(root)
>>> cb.pack()
>>> style = ttk.Style()
```

The `Style` object is, perhaps, slightly misnamed; it doesn't point to a single style, but rather gives us a handle to examine and alter the styles, layouts, and maps for the current theme.

In order to examine our `Combobox`, we'll first get its `stylename` using the `winfo_class()` method:

```
>>> cb_stylename = cb.winfo_class()
>>> print(cb_stylename)
TCombobox
```

We can then inspect the layout of the `Combobox` using the `Style.layout()` method:

```
>>> cb_layout = style.layout(cb_stylename)
>>> pprint(cb_layout)
[('Combobox.field',
  {'children':  [('Combobox.downarrow',
                {'side': 'right', 'sticky': 'ns'}),
                ('Combobox.padding',
                {'children': [('Combobox.textarea',
                {'sticky': 'nswe'})],
                'expand': '1',
                'sticky': 'nswe'})],
                'sticky': 'nswe'})]
```

By passing the style name (in this case, `TCombobox`) to the `style.layout()` method, we get back a layout specification that shows the hierarchy of elements used to construct this widget.

The elements, in this case, are `"Combobox.field"`, `"Combobox.downarrow"`, `"Combobox.padding"`, and `"Combobox.textarea"`. As you can see, each element has associated positioning properties similar to what you'd pass into `pack()`.

The `layout` method can also be used to replace a style's layout by passing in a new layout specification. Unfortunately, this requires replacing the entire layout specification—you can't just adjust or replace a single element in place.

To see how the style connects to the elements, we can use the `style.element_options()` method. This method takes an element name and returns a list of options that can be used to alter it.

For example:

```
>>> pprint(style.element_options('Combobox.downarrow'))
('background', 'relief', 'borderwidth', 'arrowcolor', 'arrowsize')
```

This tells us that the `downarrow` element of the `Combobox` uses these style properties to determine its appearance. To change these properties, we'll have to use the `style.configure()` method.

Let's change the color of the arrow to `red`:

```
>>> style.configure('TCombobox', arrowcolor='red')
```

You should see that the `arrowcolor` has changed to `red`. This is all we need to know to configure widgets for static changes, but what about dynamic changes?

To make dynamic changes, we'll need to understand our widget's state.

We can inspect or alter the state of our `Combobox` using the `state` method:

```
>>> print(cb.state())
()
>>> cb.state(['active', 'invalid'])
('!active', '!invalid')
>>> print(cb.state())
```

```
('active', 'invalid')
```

`Combobox.state()` with no arguments will return a tuple with the currently set state flags; when used with an argument (which must be a sequence of strings), it will set the corresponding state flags.

To turn off a state flag, prepend a `!` to the flag name:

```
>>> cb.state(['!invalid'])
('invalid',)
>>> print(cb.state())
('active',)
```

When you call `state()` with an argument to change the value, the return value is a tuple containing a set of states that would, if applied, undo the state change you just set. This might be useful in a situation where you want to temporarily set a widget's state, then return it to its previous (unknown) state.

You can't just use any strings for `state()`; they must be one of the following:

- `active`
- `disabled`
- `focus`
- `pressed`
- `selected`
- `background`
- `readonly`
- `alternate`
- `invalid`

Exactly how different widgets use each of these states depends on the widget; not every `state()` is configured to have an effect by default.

Widget states interact with the widget style through the use of a map. We use the `style.map()` method to inspect or set the map for each style.

Take a look at the default map for `TCombobox`:

```
>>> pprint(style.map(cb_stylename))
{'arrowcolor': [('disabled', '#a3a3a3')],
 'fieldbackground': [('readonly', '#d9d9d9'),
                     ('disabled', '#d9d9d9')]}
```

As you can see, `TCombobox` has a style map for the `arrowcolor` and `fieldbackground` properties by default. Each style map is a list of tuples, and each tuple is one or more state flags followed by a value for the setting. When all of the state flags match the current state of the widget, the value takes effect.

The default map turns the arrow color to a light gray color when the `disabled` flag is set, and turns the field background to a different light gray color when either the `disabled` or `readonly` flags are set.

We can set our own style mapping using the same method:

```
>>> style.map('TCombobox', arrowcolor=[('!invalid',  'blue'), ('invalid', 'fo
{}
>>> pprint(style.map('TCombobox'))
{'arrowcolor': [('!invalid', 'blue'), ('invalid', 'focus', 'red')],
 'fieldbackground': [('readonly', '#d9d9d9'), ('disabled', '#d9d9d9')]}
```

Here, we've configured the `arrowcolor` property to be `blue` when the `invalid` flag is not set, and `red` when both the `invalid` and `focus` flags are set. Notice that while our call to `map` completely overwrote the `arrowcolor` style map, the `fieldbackground` map was unaffected. This means you can replace style mappings individually, but you can't simply append to the existing map for a given property.

So far, we've been operating on the `TCombobox` style, which is the default style for all `Combobox` widgets. Any changes we made would impact every `Combobox` in the application. We can also create custom styles derived from the existing style by prepending a name and a dot to an existing style name.

For example:

```
>>> style.configure('Blue.TCombobox', fieldbackground='blue')
>>> cb.configure(style='Blue.TCombobox')
```

`Blue.TCombobox` inherits all of the properties of `TCombobox` (including the `blue downarrow` we previously configured), but can add or override them with settings of its own that don't affect `TCombobox`. This allows you to create custom styles for some widgets without affecting other widgets of the same type.

We can alter the look of all the Ttk widgets at once by changing the theme. Remember that a theme is a collection of styles, so by changing the theme, we'll be replacing all the built-in styles and layouts.

Different themes are shipped on different platforms; to see the themes available on your platform, use the `theme_names()` method:

```
>>> style.theme_names()
('clam', 'alt', 'default', 'classic')
```

(These are the themes available on Debian Linux; yours may differ.)

To query the current theme, or to set a new theme, use the `theme_use()` method:

```
>>> style.theme_use()
'default'
>>> style.theme_use('alt')
```

Notice how the previous styling is gone when you change the theme. If you switch back to the default, however, you'll see that your changes were retained.

Styling our form labels

The first thing we can tackle with our knowledge of styling is our form widgets. Our colorization of the form is rather ugly and incomplete due to the `LabelInput` widgets retaining their default, drab color. We'll need to style each of those widgets to match the color of its `LabelInput`.

In the `views.py` file, add this near the start of the `DataRecordForm.__init__()` method:

```
    style = ttk.Style()
```

We're creating our `Style` object so that we can start working with our Ttk styles. What styles do we need?

- We need a style for Ttk `Label` widgets for each section, since we'll need different colors for the widgets in `RecordInfo`, `EnvironmentInfo`, and `Plant Info`.
- We'll need to style our Ttk `Checkbutton`, since it uses its own built-in label rather than a separate label widget. Since there's only one right now, we only need one style for it.

Let's create those styles:

```
        style.configure('RecordInfo.TLabel', background='khaki')
        style.configure(
            'EnvironmentInfo.TLabel',
             background='lightblue')
        style.configure(
            'EnvironmentInfo.TCheckbutton',
            background='lightblue')
        style.configure('PlantInfo.TLabel', background='lightgreen')
```

As you can see, we're creating a custom style based on `TLabel`, but this is prefixed for each individual section. For each style, we're just setting the `background` color appropriately.

Now comes the tedious task of adding this style to each widget:

```
        self.inputs['Date'] = w.LabelInput(
            recordinfo, "Date",
            field_spec=fields['Date'],
            label_args={'style': 'RecordInfo.TLabel'})
```

In each `LabelInput` call, you'll need to add a `label_args` argument that sets the `style` to the appropriate `TLabel` style for the section. Go through and do this for all the widgets.

For the `Checkbutton`, you'll need to do it differently:

```
        self.inputs['Equipment Fault'] = w.LabelInput(
            environmentinfo, "Equipment Fault",
            field_spec=fields['Equipment Fault'],
            label_args={'style': 'EnvironmentInfo.TLabel'},
            input_args={'style': 'EnvironmentInfo.TCheckbutton'})
```

Here, we've set `input_args`, since the style applies to the `Checkbutton` rather than the label (leave `label_args`; we'll need that in a minute).

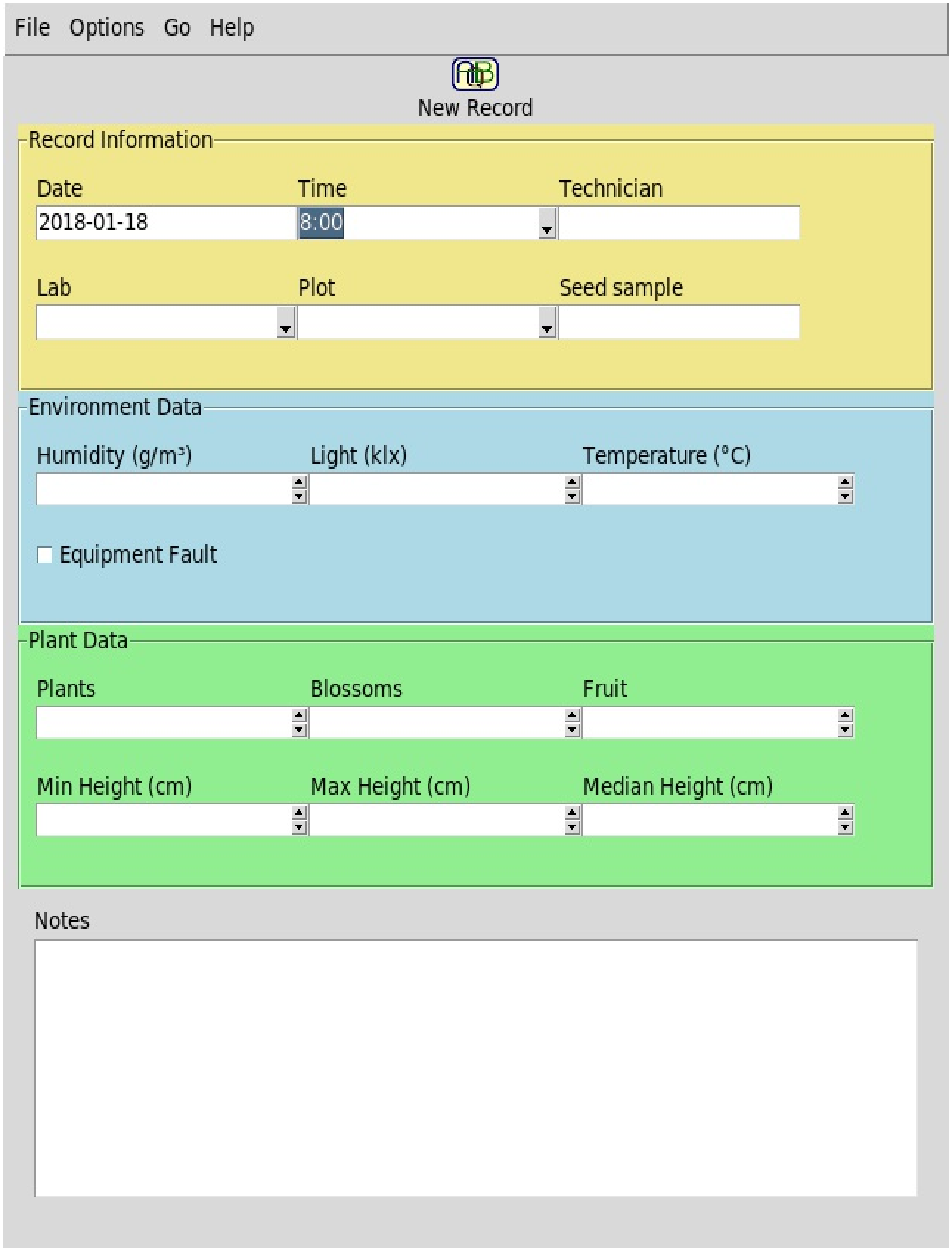
If you run the program at this point, you'll see a marked improvement, but it's not quite there yet; the error labels are still the old, default color.

To fix this, we just need to edit our `LabelInput` widget to use the `label_args` for the error label as well.

Open `widgets.py` and fix the `self.error_label` assignment in `LabelInput.__init__()`:

```
        self.error_label = ttk.Label(self, textvariable=self.error,
                                     **label_args)
```

Now, your application should have consistent colors and look a lot more attractive:



Date	Time	Technician
2018-01-18	8:00	

Styling input widgets on error

Our data entry staff has complained that the error-styling in our fields is not terribly noticeable. Currently, we're just setting the `foreground` color to `red`.

This has a couple of problems:

- For empty fields, there's nothing to actually color `red`
- Our color blind user has trouble distinguishing the `red` from the normal text color

We'll use our styling knowledge to improve the error styling and make invalid fields more noticeable.

Before we can do that, though, you may have to fix a minor issue with one of our widgets.

Making our Spinbox a Ttk widget

If you're using Python 3.6 or earlier, the `Spinbox` widget is only available in `tkinter`, and not `ttk`. We'll need to fix this so that our error-styling can be consistent.

At the time of writing this book, the author has submitted a patch to Python 3.7 to include the Ttk `Spinbox`. If you're using Python 3.7 or later, you can just use `ttk::spinbox` and skip this section.

Since `Spinbox` is already in the Tcl/Tk Ttk library, creating a Python class for it is surprisingly easy.

Add this code near the top of `widgets.py`:

```
class TtkSpinbox(ttk.Entry):

    def __init__(self, parent=None, **kwargs):
        super().__init__(parent, 'ttk::spinbox', **kwargs)
```

This is all that's needed to create a Ttk `Spinbox` for this application. We're simply subclassing `ttk.Entry`, but changing the Ttk widget being used in the `__init__` statement. If we needed any `Spinbox` methods that `Entry` lacks, we'd need to provide those; for this application, we don't need anything else.

Now, we only need to update our `ValidatedSpinbox` class to inherit `TtkSpinbox` rather than `tk.Spinbox`:

```
class ValidatedSpinbox(ValidatedMixin, TtkSpinbox):
```

Updating ValidatedMixin

Now that we're working with all Ttk widgets, we can update our `ValidatedMixin` class with some dynamic styling.

We'll begin in the `__init__()` method by creating a `Style` object:

```
style = ttk.Style()
```

Since this is a mixin class, we don't know the original style name of the widget we're mixing with, so we'll have to fetch that.

Remember that we can do this with `winfo_class()`:

```
        widget_class = self.winfo_class()
        validated_style = 'ValidatedInput.' + widget_class
```

After getting the widget class, we're creating a derivative style by prepending `ValidatedInput` to it. In order to toggle our input appearance between error and non-error appearances, we'll create a style map that switches with the state of the `invalid` state flag.

You can do this with a call to `style.map()`:

```
        style.map(
            validated_style,
            foreground=[('invalid', 'white'), ('!invalid', 'black')],
            fieldbackground=[('invalid', 'darkred'), ('!invalid', 'white')]
        )
```

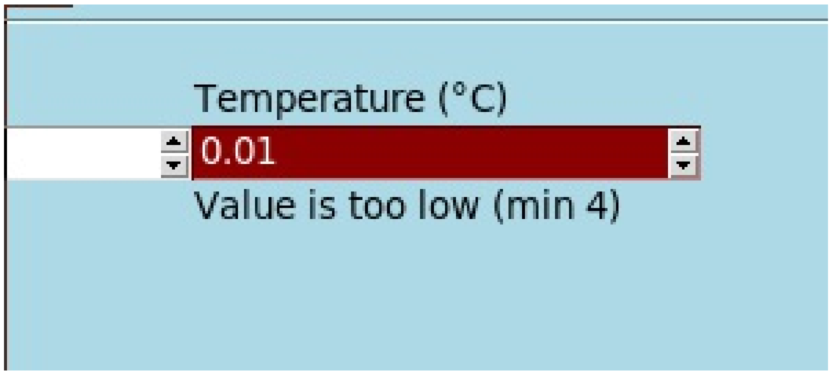
We're still using red, since it's an established "error color", but this time we're inverting the field from dark-on-light to light-on-dark. This should help our colorblind user to distinguish errors, even though they are red.

Finally, we need to update our call to `self.config` to include setting the widget's style to our new validated style:

```
        self.config(
            style=validated_style,
                validate='all',
                ...
```

Ttk widgets automatically set their `invalid` flags as part of the built-in validation system. Currently, we have a method called `_toggle_error()`, which is called whenever validation begins or fails and sets the error state on and off. We can remove that method completely, and all references to it.

If you try the application now, you'll see that fields with errors now turn a dark red color with white text:



Setting themes

Generally speaking, the default Ttk theme on any given platform is probably the best one to use on that platform, but looks are subjective and sometimes we might feel that Tkinter gets it wrong. Having a way to adjust the theme might help to smooth out some rough edges and make some users feel more comfortable with the look of the application.

As we've already seen, querying available themes and setting a new theme is fairly simple. Let's create a configuration option to change the theme of our application.

Building a theme selector

Themes aren't something users are going to need to change often, and as we've seen, changing the theme can undo style changes we've made to our widgets. In light of this, we'll play it safe by designing our theme changer in such a way that it requires a restart of the program to make the actual change.

We'll start by adding a theme option to our `SettingsModel`:

```
    variables = {
        ...
        'theme': {'type': 'str', 'value': 'default'}
    }
```

Every platform has a `theme` aliased to `default`, so this is a safe and sensible default value.

Next, our `Application.__init__()` method will need to check this value and set the `theme` accordingly.

Add this code just after the call to `load_settings()`:

```
        style = ttk.Style()
        theme = self.settings.get('theme').get()
        if theme in style.theme_names():
            style.theme_use(theme)
```

We create a `Style` object, query our settings for the theme name, then (assuming the saved `theme` is in the available themes) set the `theme` accordingly.

What remains now is to create the UI.

In the `views.py` file, we'll create a new submenu for the `options_menu`:

```
        style = ttk.Style()
        themes_menu = tk.Menu(self, tearoff=False)
        for theme in style.theme_names():
            themes_menu.add_radiobutton(
                label=theme, value=theme,
                variable=settings['theme']
            )
        options_menu.add_cascade(label='Theme', menu=themes_menu)
```

Here, we simply loop through the available themes and add a `Radiobutton` for each theme, tying it to our `settings['theme']` variable.

It may not be obvious to users that changing the theme requires a restart, so let's make sure to let them know.

We'll add a `trace` to the variable:

```
        settings['theme'].trace('w', self.on_theme_change)
```

The `on_theme_change` method will just display a warning dialog informing the user that a restart will be needed to realize the change.

Add it to the end of the `MainMenu` class:

```
    def on_theme_change(self, *args):
        """Popup a message about theme changes"""
        message = "Change requires restart"
        detail = (
            "Theme changes do not take effect"
            " until application restart")
            messagebox.showwarning(
            title='Warning',
            message=message,
            detail=detail)
```

Now, you can run the application and try changing the `theme`. Which theme looks best on your platform?

You might find that some themes on your platform break the widget styling in the form. Remember that themes don't just change default colors and fonts, they change the layout and contents of the widget elements themselves. Sometimes, a style setting doesn't carry across different themes due to this change of property names.

Summary

In this chapter, we overhauled the look and feel of our application for both aesthetic and usability improvements. You learned how to work with color and font settings for Tkinter widget, and the intricate world of Ttk styles.

In the next chapter, we'll take steps to make sure our program runs effectively across major desktop platforms. You'll learn strategies to avoid cross-platform pitfalls in both general Python programming and Tkinter programming in particular. We'll also explore the various guidelines platform vendors offer to developers targeting their platforms.

Maintaining Cross-Platform Compatibility

Your application is being requested throughout the lab as a way to visualize and work on experimental data files. As a result, it now needs to run on the Windows, macOS, and Linux systems equally well. Fortunately for you, Python and Tkinter are supported on the three main operating systems, and you'll be pleasantly surprised to find that it runs unaltered on all three. However, there are some small issues that you need to address and remain aware of for your application to be a good citizen on each platform.

In this chapter, we'll cover the following topics:

- Learning to write cross-platform Python that works across Windows, macOs, and Linux
- Learning how to write Tkinter code that works consistently across platforms
- Fixing some minor cross-platform issues in our application

Writing cross-platform Python

At the time of writing, Python is supported on over three dozen operating system platforms, covering everything from common desktop systems like Windows to high-end commercial Unixes to obscure OS projects such as Haiku or **AROS Research Operating System**. Across all these platforms, most Python code works without any significant alteration, as Python has been designed to translate high-level functionality into appropriate low-level operations on each one. Even so, there are situations where OS differences cannot be (or simply have not been) abstracted away, and careful handling is required to avoid platform-specific failures.

In this section, we'll look at some of the larger issues that impact cross-platform Python.

Filenames and filepaths across platforms

Filesystems are probably the biggest source of pitfalls for cross-platform development. Although most platforms share the concept of files and directories arranged in a hierarchy, there are some crucial differences that can trip up developers who are unfamiliar with other operating systems.

Path separators and drives

When it comes to identifying locations on a filesystem, operating systems generally use one of the following two models:

- **Windows/DOS**: In this model, each partition or device is assigned a volume label (usually a single letter), and each volume has its own filesystem tree. Paths are separated by a backslash (`\`) character. This system is used by Windows, DOS, and VMS.
- **Unix**: In this model, there is one filesystem tree, into which devices and partitions are mounted at arbitrary points. Paths are separated by a forward slash (`/`). This model is used by macOS, Linux, BSD, iOS, Android, and other Unix-like operating systems.

Thus, a path like `E:\Server\Files\python` is meaningless on Linux or macOS, while a path like `/mnt/disk1/files/python` is equally meaningless on Windows. This could make it quite difficult to write code that accesses files in a cross-platform way, but Python gives us a few tools to deal with the differences.

Path separator translation

If you use the Unix-style forward slash path separators on a Windows system, Python will automatically translate them into backslashes. This is quite useful for cross-platform purposes because using backslashes in strings can be problematic.

Note that the reverse is not true: Python will not translate backslashes into Unix-style forward slashes. A path like `r'\usr\bin\python'` *will not work on macOS or Linux.*

The os.path module

Even with automatic path-separator interpolation, building or hardcoding paths as strings is a messy business. Python's powerful string manipulation methods make it tempting to try to work with paths as strings, and many programmers attempt to do so.

The result is often ugly, non-portable code as follows:

```
script_dir = '/'.join(some_path.split('/')[:-1])
```

While this approach might work most of the time (even on Windows), it's prone to breaking on some edge cases (for example, `some_path = '/script.sh'`). For this reason, the Python standard library includes the `os.path` module for working with filesystem paths. We've seen it quite a bit already, but it warrants another look owing to its importance in cross-platform compatibility.

The `path` module appears to be a collection of functions and constants that help abstract common filenames and directory operations, though it's actually a wrapper around the low-level modules `posixpath` for Unix-like systems and `ntpath` for Windows. When you import `path`, Python simply detects your operating system and loads the appropriate low-level library.

The following table shows some common `os.path` functions that are useful for cross-platform developers:

Function	Purpose
`join()`	This function joins two or more path segments in a platform-appropriate way
`expanduser()`	This function expands the `~` or `~username` shortcuts, which point to user home directories and to an absolute path
	This function expands the filesystem and shell variables

`expandvars()`	present in a path
`dirname()`	This function extracts the parent directory of the path
`isfile()`	This function determines whether the path points to a file
`isdir()`	This function determines whether the path points to a directory
`exists()`	This function determines whether the path exists

The pathlib module

A more recent addition to the Python standard library is the `pathlib` module, a more object-oriented and somewhat higher-level take on filesystem paths, which you may remember from Chapter 7, *Navigating Records with Treeview*. Unlike `os.path`, which is just a collection of functions and constants, `pathlib` offers the `Path` object, which represents a filesystem location.

We typically use `pathlib` by importing the `Path` class from it, as follows:

```
>>> from pathlib import Path
>>> p = Path()
>>> print(p)
.
>>> print(p.absolute())
'/home/alanm'
```

`Path` defaults to the current working directory, but you can also provide it with an absolute or relative path string. Relative paths will be calculated against the current working directory.

These `Path` objects have a variety of useful properties and methods:

```
# Create a Path object for the current working directory
p = Path()

# find the parent directory
parent = p.parent

# Check if the path /var/log exists
has_var_log = Path('/var/log').exists()

# Join Paths together, using the division operator
image_path = Path(__file__) / 'images' / 'png'
```

Refer to the `pathlib` documentation at https://docs.python.org/3/library/pathlib.html for more information on this powerful library.

TIP

Should you use `os.path` or `pathlib.Path`? The `pathlib` module provides a fairly high-level interface that excels at complex path manipulations, but it can be overkill for simple checks or joins. Either one works fine, but if you find yourself doing more than a few lines of path-related operations, `pathlib` is probably going to be cleaner.

Case-sensitivity

Platforms also differ in terms of filesystem case sensitivity. On Linux, `log.txt`, `LOG.txt`, and `LoG.TxT` are all different files that can coexist in the same directory. On Windows, they will not.

The following table breaks down the case sensitivity of major operating systems:

System	Case-sensitive
Windows	No
macOS	Not default (configurable)
Linux	Yes
Berkeley Software Distribution (**BSD**), most other Unix systems	Yes

Problems with case (in)sensitivity usually depend on which system you're accustomed to:

- Programmers used to a case-insensitive system tend to run into problems with inconsistent use of cases between the filesystem and program
- Programmers used to a case-sensitive system can have problems when depending on a case to differentiate between file or directory names (for example, `ImportIngest.txt` and `ImportingEst.txt`)

Avoiding these issues is fairly simple with the following few basic rules:

- Use lowercase for file and path names unless there is a good reason not to.

- If you do mix cases, follow consistent rules, so that you don't need to remember arbitrary case usage.
- Avoid CamelCase or similar naming schemes that rely on case to denote word breaks. Use underscores, hyphens, or spaces (they're valid in all modern filesystems!).

Symbolic links

A symbolic link is a special filesystem construct that points to another file or directory on the system. Although they exist on Windows, they're far more commonly used on Linux, macOS, and other Unix-like systems; thus, they can be a point of confusion for programmers coming from a Windows environment.

Symbolic links are not to be confused with desktop shortcuts, which also exist on all three major platforms. Shortcuts are just metadata files implemented at the desktop environment level, whereas symbolic links are implemented at the filesystem level.

File and path operations sometimes need to clarify if they're working with the symbolic link itself or the file that the link points to.

For example, consider a link in our current directory, `secret_stuff.txt`, that points to the nonexistent file `/tmp/secret_stuff.txt`, as follows:

```
>>> from os import path
>>> path.exists('secret_stuff.txt')
False
>>> path.lexists('secret_stuff.txt')
True
```

The regular `path.exists()` function will follow the link and discover that the file in question does not exist. `os.path` also includes a `lexists()` function that will tell us if the link exists, even if the file doesn't. This situation could be a problem; for example, your program might be attempting to create a directory with the same name as a broken symbolic link. In this case, `os.path.exists` or `Path.exists` would both return `False`, but the name conflict would still exist, and directory creation would fail. Checking `os.path.lexists` or `Path.is_symlink` as well would be a good idea in this case.

The following table shows some of the `os.path` functions that help deal with symbolic links:

Method	Description

`islink()`	Returns `True` if a path is a symbolic link
`lexists()`	Returns `True` if a path exists, even if it's a broken symbolic link
`realpath()`	Return the actual path, resolving any symbolic links to real files and directories

The `pathlib.Path` objects also feature the following handy link-related methods:

Method	**Description**
`is_symlink()`	Returns `True` if the path is a symbolic link
`resolve()`	Returns a path with all symbolic links resolved to real files and directories
`lchmod()`	Changes permissions on a symbolic link, rather than the file it is pointed to
`lstat()`	Returns filesystem information on a symbolic link, rather than the file it is pointed to

Path variables

Most platforms, including Windows, macOS, and Linux, support some kind of shell variables, which are often automatically set up by the system to point to common filesystem locations. The `os.path` module provides the `expandvars` function to expand these variables into their actual values (`pathlib` has no equivalent method). While these variables can be useful in locating common path locations, the cross-platform developer should understand that they are not consistent across platforms.

Some commonly used variables across different systems include the following:

Description	Windows	macOS	Linux
Current user home directory	`%HOME%`, `%USERPROFILE%`	`$HOME`	`$HOME`
Temporary directory	`%TMP%`, `%TEMP%`	`$TMPDIR`	None
Path to default shell	N/A	`$SHELL`	`$SHELL`
Current working directory	None	`$PWD`	`$PWD`
Configuration directory	`%APPDATA%`, `%LOCALAPPDATA%`	None	`$XDG_CONFIG_HOME` (often not set)
OS directory	`%WINDIR%`, `%SYSTEMROOT%`	N/A	N/A
Program files directory	`%PROGRAMFILES%`, `%PROGRAMW6432%`	N/A	N/A

Note that Windows variables can be spelled using the native `"%VARIABLENAME%"` format or the Unix-style `"$VARIABLENAME"` format; macOS and Linux only accept the Unix format. Using these variables is not necessarily a bad idea (they can help abstract differences between versions or configurations of an OS), but be aware that they are not consistently available, or even meaningful, across platforms.

Inconsistent library and feature support

While it's understandable that many third-party Python libraries only support a limited number of platforms, you might be surprised to learn that the standard library contains a slightly different set of modules depending on the platform. Even those that do exist across platforms might behave slightly differently, or have inconsistent contents, depending on the platform.

Naturally, these have to be handled carefully in cross-platform applications.

Python's platform-limited libraries

In sections 34 and 35 of Python's standard library documentation (`https://docs.python.org/3/library/index.html`), you'll find a list of libraries available only on Windows or Unix-like systems, respectively. Careful reading of the documentation shows that there are a couple more platform-limited libraries listed in other sections as well.

Following is a list of the more common platform-limited libraries you may encounter:

Library	Description	Availability
`ossaudiodev`	**Open Sound System** (**OSS**) audio server interface	Linux, FreeBSD
`winsound`	Windows audio interface	Windows
`msilib`	Windows software packaging tools	Windows
`winreg`	Windows registry tools	Windows
`syslog`	Unix system log interface	Linux, macOS, BSD
`pwd`, `spwd`	Unix password database interface	Linux, macOS, BSD
`resource`	System resource limits	Linux, macOS, BSD
`curses`	Terminal-based UI library	Linux, macOS, BSD

In some cases there are higher-level, cross-platform libraries that you can use to replace these (for example, use `logging` instead of `syslog`), but in other cases the functionality is so platform-specific that you may have no choice (`winreg`, for example). In this case, you'll need to do a platform check before importing these libraries, as you'll get an `ImportError` exception on unsupported platforms.

Checking low-level function compatibility

Even in universally available libraries, there are sometimes functions or methods that are unavailable or exhibit different behaviors depending on the platform. The `os` module is perhaps the most notable case.

The `os` module is a relatively thin wrapper around system calls or commands, and while it attempts to abstract some roughly analogous calls across platforms, many of its functions are too platform-specific to make available universally.

The `os` module documentation at `https://docs.python.org/3/library/os.html` contains complete details on platform support, but some examples are listed here:

Library	Description	Availibility
`getuid`, `getgid`, `getgroups`, `geteuid`	Get user or group information for current process	Unix-like
`setuid`, `setgid`, `setgroups`, `seteuid`	Set user or group information for current process	Unix-like
`getpriority`, `setpriority`	Get or set priority of the current process	Unix-like
`chown`, `lchown`	Change owner of a file or its symbolic link	Unix-like
`startfile`	Open a file as if it were double-clicked	Windows

Attempting to use an unavailable function will cause an exception, so none of these functions should be in a cross-platform application without appropriate checks or exception handling. By far, most of the platform-limited functions in `os` are limited to Unix-like systems (Linux, macOS, BSD, and so on), and most of the analogous functions for Windows will be found in the third-party `pywin32` package (which is only available for Windows, of course).

In general, you need to check the documentation of the libraries you use to make sure they're available on all the platforms you intend to support. Caution is especially warranted when using libraries that interact with operating system functions (such as window management, filesystems, user authentication, and so on) or with services that are only available on certain platforms (Microsoft SQL Server, for example).

The dangers of the subprocess module

The `subprocess` module provides tools to launch and manage other programs and commands from within your Python application. For programmers already familiar with their operating system's command-line interface, it often provides a fast and convenient way to accomplish filesystem operations or other administrative tasks. It's also highly effective at sabotaging cross-platform compatibility.

For example, you might be tempted to copy files as follows:

```
import subprocess
subprocess.call(['cp', 'file1.txt', 'file2.txt'])
```

This would work on Unix-like operating systems, but fail on Windows as `cp` is not a valid Windows shell command. The better option in this case is to use the `shutil` library, which contains high-level functions for copying files.

To avoid problems here, follow these guidelines:

1. Look for high-level libraries before resorting to `subprocess` to solve a problem
2. If you must use `subprocess`, carefully study the called command on each supported platform, making sure the syntax, output, and behavior is identical
3. If it's not, make sure to create different cases for each platform

Text file encodings and formats

The text files on different platforms use different character encodings and end-of-line characters by default. Although most operating systems can handle a wide variety of encodings, each system has a default (often determined by language or localization settings) that will be used if none is specified. Text files on different platforms also use different character codes for end-of-line characters.

The defaults for English versions of major operating systems are shown here:

OS	**Default**	**Default new line**
Windows	cp1252	Carriage return + line feed (`\r\n`)
Linux (most modern distributions)	UTF-8	Line feed (`\n`)
macOS	US-ASCII	Line feed (`\n`)

Most of the time, these differences do not represent a problem, especially if you are only reading and writing files in Python and working with standard English characters.

Consider, however, a scenario where you attempt to append a unicode character to a text file, like so:

```
with open('testfile.test', 'a') as fh:
    fh.write('\U0001F4A9')
```

On systems with a non-unicode default encoding (such as the English versions of Windows and macOS), the preceding code will raise an exception, like so:

```
# Error on macOS
UnicodeEncodeError: 'ascii' codec can't encode character '\U0001f4a9' in posi
# Error on Windows
UnicodeEncodeError: 'charmap' codec can't encode character '\U0001f4a9' in po
```

To avoid this problem, you can manually specify a character encoding when opening a file, as follows:

```
with open('testfile.test', 'a', encoding='utf-8') as fh:
    fh.write('\U0001F4A9')
```

It's a good idea to do this whenever saving data you don't control (such as user-entered data).

Graphical and console modes

On Windows, programs are launched in either GUI or console mode, as determined by metadata in the executable. The Python distribution for Windows includes a utility called Python launcher, which is associated with Python files during installation. Python launcher will launch your application in either GUI or console mode depending on its file extension, as follows:

- Files ending in the `.py` extension will be launched in console mode using `python.exe`. This will cause a command console window to open in the background, which must stay open while the program runs.
- Files ending in `.pyw` will be launched in GUI mode using `pythonw.exe`. No console window will be launched, and the program will not block the console; however, `print()` will have no effect and `sys.stderr`, and `sys.stdout` will not exist. Trying to access them will cause an exception.

To avoid problems when deploying GUI applications to Windows, follow these practices:

1. Remove any `sys.stdout` or `sys.stderr` statements from the code
2. Create a copy of the main executable script with a `.pyw` extension

While macOS does not distinguish between GUI and console applications (apart from the obvious presence of a GUI), its desktop launches regular `.py` files by launching a Terminal window, just like Windows. However, macOS Python includes a `pythonw.exe` file that launches without the Terminal, but there are two problems. First, it is not associated with the `.pyw` files by default; you'd need to do that manually if you want that behavior. Second, depending on how you installed Python 3 (for instance, if you installed it using `homebrew`), your installation may not have `pythonw`.

There is a proper way to set up applications on macOS so that they behave like proper GUI applications, which we'll cover in `Chapter 15`, *Packaging with setuptools and cx_Freeze*.

Writing code that changes according to the platform

As you've seen so far, there are certain situations where you simply can't avoid writing platform-specific code, either because a high-level library is unavailable or because the actions that need to be performed are fundamentally different.

In this case, it becomes necessary to detect the platform. There are a few ways of doing this in Python, including `os.system()` and `sys.platform`, but the `platform` module contains the best set of functionality for determining the OS details most useful in making decisions.

We'll mostly rely on the `system()` function, which returns a string identifying the operating system: `Windows`, `Linux`, `freebsd7`, or `Darwin` (for macOS).

Some other useful functions include `release()`, which returns the version string of the OS (for example, "10" on Windows 10, "17.3.0" on **macOS High Sierra**, or the kernel version on Linux); and `architecture()`, which tells us if the system is 64 bit or 32 bit.

For simple differences in code, using this information in a nested `if...else` chain, as follows, usually suffices:

```
import platform
import subprocess

os_name = platform.system()
if os_name in ('Darwin', 'freebsd7'):
    cmd = ['ps', '-e', '-o', "comm=''", '-c']
elif os_name == 'Linux':
    cmd = ['ps', '-e', '--format', 'comm', '--no-heading']
elif os_name == 'Windows':
    cmd = ['tasklist', '/nh', '/fo', 'CSV']
else:
    raise NotImplemented("Command unknown for OS")

processes = subprocess.check_output(cmd)
print(processes)
```

In this example, we're checking the value of `platform.system()`, then defining a `cmd` variable based on its value. Then, we pass the `cmd` list to `subprocess.check_output()` to run the command and obtain its output.

This works acceptably for the occasional call, but for more complex situations, it makes sense to bundle platform-specific code into backend classes which we can then select on the basis of our platform string, as in this example:

1. To begin, we'd create a `backend.py` file with a `GenericBackend` class implementing a `get_process_list()` method, like this:

```
import subprocess
class GenericBackend():
    cmd = []
    def get_process_list(self):
        if self.cmd:
            return subprocess.check_output(self.cmd)
        else:
            raise NotImplemented
```

2. Next, we'd create platform-specific subclasses as follows, each defining a `cmd` list appropriate to the platform:

```
class LinuxBackend(GenericBackend):
    cmd = ['ps', '-e', '--format', 'comm', '--no-heading']

class MacBsdBackend(GenericBackend):
    cmd = ['ps', '-e', '-o', "comm=''", '-c']

class WindowsBackend(GenericBackend):
    cmd = ['tasklist', '/nh', '/fo', 'CSV']
```

3. Finally, we create a selector function to return an appropriate backend class when given an OS name:

```
def get_backend(os_name):
    backends = {'Linux': LinuxBackend, 'Darwin': MacBsdBackend,
                'Windows': WindowsBackend, 'freebsd7': MacBsdBacke
    try:
        return backends[os_name]
    except KeyError:
        raise NotImplemented("No backend for OS")
```

4. With `backend.py` written, we can create a simple `main.py` file that uses it as follows:

```
import platform
from backend import get_backend

os_name = platform.system()
os_backend = get_backend(os_name)()

print(os_backend.get_process_list())
```

We need only import the `get_backend()` function into our application, then use it to retrieve and instantiate the appropriate backend class. You should be able to run this script on Linux, Windows, macOS, or BSD and get back a process list. Other platforms can be easily added by creating more backend classes and updating `get_backend()` .

Writing cross-platform Tkinter

As you've seen so far, Tkinter mostly works identically across platforms, and even has the capability to do the right thing on each platform with minimal effort. However, there are some minor issues to be aware of as you support a Tkinter application across multiple operating systems. In this section, we'll explore the more significant differences.

Tkinter version differences across platforms

Even if you install the latest version of Python from `python.org`, the actual version of Tcl/Tk installed on your system may vary widely. This can cause problems if you rely on features in the most recent Tk.

The following chart shows the versions installed by default on different systems:

OS	Tk version
Windows	8.6.6
macOS	8.5.9
Debian Linux 9	8.6.6
Ubuntu Linux 18.04	8.6.8

Windows and most Linux distributions are shipping a relatively recent version of 8.6, but macOS defaults to use its system-installed Tk version, which is 8.5.9. This can be a problem if you want to use any of the new 8.6 features, such as we encountered in `Chapter 8`, *Improving the Look with Styles and Themes*, when working with the PNG files. Although it's possible to upgrade Tk on macOS, it is not recommended by Apple or the Python documentation. If your cross-platform plans include macOS, you'll need to decide whether you are willing to limit yourself to features in 8.5 or if you want to require macOS users to make a non-recommended upgrade.

Application menus across platforms

The application menu is probably one of the most visible areas where both capabilities and convention vary between platforms. As mentioned in `Chapter 6`, *Creating Menus with Menu and Tkinter Dialogs*, we should be aware of both the limitations and the expectations on major operating systems when designing our menus.

Menu widget capabilities

The `Menu` widget, which we learned about in `Chapter 6`, *Creating Menus with Menu and Tkinter Dialogs*, is different from most other Tkinter widgets in that it relies on the menu facilities of the underlying platform. This allows your application to have a menu that behaves natively; for example, on macOS, the menu appears in the global menu area at the top of the screen, while on Windows it appears in the application window under the taskbar.

Because of this design, there are some limitations when working with cross-platform `Menu` widgets. To demonstrate this, follow these steps to build a very non-cross-platform menu:

1. We'll begin by creating a simple Tk window with a menu, with the following code:

```
import tkinter as tk
from tkinter.messagebox import showinfo

root = tk.Tk()
menu = tk.Menu(root)
```

2. Now, we'll create a cascade menu with one command in it, as follows:

```
smile = tk.PhotoImage(file='smile.gif')
smile_menu = tk.Menu(menu, tearoff=False)
smile_menu.add_command(image=smile,
                       command=lambda: showinfo(message="Smile!"))
menu.add_cascade(image=smile, menu=smile_menu)
```

   Instead of adding the cascade with a label, we're using `PhotoImage` so that it has an icon.

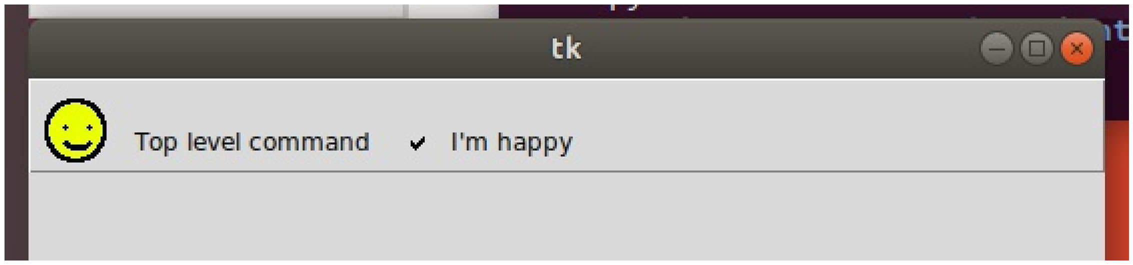
3. Next, let's add a command directly to the main menu as follows:

```
menu.add_command(label='Top level command',
                 command=lambda: showinfo(message='By your command
```

4. Last of all, we'll create a `Checkbutton` widget directly to the main menu, and finish with the usual boilerplate:

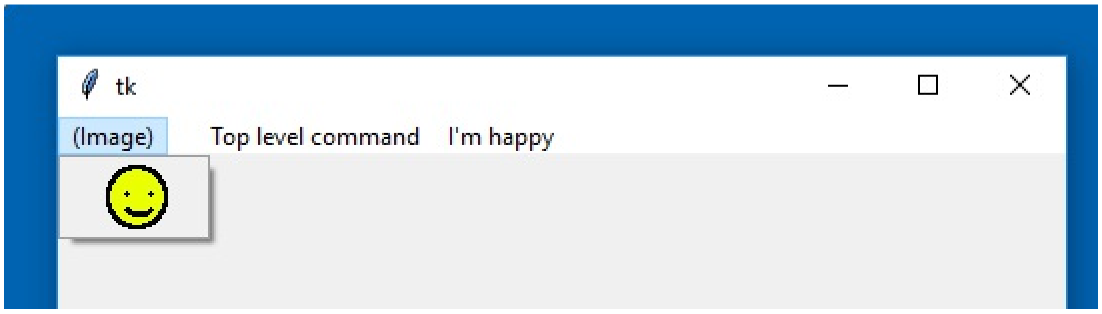
```
        boolvar = tk.BooleanVar()
        menu.add_checkbutton(label="It is true", variable=boolvar)

        root.config(menu=menu)
        root.mainloop()
```

5. If you run the preceding code on Linux (in this case, Ubuntu 17.10), it seems to work as expected:



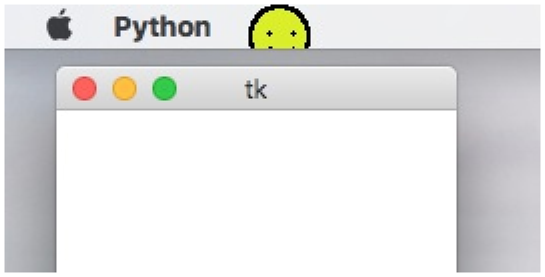
   We have our first cascade labeled with the smiley face GIF, our top-level menu command, and our top-level `Checkbutton` (which we've checked, because our menu works and we're happy!).

6. Next, let's try this same code on Windows, as shown in the following screenshot:



   Instead of our smiling icon in the top menu, we only have the text (Image). Even if we specify a label, this text shows up. Fortunately, the image does appear when we use it in the cascade. The top-level command appears and works just fine, but the `Checkbutton` widget does not. The label appears, and can be clicked on, but the checkbox itself does not appear. We're not so happy now.

7. Finally, let's try this menu on macOS, as follows:



On macOS, our menu shows up not in the program window, but in the top global menu, as users would expect it to. However, there are some obvious problems.

First, while our smiling icon appears, it's cut off. Since the top bar is a fixed height and Tkinter will not resize our icon for us, images larger than the top bar height get truncated, and there are bigger problems: neither the top-level command nor the `Checkbutton` widget are anywhere to be seen. Only our cascade menu shows up.

On each platform, we're limited by the capabilities of the menu system, and while it appears anything goes for top menus in Linux, the other two operating systems require more care when constructing menus.

To avoid any issues here, follow these guidelines:

- Avoid commands and using `Checkbutton` and `Radiobutton` in the main menu. Stick to cascade menus only.
- Don't use images in the main menu.
- If you must do either of the preceding points, create separate menus for each platform.

Menu guidelines and standards

Each of our major platforms offers standards to direct developers in making user interfaces that meet the expectations of that system's users. While these standards should be taken into consideration for the whole application, one of the most visible areas affected by them is the layout of the application menu (or menu bar, to use the standard terminology).

Let's look at what each standard has to say about menu layouts.

Windows user experience interaction guidelines

Microsoft's Windows user experience interaction guidelines, available at `https://developer.microsoft.com/en-us/windows/desktop/design`, offer developers a wealth of information for designing applications that fit right in to the Windows desktop. Among many guidelines offered for menu bar design is a description of the standard menu items and how they should be arranged.

We'll refer to this guideline when customizing our application for Windows.

Apple's human interface guidelines

Apple's human interface guidelines are available at `https://developer.apple.com/macos/human-interface-guidelines/`, and offer a detailed set of rules for creating macOS-friendly interfaces.

While much of the basic advice for menu bar design is similar to that offered by Microsoft, the layout recommendations are quite different and much more specific. For example, the first cascade on a macOS application should be the **app menu**, a menu named after the application, which contains items like about and preferences.

We'll attempt to bring our macOS users a menu closer to Apple's standards later in this chapter.

Linux and BSD human interface guidelines

In sharp contrast to Windows and macOS, Linux, BSD, and other X11 systems have no blessed default desktop environments or controlling entities to dictate UI standards. There are well over a dozen full desktop environments available for these platforms, each with its own goals and ideals about user interaction.

While there are multiple projects working to create **human interface guidelines** (**HIG**), we'll be following the Gnome HIG, used by the Gnome, MATE, and XFCE desktops, available at `https://developer.gnome.org/hig/stable/`. The Gnome desktop is the default desktop environment on many Linux distributions, including Red Hat, newer versions of Ubuntu, and Debian, which is our target environment.

Accelerator keys

Accelerator keys are keyboard shortcuts assigned to common application actions, particularly menu items. Thus far, we've added no accelerator keys, which is bad for keyboard-only users.

In Tkinter, accelerator keys can be assigned to a widget using the `bind()` method, which we learned about in `Chapter 4`, *Reducing User Error with Validation and Automation*. We can also use the `bind_all()` method, which can be called on any widget and effectively binds an event globally. Our menu items also take an `accelerator` argument, which can be used to specify a string that will be shown in the menu as an accelerator key hint.

The UI guidelines on each platform define standard accelerator keys for common actions, most of which are the same across platforms since they descend from the IBM **Common User Access** (**CUA**) established in the 1980s. The most notable difference is the use of the command (⌘) key on macOS in place of the control (*ctrl*) key used by Windows and Linux.

As we rewrite our application menus for cross-platform compatibility, we'll also add platform-appropriate accelerator keys.

Fonts

In Chapter 8, *Improving the Look with Styles and Themes*, we learned how easy it is to customize Tkinter's fonts to change the look and feel of your application. Doing so, however, can cause inconsistencies across platforms.

There are around 18 fonts that are shared between macOS and Windows, but not all of them look identical on both platforms. As for Linux, most distributions ship with none of those 18 fonts due to license issues. Unless you can guarantee that a particular font is available on all supported platforms, it's best to avoid naming specific font-families in your styles. Fortunately, if you do happen to specify a nonexistent font, Tkinter will just use the default, but even that could cause layout or readability issues in certain cases.

To be safe, stick with Tkinter's named fonts, which are automatically set to the same defaults on each platform.

Theme support

As we saw in `Chapter 8`, *Improving the Look with Styles and Themes*, Ttk provides a number of themes which differ from platform to platform. Each platform contains an alias called "default", which points to the most sensible theme for that platform.

Attempting to set a theme that doesn't exist results in an exception, so avoid hardcoding a theme setting in your application, and make sure theme choices are checked against the output of `Style.theme_names()` .

Window zoomed state

Windowing environments have the concept of a "zoomed" window, which takes over the screen completely.

On Windows or macOS, it can be activated using the root window's `state()` method, as follows:

```
from tkinter import *
root = Tk()
root.state('zoomed')
root.mainloop()
```

On Windows or macOS, this creates a window that takes over the screen; on Linux or BSD, however, it raises an exception because X11 does not provide anything for setting a `zoomed` state.

On X11, this is accomplished by turning on the Window's `-zoomed` attribute as follows:

```
root.attributes('-zoomed', True)
```

Unfortunately, the preceding code raises an exception on Windows and macOS. If you need to be able to set this state in a program, you'll need to use some platform-specific code.

Improving our application's cross-platform compatibility

Our application does pretty well across platforms, but there are some things we can do to improve it:

- First, our application stores its preferences in the user's home folder, which is not ideal on any platform. We will fix our application to use the correct location on each platform for user configuration files.
- Second, we're creating our CSV files without specifying any encoding; if a user inserted a unicode character (say, in the `Notes` field), file saving would raise an exception and fail.
- Finally, the current menu structure does not really come close to following any of the human interface guidelines we've discussed. We'll implement separate menus for each platform to ensure users have a UI that is consistent with their platform.

Storing preferences correctly

Each platform defines a proper location for storing user configuration files as follows:

- Linux and other X11 systems store configuration files in a location defined in the `$XDG_CONFIG_HOME` environment variable, which defaults to `~/.config` if it's not defined.
- macOS user config files are stored in `~/Library/Application Support/`.
- Windows user config files are stored in `%USERPROFILE%\AppData\Local`. Though if your environment uses **Active Directory** (**AD**) with roaming profiles, you might prefer to use `%HOME%\AppData\Roaming` instead.

To realize this in our application, we'll edit our `Application` object to pass the correct path into `SettingsModel`. Remember that our `SettingsModel` constructor takes a `path` keyword argument that determines the directory in which the file will be saved. Let's take a look at the following steps:

1. To begin, open `application.py` and add a new class property just before `__init__()`, as follows:

```
        config_dirs = {
            'Linux': environ.get('$XDG_CONFIG_HOME', '~/.config'),
            'freebsd7': environ.get('$XDG_CONFIG_HOME', '~/.config'),
            'Darwin': '~/Library/Application Support',
            'Windows': '~/AppData/Local'}
```

2. The `config_dirs` dictionary defines the preferred configuration directory path for each platform. We're pulling the Linux and BSD environment variables from the `environ` object, which we'll need to import from the `os` module, as follows:

```
        from os import environ
```

3. Now, we just need to look up the correct directory using `platform.system()` and pass it to `SettingsModel`.
4. Replace the current instantiation of `SettingsModel` with the following code

lines:

```
      config_dir = self.config_dirs.get(platform.system(), '~')
      self.settings_model = m.SettingsModel(path=config_dir)
```

5. Now, start up the application and change some of the options. The application should create a new config file in the appropriate location for your operating system.

Specifying an encoding for our CSV file

Our application is currently saving CSV files using system default encoding. This could be a problem for Windows and macOS users if they try to use unicode characters.

In `models.py`, we need to locate the three instances of `open()` in our `CSVModel` class and add an encoding, as follows:

```
with open(self.filename, 'w', encoding='utf-8') as fh:
                ...
```

With this change, the unicode characters should no longer be a problem.

Making platform-appropriate menus

To create our platform-specific main menus, we'll create multiple menu classes and use a selector function as explained in the previous section. Before we can do this, we'll need to prepare our `MainMenu` class so that it's easier to subclass.

Preparing our MainMenu class

Let's take a look at the following steps for preparing our `MainMenu` class:

1. To begin, let's create a new file in our module called `mainmenu.py`.
2. Cut the entire `MainMenu` class out of `views.py` and paste it into `mainmenu.py`. The first thing we'll do is change its name to explain its role more clearly:

```
class GenericMainMenu(tk.Menu):
```

3. In order to make it easier for subclasses to build different menu structures, we're going to split all the code that creates the menu widgets into their own method. We'll call this method `_build_menu()`:

```
def _build_menu(self):
    # The file menu
    file_menu = tk.Menu(self, tearoff=False)
    ...
```

4. Move the entire `__init__()` method after the call to `super()` into this method. Each of our child classes will override this method and create its own menu structure. Since we no longer have `settings` or `callbacks` in this method, we'll need to make them instance properties in `__init__()` , and we'll need to call `_build_menu()` at the end of `__init__()`. The `__init__()` method should be as follows:

```
def __init__(self, parent, settings, callbacks, **kwargs):
    super().__init__(parent, **kwargs)
    self.settings = settings
    self.callbacks = callbacks
    self._build_menu()
```

5. To complete `_build_menu()`, update any `settings` or `callbacks` references to `self.settings` and `self.callbacks`, as follows:

```
file_menu.add_command(
    label="Select file…",
    command=self.callbacks['file->select'])
```

We would also like our menus to have appropriate accelerator keys for each OS; to do that, we'll take a look at these steps:

1. Create a method that will return a dictionary of key events and the commands.   Why use a method for this, and not just a class property? In order to retrieve the functions, we need access to `self.callbacks`, which only exists in an instance. Therefore, we need to create this list at the instance level. The method looks like this:

```
        def get_keybinds(self):
            return {
                '<Control-o>': self.callbacks['file->select'],
                '<Control-q>': self.callbacks['file->quit'],
                '<Control-n>': self.callbacks['new_record'],
                '<Control-l>': self.callbacks['show_recordlist']
            }
```

2. To actually set these bindings, we'll create another method that will iterate this dictionary and call `bind_all()` to create our bindings. This method won't need to be overridden by child classes. We'll call this method, `_bind_accelerators()`:

```
        def _bind_accelerators(self):
            keybinds = self.get_keybinds()
            for key, command in keybinds.items():
                self.bind_all(key, command)
```

Remember that the `bind_all()` method, which can be called by any widget, binds events globally; if we use `bind`, our `keybinds` will only work when the menu is in focus.

3. This approach almost works, but there's a small hitch; unlike commands called from a menu item, bound events pass an `event` object to the called function. Many of our callbacks don't take arguments, and will raise an exception if called with an exception. We could alter all our callbacks to eat any extra arguments, but we will never use that argument since our menu items don't send it. Instead, we'll create a wrapper that strips out the arguments:

```
        @staticmethod
        def _argstrip(function, *args):
            return function()
```

The `@staticmethod` decorator makes this method static, meaning that Python won't automatically pass `self` in as the first argument. Static methods are useful for utility methods like this one that don't need to access the object instance.

4. To wrap our callbacks in this method, we'll use the `partial` function from the `functools` standard library module. `partial` takes a callable and any number of arguments, and returns a reference to a function with the arguments already populated. We'll use this to prepare versions of `_argstrip()` with the callbacks already populated. Start by adding `partial` to the file's imports:

```
from functools import partial
```

5. Now, update `_bind_accelerators()` as follows:

```
        for key, command in keybinds.items():
            self.bind_all(key, partial(self._argstrip, command))
```

   You may ask, why not use a `lambda` function to solve this problem, as in `lambda x: command()`? The problem is that `lambda` will not look up the value of `command` until it's called, at which point `command` will be the last item in `dict`. In effect, all accelerators would be bound to the last command in the dictionary! `partial`, by contrast, looks up the value of `command` immediately.

6. The last change to make to our `GenericMainMenu` is to add accelerator labels to the appropriate commands, which will be displayed to the right of the menu option. We set this label using the `accelerator` argument of `Menu.add`, as follows:

```
        file_menu.add_command(
            label="Select file…",
            command=self.callbacks['file->select'],
            accelerator='Ctrl+O'
        )
```

Understand that this argument is strictly cosmetic and does not bind any keys to the menu item; our `bind_all()` calls actually enable the accelerator. Also note that we're putting in the literal text we want to display, not the event syntax passed to `bind()` and `bind_all()`.

7. Add this argument to the `Quit`, `New Record`, and `Record List` items as well.

Building the Windows menu

After studying the Microsoft user experience interaction guidelines, you deem the following changes are necessary to make our menu Windows-friendly:

- `file->quit` should be changed to `file->exit`, and there should be no accelerator for it. Windows uses `Alt-F4` to close programs, and this is handled by Windows automatically.
- Windows can handle commands in the menu bar just fine, and the guidelines encourage this for frequently used functionality. We'll move our `Record List` and `New Record` commands directly to the main menu.
- `Options` is supposed to go under a `Tools` menu, separated from the rest of the items in tools. Although we have nothing else under tools at the moment, we likely will in the future, so we'll create this.

Let's implement these changes and create our Windows menu class:

1. Start by subclassing the `GenericMainMenu` class and overriding `_build_menu()` as follows:

```
        class WindowsMainMenu(GenericMainMenu):
            def _build_menu(self):
```

2. To make things faster, copy in the entire `_build_menu()` method from the parent class, so we can just edit the lines that need to be changed.
3. Start with the `file->quit` command, changing the label and removing the accelerator as follows:

```
    file_menu.add_command(
        label="Exit",
        command=self.callbacks['file->quit'])
```

4. Next, we'll remove the `Go` menu entirely and add its commands directly to the main menu instead, as follows:

```
    self.add_command(label="Record List",
        command=self.callbacks['show_recordlist'],
        accelerator='Ctrl+L')
    self.add_command(label="New Record",
        command=self.callbacks['new_record'],
        accelerator='Ctrl+N')
```

5. Finally, we'll create the `Tools` menu and add the separator and `Options` menu to it:

```
        tools_menu = tk.Menu(self, tearoff=False)
        options_menu = tk.Menu(tools_menu, tearoff=False)
        ...
        # after the end of the options configuration
        tools_menu.add_separator()
        tools_menu.add_cascade(label='Options', menu=options_menu)
        self.add_cascade(label='Tools', menu=tools_menu)
```

6. Last of all, we need to remove the `Control-q` key binding as follows:

```
    def get_keybinds(self):
        return {
            '<Control-o>': self.callbacks['file->select'],
            '<Control-n>': self.callbacks['new_record'],
            '<Control-l>': self.callbacks['show_recordlist']}
```

Building the Linux menu

Our GenericMenu class is pretty close to the Gnome HIG, but there is one change to be made: our Options menu doesn't really belong; rather, we need to split its items into two categories.

The autofill options, since they change the way data is entered in the form, belong in an edit menu. The font and theme options, since they only change the appearance of the application and not the actual data, belong in a view menu.

Let's make the modifications necessary to create our Linux menu:

1. Start the class by subclassing GenericMainMenu and overriding the _build_menu() method:

```
class LinuxMainMenu(GenericMainMenu):
    def _build_menu(self):
```

2. Once again, copy in the code from the parent and edit what needs to be changed.
3. First, let's create the edit menu just after the file menu, as follows:

```
# The edit menu
edit_menu = tk.Menu(self, tearoff=False)
edit_menu.add_checkbutton(
    label='Autofill Date',
    variable=self.settings['autofill date'])
edit_menu.add_checkbutton(
    label='Autofill Sheet data',
    variable=self.settings['autofill sheet data'])
self.add_cascade(label='Edit', menu=edit_menu)
```

4. Make sure to remove the autofill items from the Options menu.
5. Next, rename Options to View like so:

```
view_menu = tk.Menu(self, tearoff=False)
font_size_menu = tk.Menu(view_menu, tearoff=False)
...
view_menu.add_cascade(label='Font size', menu=font_size_menu)
...
```

```
        themes_menu = tk.Menu(view_menu, tearoff=False)
        ...
        view_menu.add_cascade(label='Theme', menu=themes_menu)
        self.add_cascade(label='View', menu=view_menu)
```

We don't need to change anything else; our accelerators and the rest of the menu line up pretty well with the Gnome HIG.

Building the macOS menu

The macOS menu will need extensive changes. Unlike the Windows and Gnome guidelines, which mostly suggest categories, the Apple guidelines are very specific about which menus should be created and which items belong in them. Furthermore, macOS also creates and pre-populates some of these menus with default commands, so we'll need to use special arguments to hook into those menus and add our own items.

The changes we need to make to comply with Apple's HIG are as follows:

- We need to create an app menu. This is the first menu macOS creates, just to the right of the Apple icon on the menu bar. It's created by default, but we'll need to hook into it to add some custom items.
- The about command belongs in the app menu; we'll move it there and remove the unused `Help` menu.
- Since macOS will provide a quit command for us, we'll remove ours.
- As we did with the Linux menu, our options will be split between the edit and view menus.
- We need to add a Window menu; this is another autogenerated menu that macOS fills with window management and navigation functions. Our navigation items will be moved from the `Go` menu to this menu.
- Finally, macOS uses the *command* key rather than the *ctrl* key to activate accelerators. We need to update both our key bindings and menu labels accordingly.

Let's make the necessary changes to build our macOS menu:

1. As before, we'll subclass `GenericMainMenu` and start our own `_build_menu()` method as follows:

```
    class MacOsMainMenu(GenericMainMenu):
        def _build_menu(self):
```

2. The first order of business is the app menu. To access this built-in menu, all we need to do is create `tk.Menu` and pass in a `name` argument

which is set to `apple`, like so:

```
        app_menu = tk.Menu(self, tearoff=False, name='apple')
```

3. The app menu should contain both our about option and our quit option, but we only need to add the former since macOS automatically adds a quit action. Let's add in the about item as follows:

```
        app_menu.add_command(
            label='About ABQ Data Entry',
            command=self.show_about)
        self.add_cascade(label='ABQ Data Entry', menu=app_menu)
```

   Note the difference in the label text. Apple's HIG specifies that this should read `About program name` rather than just `About`. Note that we also manually add the cascade to the main menu. If we didn't do this, macOS would still create the app menu, but our about item would not be there.

Your app menu will currently read `Python` rather than `ABQ Data Entry`. We'll address this when we package our application in `Chapter 15`, Packaging with Setup Tools and cx_Freeze.

   The file menu is exactly the same as `GenericMainMenu`, except that the accelerator string needs to be changed. Tkinter will automatically replace the strings `Command` or `Cmd` with the symbol for the *command* key (⌘), this should be `Cmd-o`.

4. The `Edit` and `View` menus are next, and they are identical to the menus we made for the `LinuxMainMenu` class. Copy those in from that class.
5. The Window menu is the proper location for our navigation controls. Just as with the app menu, we access this built-in menu using a `name` argument. In this case, set the name to `window` as follows:

```
        window_menu = tk.Menu(self, name='window', tearoff=False)
```

6. Add the `Record List` and `New Record` items to this menu, making sure to update the accelerator strings, and then add the cascade to the main menu.

7. The only thing left to do for the `macOSMainMenu` class is to fix the key bindings, changing `Control` to `Command` and removing the superfluous `Command-q` binding as follows:

```
        def get_keybinds(self):
            return {
                '<Command-o>': self.callbacks['file->select'],
                '<Command-n>': self.callbacks['new_record'],
                '<Command-l>': self.callbacks['show_recordlist']}
```

Creating and using our selector function

With our classes created, let's add a simple selector function to return the appropriate class for each platform:

1. . Add the `get_main_menu_for_os()` method at the end of the `mainmenu.py` file as follows:

```
        def get_main_menu_for_os(os_name):
            menus = {
                'Linux': LinuxMainMenu,
                'Darwin': MacOsMainMenu,
                'freebsd7': LinuxMainMenu,
                'Windows': WindowsMainMenu
            }
            return menus.get(os_name, GenericMainMenu)
```

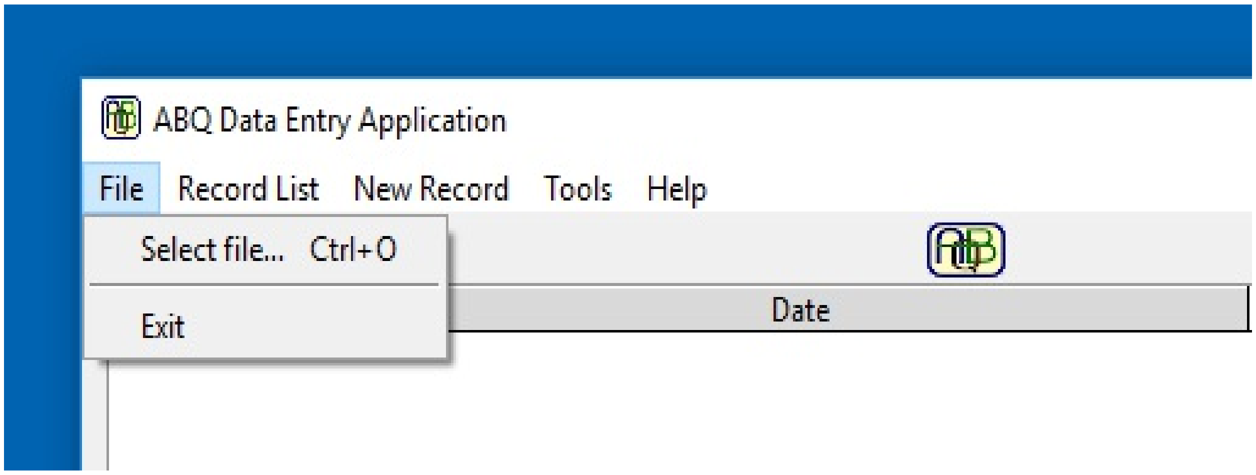
2. The keys in this dictionary are the output strings from `platform.system()`, which we point to a platform-appropriate menu class. In the event we've passed some new system, we default to the `GenericMainMenu` class. The `application.py` file only needs to import this function:

```
        from .mainmenu import get_main_menu_for_os
```

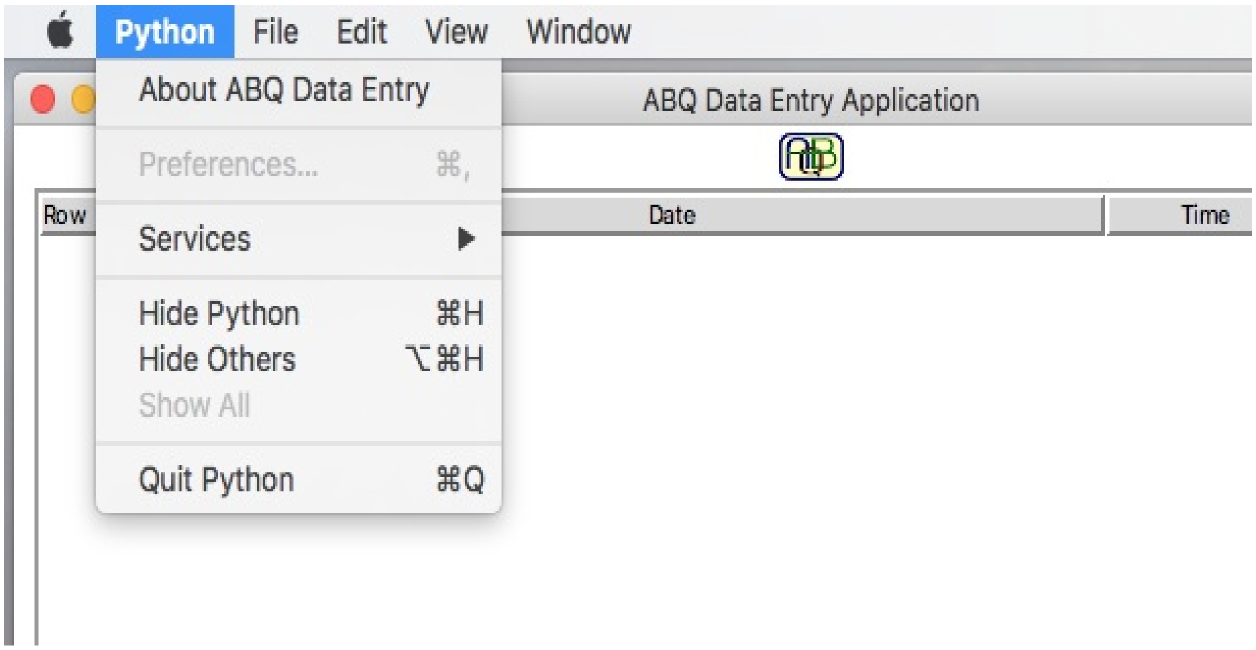
3. Now, instead of calling `v.MainMenu()` (which no longer exists), we use the following function:

```
        menu_class = get_main_menu_for_os(platform.system())
        menu = menu_class(self, self.settings, self.callbacks)
```

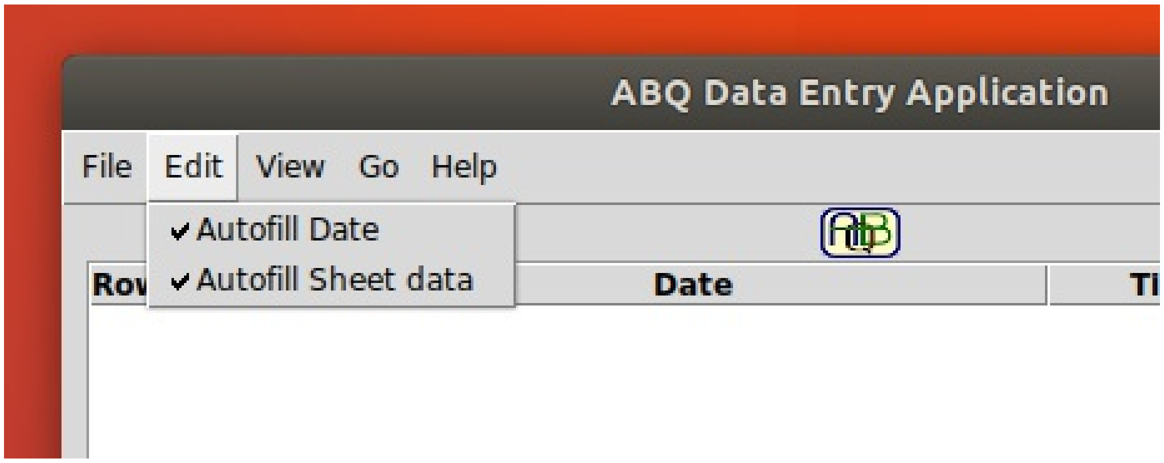
4. Now when you run the application, your menu appearance will change according to the platform. On Windows, you should see something like this:



On macOS, you'll see something like this:



Finally, on Linux or BSD, you'll see a menu as shown in the following screenshot:


ABQ Data Entry Application
File
Edit
View
Go
Help
✓ Autofill Date
✓ Autofill Sheet data
Row
Date
Ti

Summary

In this chapter, we learned about writing Python software that works well across multiple platforms. You learned how to avoid common platform pitfalls in Python code and how to write software that intelligently adapts to the needs of different operating systems. You also learned about published guidelines that help developers write software that meets platform users' expectations.

In the next chapter, we're going to learn about automated testing. You'll learn to write tests that ensure your code works correctly, both for regular Python code and specifically for Tkinter code, and to take advantage of the testing framework included in the Python standard library.

Creating Automated Tests with unittest

With the size and complexity of your application rapidly expanding, you've become nervous about making changes. What if you break something? How will you know? You need a reliable way to make sure your program is working properly as the code changes.

Fortunately, we have a way: automated testing. In this chapter, you'll cover the following topics:

- Learning the basics of automated testing
- Learning specific strategies for testing Tkinter applications
- Applying this knowledge to our data entry application

Automated testing basics

Up until now, testing our application has been a process of launching it, running it through a few basic procedures, and verifying that it did what we expected it to do. This approach works acceptably on a very small script, but, as our application grows, it becomes an increasingly time-consuming and error-prone process to verify the application's behavior. Using automated testing, we can consistently verify our application logic within seconds.

There are several forms of automated testing, but the two most common are **unit testing** and **integration testing**. Unit tests work with discrete pieces of code in isolation, allowing us to quickly verify the behavior of specific sections. Integration tests verify the interactions of multiple units of code. We'll be writing both kinds of tests to verify the behavior of our application.

A simple unit test

At its most basic, a unit test is just a short program that runs a unit of code under different conditions and compares its output against expected results.

Consider the following calculation class:

```
import random

class MyCalc:

    def __init__(self, a, b):
        self.a = a
        self.b = b

    def add(self):
        return self.a + self.b

    def mod_divide(self):
        if self.b == 0:
            raise ValueError("Cannot divide by zero")
        return (int(self.a / self.b), self.a % self.b)

    def rand_between(self):
        return ((random.random() * abs(self.a - self.b)) +
        min(self.a, self.b))
```

This class is initialized with two numbers and can then perform a variety of arithmetic methods on them.

Let's create a naive test for this function as follows:

```
from mycalc import MyCalc

mc1 = MyCalc(1, 100)
mc2 = MyCalc(10, 4)

try:
    assert mc1.add() == 101, "Test of add() failed."
    assert mc2.mod_divide() == (2, 2), "Test of mod_divide() failed."
except AssertionError as e:
    print("Test failed: ", e)
else:
    print("Tests succeeded!")
```

Our test code creates a `MyCalc` object and then uses `assert` statements to check the output of `add()` and `mod_divide()` against expected values. The `assert` keyword in Python is a special statement that raises an `AssertionError` exception if the statement that follows it evaluates to `False`. The message string after the comma is the error string that will be passed to the `AssertionError` exception.

The code `assert statement, "message"` is essentially equivalent to this:

```
if not statement:
    raise AssertionError("message")
```

Currently, all tests pass if you run the test script for `MyCalc`. Let's try changing the `add()` method as follows to make it fail:

```
    def add(self):
        return self.a - self.b
```

Now, running the test gives this error:

```
Test failed:  Test of add() failed.
```

What is the value of such tests? Suppose someone decides to refactor our `mod_divide()` method as follows:

```
    def mod_divide(self):
        ...
        return (self.a // self.b, self.a % self.b)
```

Since this passes our tests, we can be pretty sure this algorithm is correct, even if we didn't understand the code. If there were a problem with the refactor, our tests should show that fairly quickly.

Testing pure mathematical functions is fairly simple; unfortunately, testing real application code presents us with some challenges that demand a more sophisticated approach.

Consider these issues:

- Code units often rely on a pre-existing state that must be set up before the test and cleared up afterwards.
- Code may have side effects that change objects outside the code unit.

- Code may interact with resources that are slow, unreliable, or unpredictable.
- Real applications contain many functions and classes that require testing, and ideally we'd like to be alerted to all problems at once. Our tests, as written, would stop on the first failed assertion, so we'd only get alerted to one problem at a time.

To address these issues and others, programmers rely on **testing frameworks** to make writing and executing automated tests as simple and reliable as possible.

The unittest module

The `unittest` module is the Python standard library's automated testing framework. It provides us with some powerful tools to make testing our code reasonably easy.

`unittest` is based on these standard unit testing concepts found in many test frameworks:

- **Test**: A **test** is a single method that will either finish or raise an exception. Tests generally focus on one unit of code, such as a function, method, or process. A test can either pass, meaning the test was successful; fail, meaning the code failed the test; or error, meaning the test itself encountered a problem
- **Test case**: A test case is a collection of tests which should be run together and contain similar setup and tear-down requirements, typically corresponding to a class or module. Test cases can have fixtures, which are items that need to be set up before each test and torn down after each test to provide a clean, predictable environment in which the test can run
- **Test suite**: A test suite is a collection of test cases which cover all the code for an application or module.
- **Mock**: A mock is an object that stands in for an external resource, such as a file or database. Mocks are patched over those resources during the test.

To explore these concepts in depth, let's test our `MyCalc` class using `unittest`.

Writing a test case

Let's create a test case for the `MyCalc` class in the `test_mycalc.py` as follows:

```
from mycalc import MyCalc
import unittest

class TestMyCalc(unittest.TestCase):
    def test_add(self):
        mc = MyCalc(1, 10)
        assert mc.add() == 11

if __name__ == '__main__':
    unittest.main()
```

The names of both your test modules and your test methods should be prefixed with `test_`. Doing so allows the `unittest` runner to automatically find test modules and distinguish test methods from other methods in your test case classes.

As you probably guessed, the `TestCase` class represents a test case. To make our test case for `MyCalc`, we subclass `TestCase` and start adding the `test_` methods to test various aspects of our class. Our `test_add()` method creates a `MyCalc` object, then makes an assertion about the output of `add()`. To run the test case, we add a call to `unittest.main()` at the end of the file.

If you run your test file at the command line, you should get the following output:

```
.
----------------------------------------------------------------------
Ran 1 test in 0.000s

OK
```

The single dot on the first line represents our test (`test_add()`). For each test method, `unittest.main()` will output a dot for passing, `F` for failure, or `E` for error. At the end, we get a summary of what happened.

To see what happens when a test fails, let's alter our test to be incorrect:

```
    def test_add(self):
        mc = mycalc.MyCalc(1, 10)
        assert mc.add() == 12
```

Now when you run the test module, you should see a failure as follows:

```
F
======================================================================
FAIL: test_add (__main__.TestMyCalc)
----------------------------------------------------------------------
Traceback (most recent call last):
  File "test_mycalc.py", line 8, in test_add
    assert mc.add() == 12
AssertionError
----------------------------------------------------------------------
Ran 1 test in 0.000s

FAILED (failures=1)
```

Note the single `F` at the top, representing our failed test. After all the tests have run, we get the full traceback of any failed tests, so that we can easily locate the failing code and correct it. This traceback output isn't very ideal, though; we can see that `mc.add()` didn't equal `12`, but we don't know what it was equal to. We could add a comment string to our `assert` call, but `unittest` provides a nicer method.

TestCase assertion methods

`TestCase` objects have a number of assertion methods that provide a cleaner and more robust way to run various tests on our code output.

For example, there is the `TestCase.assertEqual()` method to test equality, which we can use as follows:

```
    def test_add(self):
        mc = mycalc.MyCalc(1, 10)
        self.assertEqual(mc.add(), 12)
```

When we run our tests with this code, you can see that the traceback is improved:

```
Traceback (most recent call last):
  File "test_mycalc.py", line 11, in test_add
    self.assertEqual(mc.add(), 12)
AssertionError: 11 != 12
```

Now, we can see the value that `mc.add()` created, which is much more helpful for debugging. `TestCase` contains more than 20 assertion methods that can simplify testing for a variety of conditions such as class inheritance, raised exceptions, and sequence membership.

Some more commonly used ones are listed in the following table:

Method	**Tests**
`assertEqual(a, b)`	`a == b`
`assertTrue(a)`	`a` is `True`
`assertFalse(a)`	`a` is `False`
`assertIn(item, sequence)`	`item` is in `sequence`
`assertRaises(exception, callable, args)`	`callable` called with `args` raises `exception`
`assertGreater(a, b)`	`a` is greater than `b`

`assertLess(a, b)`	`a` is less than `b`

You can easily add your own custom assertion methods to your test case as well; it's simply a matter of creating a method that raises an `AssertionError` exception under some condition.

Let's use an assertion method to test that `mod_divide()` raises `ValueError` when `b` is `0`:

```
    def test_mod_divide(self):
        mycalc = mycalc.MyCalc(1, 0)
        self.assertRaises(ValueError, mycalc.mod_divide)
```

`assertRaises` passes if the function raises the given assertion when called. If we need to pass any arguments into the tested function, they can be specified as additional arguments to `assertRaises()`.

`assertRaises()` can also be used as a context manager like so:

```
        mycalc = MyCalc(1, 0)
        with self.assertRaises(ValueError):
            mycalc.mod_divide()
```

This code accomplishes the exact same thing, but is a little clearer and more flexible.

Fixtures

Rather than perform the tedious task of creating the `MyCalc` objects in every test, our `TestCase` object can have a `setUp()` method that automatically creates any resources our tests need.

For example, take a look at the following code:

```
    def setUp(self):
        self.mycalc1_0 = mycalc.MyCalc(1, 0)
        self.mycalc36_12 = mycalc.MyCalc(36, 12)
```

Now, every test case can use these objects to run its tests. The `setUp()` method will be rerun before every test, so these objects will always be reset between test methods. If we have items that need to cleaned up after each test, we can define a `tearDown()` method, which will be run after each test (in this case, it's not necessary).

Now, for example, our `test_add()` method can be much simpler:

```
    def test_add(self):
        self.assertEqual(self.mycalc1_0.add(), 1)
        self.assertEqual(self.mycalc36_12.add(), 48)
```

In addition to the instance methods `setUp()` and `tearDown()`, `TestCase` has class methods for setup and tear down as well, namely `setUpClass()` and `tearDownClass()`. These can be used for slower operations that can be run when the test case is created and destroyed, rather than needing to be refreshed between each test method.

Using Mock and patch

The `rand_between()` method generates a random number between `a` and `b`. Because we can't possibly predict its output, we can't provide a fixed value to test it against. How can we test this method?

A naive approach is as follows:

```
    def test_rand_between(self):
        rv = self.mycalc1_0.rand_between()
        self.assertLessEqual(rv, 1)
        self.assertGreaterEqual(rv, 0)
```

This test passes if our code is correct, but it doesn't necessarily fail if the code is wrong; in fact, if the code is wrong, it may pass or fail unpredictably. For example, if `MyCalc(1, 10).rand_between()` was incorrectly returning values between 2 and 11, there is only a 10% chance that the test would fail on each run.

We can safely assume that a standard library function such `random()` works correctly, so our unit test should really test whether our method correctly handles the number provided to it by `random()`. If we could temporarily replace `random()` with a function that returns a fixed value, it would be simple to test the correctness of our subsequent calculations.

The `unittest.mock` module provides us with the `Mock` class for this purpose. `Mock` objects can be used to predictably simulate the behavior of another class, method, or library. We can give our `Mock` objects return values, side effects, properties, methods, and other features needed to fake the behavior of another object, then drop it in place of that object before running our tests.

Let's create a fake `random()` function using `Mock` as follows:

```
from unittest.mock import Mock

#... inside TestMyCalc
    def test_rand_between(self):
        fakerandom = Mock(return_value=.5)
```

The `Mock` object's `return_value` argument allows us to hard code a value to be returned whenever it's called as a function. Here, `fakerandom` will always return `0.5`.

Now we can put `fakerandom` in place of `random()` as follows:

```
        orig_random = mycalc.random.random
        mycalc.random.random = fakerandom
        rv = self.mycalc1_0.rand_between()
        self.assertEqual(rv, 0.5)
        mycalc.random.random = orig_random
```

We start by saving a reference to `mycalc.random.random` before replacing it. Note that we're specifically replacing only the version of `random` being used in `mycalc.py` so that we don't affect `random` anywhere else. It's a best practice to be as specific as possible when patching libraries to avoid unforeseen side effects.

With `fakerandom` in place, we call our method and test the output. Because `fakerandom` will always return `0.5`, we know that the answer should be (0.5 × 1 + 0) or `0.5` when `a` is `1` and `b` is `0`. Any other value would indicate an error in our algorithm. Last of all, we revert `random` to the original function so that other tests don't accidentally use the mock.

Having to store or revert the original library each time is an annoyance we can do without, so `unittest.mock` provides a cleaner approach using `patch`. The `patch` command can be used as either a context manager or a decorator, and either approach makes patching a `Mock` object into our code much cleaner.

Using our mock `random()` using `patch` as a context manager looks like this:

```
from unittest.mock import patch

    #... inside TestMyCalc
    def test_rand_between(self):
       with patch('mycalc.random.random') as fakerandom:
            fakerandom.return_value = 0.5
            rv = self.mycalc1_0.rand_between()
            self.assertEqual(rv, 0.5)
```

`The patch()` command takes an import path string and provides us with a `Mock` object that it has patched in. We can set methods and properties on the

`Mock` object and run our actual tests in the block, and the patched library will be reverted when the block ends.

Using `patch()` as a decorator is similar:

```
    @patch('mycalc.random.random')
    def test_rand_between2(self, fakerandom):
        fakerandom.return_value = 0.5
        rv = self.mycalc1_0.rand_between()
        self.assertEqual(rv, 0.5)
```

In this case, the mock object created by `patch` is passed as an argument to our test method and will remain patched for the duration of the decorated function.

Running multiple unit tests

While we can run our unit tests by including a call to `unittest.main()` at the end, that approach doesn't scale well. As our application grows, we're going to write many test files, which we'll want to run in groups or all at once.

Fortunately, `unittest` can discover and run all tests in a project with one command:

```
python -m unittest
```

So long as you have followed the recommended naming scheme of prefixing your test modules with `test_`, running this command in your project's root directory should run all your tests.

Testing Tkinter code

Testing Tkinter code presents us with a few particular challenges. First, Tkinter handles many callbacks and methods **asynchronously**, meaning that we can't count on the results of some code to be apparent immediately. Also, testing GUI behaviors often relies on external factors such as window management or visual cues that our tests cannot detect.

We're going to learn some tools and strategies that will help you craft tests for your Tkinter code.

Managing asynchronous code

Whenever you interact with a Tkinter UI—whether it's clicking a button, typing in a field, or raising a window, for example—the response is not executed immediately in-place. Instead, these actions are placed in a to-do list, called an **event queue**, to be handled later while your code execution continues. While these actions seem instant to users, test code cannot count on a requested action being completed before the next line of code.

To solve this problem, we can use these special widget methods that allow us to manage the event queue:

- `wait_visibility()`: This method causes the program to wait until a widget is fully drawn on-screen before executing the next line of code.
- `update_idletasks()`: This method forces Tkinter to process any idle tasks currently outstanding on the widget. Idle tasks are low-priority tasks such as drawing and rendering.
- `update()`: This method forces Tkinter to process all events which are outstanding on a widget, including calling callbacks, redraws, and geometry management. It includes everything that `update_idletasks()` does and more.

The event queue will be discussed in more detail in `Chapter 13`, *Asynchronous Programming with Thread and Queue*.

Simulating user actions

When automating GUI tests, we may wish to know what happens when a user clicks on a certain widget, or types a certain keystroke. When these actions happen in the GUI, Tkinter generates an `Event` object for the widget and passes it to the event queue. We can do the same thing in code, using a widget's `event_generate()` method.

Specifying an event sequence

To create an event with `event_generate()`, we need to pass in an event sequence string, in the format `<EventModifier-EventType-EventDetail>`.

Event type specifies the kind of event we're sending, such as a keystroke, mouse click, windowing event, and so on.

Tkinter has around 30 event types, but you will typically only need to work with the following:

Event types	Description
`ButtonPress`	Also `Button`, represents a mouse button click
`ButtonRelease`	Represents lifting off a mouse button
`KeyPress`	Also `Key`, represents pressing a keyboard key
`KeyRelease`	Represents lifting off a keyboard key
`FocusIn`	Represents giving focus to a widget
`FocusOut`	Represents exiting a widget
`Enter`	Represents the mouse cursor entering a widget
`Leave`	Represents the mouse cursor moving off a widget
`Configure`	Called when the widget's configuration changes, either by a `.config()` call or user action (resize, for example)

Event modifiers are optional words that can alter the event type; for example, `Control`, `Alt`, and `Shift` can be used to indicate that one of those modifier keys is held down; `Double` or `Triple` can be used to indicate a double or triple click of the described button. Multiple modifiers can be strung together if required.

Event detail, only valid for keyboard or mouse events, describes which key or button was pressed. For example, `<Button-1>` refers to the left mouse button, while `<Button-3>` refers to the right. For letter and number keys, the literal letter or number can be used; most symbols, however, are described by a word (`minus`, `colon`, `semicolon`, and so on) to avoid syntactic clashes.

For button presses and key presses, the event type is technically optional; however, it's probably a good idea to leave it in for the sake of clarity. For example, `<1>` is a valid event, but does it refer to the left mouse button or typing the `1` key? You may be surprised to find that it's the mouse button.

The following table shows some examples of valid event sequences:

Sequence	**Meaning**
`<Double-Button-3>`	Double-clicking the right mouse button
`<Alt-KeyPress-exclam>`	Holding `Alt` and typing an exclamation point
`<Control-Alt-Key-m>`	Holding `Control` and `Alt` and pressing the `m` key
`<KeyRelease-minus>`	Lifting off a pressed minus key

In addition to the sequence, we can pass other arguments to `event_generate()` which describe various aspects of the event. Many of these are redundant, but, in some cases, we need to provide extra information for the event to have any meaning; for example, mouse button events need to include the `x` and `y` arguments that specify the coordinates of the click.

Managing focus and grab

Focus refers to the widget or window which is currently receiving keyboard input. Widgets can also grab focus, preventing mouse movements or keystrokes outside their bounds.

Tkinter gives us these widget methods for managing focus and grab, some of which are useful for running tests:

Method	Description
`focus_set()`	Focuses the widget whenever its window next gains focus
`focus_force()`	Focuses a widget and the window it's in, immediately
`grab_set()`	The widget grabs all events for the application
`grab_set_global()`	The widget grabs all screen events
`grab_release()`	The widget relinquishes its grab

In a test environment, we can use these methods to make sure that our generated keyboard and mouse events are going to the correct widget or window.

Getting widget information

Tkinter widgets have a set of `winfo_` methods that give us access to information about the widget. While this set of methods leaves much to be desired, it does provide a few methods we can use in tests to provide feedback about the state of a given widget.

The following are a few `winfo_` methods that we will find useful:

Method	Description
`winfo_height()`, `winfo_width()`	Get the height and width of the widget
`winfo_children()`	Get a list of child widgets
`winfo_geometry()`	Get the size and location of the widget
`winfo_ismapped()`	Determine whether the widget is mapped, meaning it's been added to a layout using `pack()` or `grid()`, for instance
`winfo_viewable()`	Determine whether a widget is viewable, meaning it and all its parents have been mapped
`winfo_x()`, `winfo_y()`	Get the `x` or `y` coordinate of the widget's top left corner

Writing tests for our application

Let's put our knowledge of `unittest` to work and write some tests for our application. To get started, we need to create a test module for our application. Make a directory called `test` inside the `abq_data_entry` package, and create the customary empty `__init__.py` file inside. We'll create all of our test modules inside this directory.

Testing our model

Our `CSVModel` code is fairly self-contained apart from its need to read and write files. Since file operations are one of the more common things that need to be mocked out in a test, the `mock` module provides `mock_open`, a `Mock` subclass ready-made to replace Python's `open` method. When called, a `mock_open` object returns a `mock` file handle object, complete with support for the `read()`, `write()`, and `readlines()` methods.

Let's begin creating our test case class in `test/test_models.py` as follows:

```
from .. import models
from unittest import TestCase
from unittest import mock

class TestCSVModel(TestCase):
    def setUp(self):
        self.file1_open = mock.mock_open(
            read_data=(
                "Date,Time,Technician,Lab,Plot,Seed sample,Humidity,Light,"
                "Temperature,Equipment Fault,Plants,Blossoms,Fruit,"
                "Min Height,Max Height,Median Height,Notes\r\n"
                "2018-06-01,8:00,J Simms,A,2,AX478,
                 24.47,1.01,21.44,False,14,"
                "27,1,2.35,9.2,5.09,\r\n"
                "2018-06-01,8:00,J Simms,A,3,AX479,
                24.15,1,20.82,False,18,49,"
                "6,2.47,14.2,11.83,\r\n"))
        self.file2_open = mock.mock_open(read_data='')
        self.model1 = models.CSVModel('file1')
        self.model2 = models.CSVModel('file2')
```

The `mock_open` and `read_data` arguments allows us to specify a string that will be returned when its file handle is read. We've created two `mock_open` objects, one containing a CSV header and two lines of data, and the other containing nothing.

We've also created two `CSVModel` objects, one with a filename of `file1` and the other with a filename of `file2`. It's worth mentioning that there's no actual connection between our models and our `mock_open` objects. The choice of the `mock_open` object, rather than the filename, will determine what data will be returned

Testing file reading in get_all_records()

To see how we use these, let's start a test for the `get_all_records()` method as follows:

```
    @mock.patch('abq_data_entry.models.os.path.exists')
    def test_get_all_records(self, mock_exists):
        mock_exists.return_value = True
```

Since our filenames don't actually exist, we're using the decorator version of `patch` to patch `os.path.exists` with a mock function that always returns `True`. We can later change the `return_value` value if we want to test a scenario where the file doesn't exist.

To run the `get_all_records()` method, we'll use the context manager form of `patch()` as follows:

```
        with mock.patch('abq_data_entry.models.open', self.file1_open):
            records = self.model1.get_all_records()
```

Any call to `open()` inside the `models.py` file which has been initiated inside the context manager block will be replaced by our `mock_open` object, and the file handle returned will contain `read_data` we specified. However, before we can go on, there's an unfortunate shortcoming in `mock_open` that we'll need to work around. While it implements most file methods, it doesn't implement the iterator methods that the `csv` library requires to read data from the file handler.

A slight alteration to our `models.py` code will fix this:

```
    def get_all_records(self):
        ...
        with open(self.filename, 'r', encoding='utf-8') as fh:
            csvreader = csv.DictReader(list(fh.readlines()))
```

Instead of simply passing `fh` into `DictReader`, we need to call `readlines()` and cast it to `list`. This won't affect the program in any way, but it will allow `mock_open()` to work correctly.

There's nothing wrong with making adjustments to your code to accommodate tests; in many cases, the code will even be better for it! However, if you make an unintuitive change such as the previous one, be sure to add a comment to your code to explain why. Otherwise, someone is likely to factor it out at some point in the future.

Now we can start making assertions about the records which have been returned:

```
        self.assertEqual(len(records), 2)
        self.assertIsInstance(records, list)
        self.assertIsInstance(records[0], dict)
```

Here, we're checking that `records` contains two lines (since our read data contained two `csv` records), that it's a `list` object, and that its first member is a `dict` object (or subclass of `dict`).

Next, let's make sure all our fields made it through and that our Boolean conversion worked:

```
        fields = (
           'Date', 'Time', 'Technician', 'Lab', 'Plot',
           'Seed sample', 'Humidity', 'Light',
           'Temperature', 'Equipment Fault', 'Plants',
           'Blossoms', 'Fruit', 'Min Height', 'Max Height',
           'Median Height', 'Notes')
        for field in fields:
            self.assertIn(field, records[0].keys())
        self.assertFalse(records[0]['Equipment Fault'])
```

By iterating a tuple of all our field names, we can check that all our fields are present in the record output. Don't be afraid to use loops in a test this way to check a large amount of content quickly.

A `Mock` object can do more than just stand in for another class or function; it also has its own assertion methods that can tell us if it's been called, how many times, and with what arguments.

For example, we can check our `mock_open` object to make sure it was called with the expected arguments:

```
        self.file1_open.assert_called_with('file1', 'r', encoding='utf-8')
```

`assert_called_with()` takes a set of arguments and checks if the last call to the `mock` object used those arguments. We expected `file1_open` to be called with the filename `file1`, a mode of `r`, and an encoding of `utf-8`. By confirming that a mocked function was called with the correct arguments, and assuming the correctness of the real function (the built-in `open()` function, in this case), we can avoid having to test the actual outcome.

Testing file saving in save_record()

To demonstrate how to test file-writing with `mock_open`, let's test `save_record()`:

```
    @patch('abq_data_entry.models.os.path.exists')
    def test_save_record(self, mock_exists):
```

To test the conversion from a `dict` to a `csv` string, we'll need a sample record in both formats:

```
        record = {
            "Date": '2018-07-01', "Time": '12:00',
            "Technician": 'Test Tech', "Lab": 'E',
             "Plot": '7', "Seed sample": 'test',
            "Humidity": '10', "Light": '99',
            "Temperature": '20', "Equipment Fault": False,
            "Plants": '10', "Blossoms": '200', "Fruit": '250',
            "Min Height": '40', "Max Height": '50',
            "Median Height": '55', "Notes": 'Test Note\r\nTest Note\r\n'}
        record_as_csv = (
            '2018-07-01,12:00,Test Tech,E,17,test,10,99,20,False,'
            '10,200,250,40,50,55,"Test Note\r\nTest Note\r\n"\r\n')
```

You may be tempted to generate either the record or its expected output using code, but it's always better to stick to literals in tests; doing so makes the expectations of the test explicit and avoids logic errors in your tests.

For our first scenario, let's simulate writing to an empty but existing file by using `file2_open` and `model2` as follows:

```
        mock_exists.return_value = True
        with patch('abq_data_entry.models.open', self.file2_open):
            self.model2.save_record(record, None)
```

Setting our `mock_exists.return_value` to `True` to tell our method that the file already exists, we then patch over `open()` with our second `mock_open` object and call the `save_record()` method. Since we passed in a record with no row number (which indicates a record insert), this should result in our code trying to open `file2` in append mode and writing in the CSV-formatted record.

`assert_called_with()` will test that assumption as follows:

```
            self.file2_open.assert_called_with('file2', 'a',
                encoding='utf-8')
```

`file2_open` can tell us that it was called with the expected parameters, but how do we access its file handler so that we can see what was written to it?

It turns out we can just call our `mock_open` object and retrieve the `mock` file handle object:

```
            file2_handle = self.file2_open()
            file2_handle.write.assert_called_with(record_as_csv)
```

Once we have the `mock` file handle (which is itself a `Mock`), we can run test methods on it to find out if it was called with the CSV data as expected. In this case, the file handle's `write` method should have been called with the CSV-format record string.

Let's do a similar set of tests, passing in a row number to simulate a record update:

```
        with patch('abq_data_entry.models.open', self.file1_open):
            self.model1.save_record(record, 1)
            self.file1_open.assert_called_with('file1', 'w',
            encoding='utf-8')
```

Checking that our update was done correctly presents a problem: `assert_called_with()` only checks the last call made to the mock function. When we update our CSV file, the entire CSV file is updated, with one `write()` call per row. We can't just check that the last call was correct; we need to make sure the `write()` calls for all the rows were correct. To accomplish this, `Mock` provides us with `assert_has_calls()`, to which we can pass a list of `Call` objects to compare against the object's call history.

We create `Call` objects using the `mock.call()` function as follows:

```
            file1_handle = self.file1_open()
            file1_handle.write.assert_has_calls([
                mock.call('Date,Time,Technician,Lab,Plot,Seed sample,'
                     'Humidity,Light,Temperature,Equipment Fault,'
                     'Plants,Blossoms,Fruit,Min Height,Max Height,'
                     'Median Height,Notes\r\n'),
                mock.call('2018-06-01,8:00,J Simms,A,2,AX478,24.47,1.01,'
                    '21.44,False, '14,27,1,2.35,9.2,5.09,\r\n'),
                mock.call('2018-07-01,12:00,Test Tech,E,17,test,10,99,20,'
                    'False,10,200,250,'40,50,55,'
                    '"Test Note\r\nTest Note\r\n"\r\n')
            ])
```

The arguments to `call()` represent the arguments that were passed to the function call. The list of `Call` objects we pass to `assert_has_calls()` represents each call that should have been made to `write()` in order. The keyword argument `in_order` can also be set to `False`, in which case the order won't need to match. In this case, order matters, since a wrong order would result in a corrupt CSV file.

More tests

Testing the remainder of the `CSVModel` class and the `SettingsModel` class methods should be essentially along the same lines as these two methods. A few more tests are included in the sample code, but see if you can come up with some of your own as well.

Testing our application

We've implemented our application as a `Tk` object that acts not only as a main window but as a controller, patching together models and views defined elsewhere in the application. As you may expect, `patch()` is going to figure heavily into our testing code as we mock out all of those other components to isolate `Application`. Let's take a look at how this is done:

1. In a new file called `test_application.py`, import `unittest` and `application`. Now start a test case as follows:

```
        class TestApplication(TestCase):
            records = [
                {'Blossoms': '21', 'Date': '2018-06-01',
                 'Equipment Fault': 'False', 'Fruit': '3,
                 'Humidity': '24.09', 'Lab': 'A', 'Light': '1.03',
                 'Max Height': '8.7', 'Median Height': '2.73',
                 'Min Height': '1.67','Notes': '\n\n', 'Plants': '9',
                 'Plot': '1', 'Seed sample': 'AX477',
                 'Technician': 'J Simms', 'Temperature': '22.01',
                 'Time': '8:00'},
                {'Blossoms': '27', 'Date': '2018-06-01',
                 'Equipment Fault': 'False', 'Fruit': '1',
                 'Humidity': '24.47', 'Lab': 'A', 'Light': '1.01',
                 'Max Height': '9.2', 'Median Height': '5.09',
                 'Min Height': '2.35', 'Notes': '', 'Plants': '14',
                 'Plot': '2', 'Seed sample': 'AX478',
                 'Technician': 'J Simms', 'Temperature': '21.44',
                 'Time': '8:00'}]
            settings = {
                'autofill date': {'type': 'bool', 'value': True},
                'autofill sheet data': {'type': 'bool', 'value': True},
                'font size': {'type': 'int', 'value': 9},
                'theme': {'type': 'str', 'value': 'default'}}
```

   Our `TestApplication` class will be using mocks in place of our data and settings models, so we've created some class properties to store samples of the data which `Application` expects to retrieve from those models. The `setUp()` method is going to patch out all the external classes with mocks, configure the mocked models to return our sample data, and then create an `Application` instance that our tests can use.

2. Let's start by using `patch()` as a context manager to replace all the external resources as follows:

```
        def setUp(self):
            with \
                patch('abq_data_entry.application.m.CSVModel')\
                    as csvmodel,\
                patch('abq_data_entry.application.m.SettingsModel') \
                    as settingsmodel,\
                patch('abq_data_entry.application.v.DataRecordForm'), \
                patch('abq_data_entry.application.v.RecordList'),\
                patch('abq_data_entry.application.get_main_menu_for_os')\
              :
```

Here, we've created a `with` block using five `patch()` context managers, one for each library we're mocking out. Notice that we're only creating aliases for the model mocks, since we'll want to do some extra configuration on them. The view mocks won't really need to do much except be imported or called, and we can access them as properties of our `Application` object anyway.

Since Python 3.2, you can create a block with multiple context managers by separating each context manager call with a comma. Unfortunately, you can't put them in parenthesis, so we're using the comparatively ugly escaped-newline method of breaking this gigantic call into multiple lines.

3. Inside the block, we'll need to configure our model mocks to return the appropriate data as follows:

```
                settingsmodel().variables = self.settings
                csvmodel().get_all_records.return_value = self.records
```

Notice that we're instantiating our `settingsmodel` and `csvmodel` objects and configuring methods on the return values rather than the mocks themselves. Remember that our mocks are replacing the *classes*, not the *objects*, and it is the objects which will contain the methods our `Application` object will be calling. Therefore, we need to call them to access the actual `Mock` object that will be used by `Application` as the data or settings model.

Unlike the actual class that it stands in for, a `Mock` object called as a function will return the same object every time it's called. Thus, we don't have to save a reference to the object created by calling a mocked class; we can just call the mocked class repeatedly to access that object. Note, however, that the `Mock` class will return a unique `Mock` object each time.

4. This takes care of our mocks, so let's create an `Application` object:

```
        self.app = application.Application()
```

5. Because `Application` is a subclass of Tk, it's a good idea for us to safely dispose of it after each use; even though we're reassigning its variable name, it will go on existing and cause problems with our tests. To solve this, create a `tearDown()` method:

```
    def tearDown(self):
        self.app.update()
        self.app.destroy()
```

   Notice the call to `app.update()`. If we don't call this before destroying `app`, there may be tasks in the event queue that will try to access it after it's gone. This won't break our code, but it will clutter up our test output with error messages.

6. Now that our fixtures are taken care of, let's write a test:

```
    def test_show_recordlist(self):
        self.app.show_recordlist()
        self.app.update()
        self.app.recordlist.tkraise.assert_called()
```

   `Application.show_recordlist()` contains one line of code, which is merely a call to `recordlist.tkraise()`. Because we made `recordlist` a mock object, `tkraise` is also a mock object, and we can check to see that it was called. `assert_called()` merely checks that a method was called, without checking arguments, which is appropriate in this case because `tkraise()` takes none.

7. We can use a similar technique to check `populate_recordlist()` as follows:

```
    def test_populate_recordlist(self):
        self.app.populate_recordlist()
        self.app.data_model.get_all_records.assert_called()
        self.app.recordlist.populate.assert_called_with(self.records)
```

8. Under some circumstances, `get_all_records()` can raise an exception, in which case we're supposed to show an error message box. But since we've mocked out our data model, how can we get it to raise an

exception? The solution is to use mock's `side_effect` property as follows:

```
self.app.data_model.get_all_records.side_effect =
Exception('Test message')
```

`side_effect` can be used to simulate more complex functionality in a mocked callable. It can be set to a function, in which case the mock will run that function and return the results when called; it can be set to an iterable, in which case the mock will return the next item in the iterable each time it's called; or, as in this case, it can be set to an exception, which will be raised when the mock is called.

9. Before we can use this, we'll need to patch out `messagebox` as follows:

```
with patch('abq_data_entry.application.messagebox'):
    self.app.populate_recordlist()
    application.messagebox.showerror.assert_called_with(
        title='Error', message='Problem reading file',
        detail='Test message')
```

10. This time when we call `populate_recordlist()`, it throws an exception, prompting the method to call `messagebox.showerror()`. Since we've mocked `showerror()`, we can assert that it was called with the expected arguments.

Clearly, the hardest part of testing our `Application` object is patching in all the mocked components and making sure they behave enough like the real thing to satisfy `Application`. Once we've done that, writing the actual tests is fairly straightforward.

Testing our widgets

So far, we've done well with `patch`, `Mock`, and the default `TestCase`, but testing our widgets module is going to present some new challenges. To begin with, our widgets will need a `Tk` instance to be their root window. We can create this in each case's `setUp()` method, but this will slow down the tests considerably, and it isn't really necessary; our tests aren't going to modify the root window, so one root window will suffice for each test case. We can take advantage of the `setUpClass()` method to create a single instance of Tk just once at class instantiation. Secondly, we have a large number of widgets to test, which means we have a large number of test cases requiring the same boilerplate `Tk()` setup and tear down.

To address this, let's start our `test_widgets.py` module with a custom `TestCase` class as follows:

```
class TkTestCase(TestCase):
    """A test case designed for Tkinter widgets and views"""
    @classmethod
    def setUpClass(cls):
        cls.root = tk.Tk()
        cls.root.wait_visibility()

    @classmethod
    def tearDownClass(cls):
        cls.root.update()
        cls.root.destroy()
```

The `setUpClass()` method creates the `Tk()` object and calls `wait_visibility()` just to make sure our window is visible before our tests start working with it. Just as we did with our `Application` test, we also supply a complimentary tear-down method that updates the Tk instance and destroys it.

Unit testing the ValidatedSpinbox widget

`ValidatedSpinbox` is one of the more complicated widgets we created for our application, so it's a good place to start writing tests.

Subclass the `TkTestCase` class to create a test case for `ValidatedSpinbox` as follows:

```
class TestValidatedSpinbox(TkTestCase):

    def setUp(self):
        self.value = tk.DoubleVar()
        self.vsb = widgets.ValidatedSpinbox(
            self.root,
            textvariable=self.value,
            from_=-10, to=10, increment=1)
        self.vsb.pack()
        self.vsb.wait_visibility()

    def tearDown(self):
        self.vsb.destroy()
```

Our setup method creates a variable in which to store the widget's value, then creates an instance of the `ValidatedSpinbox` widget with some basic settings: a minimum value of -10, a maximum of 10, and an increment of 1. After creating it, we pack it and wait for it to become visible. For our tear-down method, we simply destroy the widget.

There are a couple of approaches we can take in testing our widget. The first approach is a unit testing-oriented approach, in which we focus on the actual method code, simply mocking out any external functionality.

Let's try that with the `_key_validate()` method as follows:

```
    def test__key_validate(self):
        # test valid input
        for x in range(10):
            x = str(x)
            p_valid = self.vsb._key_validate(x, 'end', '', '', x, '1')
            n_valid = self.vsb._key_validate(
                x, 'end', '-', '-' + x, '1')
            self.assertTrue(p_valid)
            self.assertTrue(n_valid)
```

We're simply iterating from 0 to 9 and testing both the positive and negative of the number against `_key_validate()`, which should return `True` for all of these values. The `_key_validate()` method takes a lot of positional arguments, and most of them are redundant; it might be nice to have a wrapper method that makes it easier to call, since our test case is potentially going to call it dozens of times.

Let's call that method `key_validate()` and add it to our `TestValidatedSpinbox` class as follows:

```
    def key_validate(self, new, current=''):
        # args are inserted char, insertion index, current value,
        # proposed value, and action code (where '1' is 'insert')
        return self.vsb._key_validate(new, 'end', current,
        current + new, '1')
```

This will make future calls to the method shorter and less error-prone.

Let's use it now to test some invalid input as follows:

```
        # test letters
        valid = self.key_validate('a')
        self.assertFalse(valid)

        # test non-increment number
        valid = self.key_validate('1', '0.')
        self.assertFalse(valid)

        # test too high number
        valid = self.key_validate('0', '10')
        self.assertFalse(valid)
```

In the first example, we're entering `a`; in the second, `1` when `0.` is already in the box, resulting in `0.1`; in the third, `0` when `10` is in the box, resulting in `100`. All of these scenarios should fail the validation method.

Integration testing the ValidatedSpinbox widget

In the preceding tests, we weren't actually entering any data into the widget; we were simply calling the key validation method directly and evaluating its output. This is good unit testing, but it isn't quite satisfying as a test of this code. Since our custom widget is so deeply dependent on Tkinter's validation API, we'd like to test that we've actually implemented this API correctly. After all, that aspect of the code was more challenging than the actual logic in our validation methods.

We can accomplish this by creating some integration tests that simulate actual user actions and then check the results of those actions. To do this cleanly, we'll first need to create some supporting methods.

Start by adding a new method to the `TkTestCase` class as follows:

```
    def type_in_widget(self, widget, string):
        widget.focus_force()
        for char in string:
            char = self.keysyms.get(char, char)
```

This class will take a widget and a string and attempt to simulate a user typing the string into the widget. The first thing we do is force the focus to the widget; we need to use `focus_force()` because our test Tk window is unlikely to be in focus when the test is being run.

Once we have focus, we'll iterate through the characters in the string and translate the raw character into the appropriate key symbols for our event sequence. Recall that some characters, particularly symbols, must be represented as strings, such as `minus` or `colon`.

To make this work, we'll need a class property called `dict` to translate between characters and their key symbols as follows:

```
keysyms = {'-': 'minus', ' ': 'space', ':': 'colon', ...}
```

More key symbols can be found at `http://www.tcl.tk/man/tcl8.4/TkCmd/keysyms.htm` *, but these should do for now.*

Once our character is translated to the appropriate key symbol, we can create our event sequences and generate our key events. Back in the `type_in_widget()` method, we can create and call a key event sequence as follows:

```
        self.root.update()
        widget.event_generate('<KeyPress-{}>'.format(char))
        self.root.update()
```

Note that we call `self.root.update()` both before and after generating the keypress event. This ensures the widget is prepared for input, and that the inputs register after being generated. `update_idletasks()` will not do here, by the way; try it and you'll find that the tests will fail.

We can create a similar method for simulating mouse button clicks as follows:

```
    def click_on_widget(self, widget, x, y, button=1):
        widget.focus_force()
        self.root.update()
        widget.event_generate("<ButtonPress-{}>".format(button),
        x=x, y=y)
        self.root.update()
```

Just as we did with our keystroke method, we first force focus, update the application, generate our events, then update again. In this method, however, we also need to specify the `x` and `y` coordinates for the mouse click. These are coordinates relative to the upper-left corner of the widget. We can also specify a button number, but we'll default to the left button (`1`).

With these methods in place, return to `TestValidatedSpinbox` and write a new test:

```
    def test__key_validate_integration(self):
        self.vsb.delete(0, 'end')
        self.type_in_widget(self.vsb, '10')
        self.assertEqual(self.vsb.get(), '10')
```

This method starts by clearing the widget, then simulates some valid input with `type_in _widget()` and checks that it was accepted by the widget. Note that in these integration tests we'll need to clear the widget each time because we are simulating keystrokes in an actual widget and triggering all the side effects of that action.

Next, let's test some invalid input by executing the following code:

```
        self.vsb.delete(0, 'end')
        self.type_in_widget(self.vsb, 'abcdef')
        self.assertEqual(self.vsb.get(), '')

        self.vsb.delete(0, 'end')
        self.type_in_widget(self.vsb, '200')
        self.assertEqual(self.vsb.get(), '2')
```

We can use our mouse click method to test the functionality of the `Spinbox` arrow buttons as well. To make this simpler, let's create a helper method in our test case class to click on the arrow we want. Add this to `TestValidatedSpinbox`:

```
    def click_arrow(self, arrow='inc', times=1):
        x = self.vsb.winfo_width() - 5
        y = 5 if arrow == 'inc' else 15
        for _ in range(times):
            self.click_on_widget(self.vsb, x=x, y=y)
```

We can target the increment arrow by clicking `5` pixels from the right and `5` from the top of the widget. The decrement arrow can be found at `5` pixels from the right and `15` from the top. This may need some adjustment depending on the theme or screen settings, of course. Now, we can test our arrow key functionality easily as follows:

```
    def test_arrows(self):
        self.value.set(0)
        self.click_arrow(times=1)
        self.assertEqual(self.vsb.get(), '1')

        self.click_arrow(times=5)
        self.assertEqual(self.vsb.get(), '6')

        self.click_arrow(arrow='dec', times=1)
        self.assertEqual(self.vsb.get(), '5')
```

By setting the value of the widget, then clicking the appropriate arrow a specified number of times, we can test that the arrows did their jobs according to the rules of our widget class.

Testing our mixin class

One additional challenge we haven't approached yet is testing our mixin class. Unlike our other widget classes, our mixin cannot really exist on its own: it depends on methods and properties found in the `ttk` widget which it's combined with.

One approach to testing this class would be to mix it with a `Mock` object which mocks out any inherited methods. This approach has merit, but a simpler (if less ideal) approach is to subclass it with the simplest possible `ttk` widget and test the resulting child class.

That approach looks like this:

```
class TestValidatedMixin(TkTestCase):

    def setUp(self):
        class TestClass(widgets.ValidatedMixin, ttk.Entry):
            pass
        self.vw1 = TestClass(self.root)
```

Here, we've created just a basic child class using `ttk.Entry` and modified nothing else. Then, we created an instance of the class.

Let's test our `_validate()` method as follows:

```
    def test__validate(self):
        args = {'proposed': 'abc', 'current': 'ab', 'char': 'c',
        'event': 'key', 'index': '2', 'action': '1'}
        self.assertTrue(self.vw1._validate(**args))
```

Because we're sending a key event to `_validate()`, it routes the request to `_key_validate()`, which simply returns `True` by default. We'll need to verify that `_validate()` does what is needed when `_key_validate()` returns `False` as well.

We'll employ `Mock` to do this:

```
        fake_key_val = Mock(return_value=False)
        self.vw1._key_validate = fake_key_val
        self.assertFalse(self.vw1._validate(**args))
        fake_key_val.assert_called_with(**args)
```

We test that `False` is returned and that `_key_validate` was called with the correct arguments.

By updating the `event` value in `args`, we can check that `focusout` events also work:

```
        args['event'] = 'focusout'
        self.assertTrue(self.vw1._validate(**args))
        fake_focusout_val = Mock(return_value=False)
        self.vw1._focusout_validate = fake_focusout_val
        self.assertFalse(self.vw1._validate(**args))
        fake_focusout_val.assert_called_with(event='focusout')
```

We've taken an identical approach here, just mocking out `_focusout_validate()` to make it return `False`.

As you can see, once we've created our test class, testing `ValidatedMixin` is like testing any other widget class. There are other test method examples in the included source code; these should be enough to get you started with creating a complete test suite.

Summary

In this chapter, we learned about automated testing and the capabilities provided by Python's `unittest` library. We wrote both unit tests and integration tests against portions of our application, and you learned methods for tackling a variety of testing challenges.

In the next chapter, we'll upgrade our backend to use a relational database. You'll also learn about relational databases, SQL, and database normalization. You'll learn to work with the PostgreSQL database server and Python's `psycopg2` PostgreSQL interface library.

Improving Data Storage with SQL

As weeks have passed by, there is a growing problem at the lab: the CSV files are everywhere! Conflicting copies, missing files, records getting changed by non-data entry staff, and other CSV-related frustrations are plaguing the project. It's clear that individual CSV files are not working out as a way to store data for the experiments. Something better is needed.

The facility has an older Linux server with a PostgreSQL database installed. You've been asked to update your program so that it stores data in the PostgreSQL database rather than in the CSV files. This promises to be a major update to your application!

In this chapter, you'll learn the following topics:

- Installing and configuring the PostgreSQL database system
- Structuring data in a database for good performance and reliability
- The basics of SQL queries
- Using the `psycopg2` library to connect your program to PostgreSQL

PostgreSQL

PostgreSQL (usually pronounced post-gress) is a free, open source, cross-platform relational database system. It runs as a network service with which you can communicate using client programs or software libraries. At the time of writing, the project has just released version 10.0.

Although ABQ has provided a PostgreSQL server which is already installed and configured, you'll need to download and install the software on your workstation for development purposes.

Shared production resources such as databases and web services should never be used for testing or development. Always set up a separate development copy of these resources on your own workstation or a separate server machine.

Installing and configuring PostgreSQL

To download PostgreSQL, visit `https://www.postgresql.org/download/`. Installers are provided for Windows, macOS, and Linux by the EnterpriseDB company, a commercial entity that provides paid support for PostgreSQL. These packages include the server, command-line client, and pgAdmin graphical client all in one package.

To install the software, launch the installer using an account with administrative rights and follow the screens in the installation wizard.

Once installed, launch pgAdmin and create a new admin user for yourself by selecting Object | Create | Login/Group Role. Make sure to visit the Privileges tab to check Superuser, and the Definition tab to set a password. Then, create a database by selecting Object | Create | Database. Make sure to set your user as an owner. To run SQL commands on your database, select your database and click Tools | Query Tool.

MacOS or Linux users who prefer the command line can also use the following these commands:

```
sudo -u postgres createuser -sP myusername
sudo -u postgres createdb -O myusername mydatabasename
psql -d mydatabasename -U myusername
```

Although Enterprise DB provides binary installers for Linux, most Linux users will prefer to use packages supplied by their distribution. You may end up with a slightly older version of PostgreSQL, but that won't matter for most basic use cases. Be aware that pgAdmin is usually part of a separate package, and that the latest version (pgAdmin 4) may not be available. Regardless, you should have no trouble following this chapter with the older version.

Connecting with psycopg2

To make SQL queries from our application, we'll need to install a Python library that can talk directly to our database. The most popular choice is `psycopg2`. The `psycopg2` library is not a part of the Python standard library. You can find the most current installation instructions at `http://initd.org/psycopg/docs/install.html`; however, the preferred method is to use `pip`.

For Windows, macOS, and Linux, the following command should work:

```
pip install --user psycopg2-binary
```

If that doesn't work, or if you'd rather install it from the source, check the requirements on the website. The `psycopg2` library is written in C, not Python, so it requires a C compiler and a few other development packages. Linux users can usually install `psycopg2` from their distribution's package management system. We'll get in-depth with the use of `psycopg2` later in the chapter.

SQL and relational database basics

Before we can start using PostgreSQL with Python, you'll need to have at least a basic understanding of SQL. If you already have one, you can skip to the next section; otherwise, brace yourself for a super-short crash course on relational databases and SQL.

For over three decades, relational database systems have remained a de-facto standard for storing business data. They are more commonly known as **SQL databases**, after the **Structured Query Language** (**SQL**) used to interact with them.

SQL databases are made up of tables. A table is something like our CSV file, in that it has rows representing individual items and columns representing data values associated with each item. A SQL table has some important differences from our CSV file. First, each column in the table is assigned a data type which is strictly enforced; just as Python will produce an error when you try to use `abcd` as an `int`, a SQL database will complain if you try to insert letters into a numeric or other non-string column. SQL databases typically support data types for text, numbers, dates and times, boolean values, binary data, and more.

SQL tables can also have constraints, which further enforce the validity of data inserted into the table. For example, a column can be given a unique constraint, which prevents two rows having the same value, or a not null constraint, which means that every row must have a value.

SQL databases commonly contain many tables; these tables can be joined together to represent much more complicated data structures. By breaking data into multiple linked tables, it can be stored in a way that is much more efficient and resilient than our two-dimensional plaintext CSV files.

Basic SQL operations

SQL is a powerful and expressive language for doing mass manipulations of tabular data, but the basics can be grasped quickly. SQL is executed as individual queries which either define or manipulate data in the database. SQL dialects vary somewhat between different relational database products, but most of them support ANSI/ISO-standard SQL for core operations. While we'll be using PostgreSQL in this chapter, most of the SQL statements we write will be portable to different databases.

To follow this section, connect to an empty database on your PostgreSQL database server, either using the `psql` command-line tool, the pgAdmin 4 graphical tool, or another database client software of your choosing.

Syntax differences from Python

If you've only ever programmed in Python, SQL may feel odd at first, as the rules and syntax are very different.

We'll be going over the individual commands and keywords, but the following are some general differences from Python:

- **SQL is (mostly) case-insensitive**: Although it's conventional for readability purposes to type the SQL keywords in all-caps, most SQL implementations are not case-sensitive. There are a few small exceptions here and there, but, for the most part, you can type SQL in whatever case is easiest for you.
- **Whitespace is not significant**: In Python, new lines and indentation can change the meaning of a piece of code. In SQL, whitespace is not significant and statements are terminated with a semicolon. Indents and new lines in a query are only there for readability.
- **SQL is declarative**: Python could be described as an imperative programming language: we tell Python what we want it to do by telling it how to do it. SQL is more of a declarative language: we describe what we want, and the SQL engine figures out how to do it.

We'll encounter additional syntax differences as we look at specific SQL code examples.

Defining tables and inserting data

SQL tables are created using the `CREATE TABLE` command as shown in the following SQL query:

```
CREATE TABLE musicians (id SERIAL PRIMARY KEY, name TEXT NOT NULL, born DATE,
```

In this example, we're creating a table called `musicians`. After the name, we specify a list of column definitions. Each column definition follows the format `column_name data_type constraints`.

In this case, we have the following four columns:

- The `id` column will be an arbitrary row ID. It's type is `SERIAL`, which means it will be an autoincrementing integer field, and its constraint is `PRIMARY KEY`, which means it will be used as the unique identifier for the row.
- The `name` field is of type `TEXT`, so it can hold a string of any length. Its constraint of `NOT NULL` means that the `NULL` values are not allowed in this field.
- The `born` and `died` fields are the `DATE` fields, so they can only hold a date value. The `born` field has no constraints, but `died` has a `CHECK` constraint enforcing that its value must be greater than the value of `born` for any given row.

Although it's not required, it's a good practice to specify a primary key for each table. Primary keys can be one field, or a combination of fields, but the value must be unique for any given row. For example, if we made `name` the primary key field, we couldn't have two musicians with the same name in our table.

To add rows of data to this table, we use the `INSERT INTO` command as follows:

```
INSERT INTO musicians (name, born, died) VALUES ('Robert Fripp', '1946-05-16'
```

The `INSERT INTO` command takes a table name and an optional list specifying the fields to receive data; other fields will receive their default value (NULL if not otherwise specified in the CREATE statement). The VALUES keyword indicates that a list of data values to be followed, formatted as a comma-separated list of tuples. Each tuple corresponds to one table row and must match the field list specified after the table name.

Note that strings are delimited by the single quote character. Unlike Python, single quotes and double quotes have different meanings in SQL: a single quote indicates a string literal, while double quotes are used for object names that include spaces or need to preserve case. Had we used double quotes here, it would have resulted in an error.

Let's create and populate an `instruments` table:

```
CREATE TABLE instruments (id SERIAL PRIMARY KEY, name TEXT NOT NULL);
INSERT INTO instruments (name) VALUES ('bass'), ('drums'), ('guitar'), ('keyb
```

Note that the VALUES lists must always use parentheses around each row, even if there's only one value per row.

Tables can be changed after they are created using the ALTER TABLE command as follows:

```
ALTER TABLE musicians ADD COLUMN main_instrument INT REFERENCES instruments(i
```

The ALTER TABLE command takes a table name, then a command altering some aspect of the table. In this case, we're adding a new column called `main_instrument`, which will be an integer. The REFERENCES constraint we've specified is known as a **foreign key** constraint; it limits the possible values of `main_instrument` to existing ID numbers in the `instruments` table.

Retrieving data from tables

To retrieve data from tables, we use the `SELECT` statement as follows:

```
SELECT name FROM musicians;
```

The `SELECT` command takes a column or comma-separated list of columns followed by a `FROM` clause, which specifies the table or tables containing the specified columns. This query asks for the `name` column from the `musicians` table.

Its output is as follows:

name
Bill Bruford
Keith Emerson
Greg Lake
Robert Fripp
David Gilmour

Instead of a list of columns, we can also specify an asterisk, which means all columns as shown in the following query:

```
SELECT * FROM musicians;
```

The preceding SQL query returns a following table of data:

ID	name	born	died	main_instrument
4	Bill Bruford	1949-05-17		
2	Keith Emerson	1944-11-02	2016-03-11	
3	Greg Lake	1947-11-10	2016-12-07	
1	Robert Fripp	1946-05-16		

5	David Gilmour	1946-03-06		

To filter out rows we don't want, we can specify a `WHERE` clause as follows:

```
SELECT name FROM musicians WHERE died IS NULL;
```

The `WHERE` command must be followed by a conditional statement; rows that satisfy the condition are shown, while rows that do not are left out. In this case, we have asked for the names of musicians who do not have a date of death.

We can specify complex conditions with the `AND` and `OR` operators as follows:

```
SELECT name FROM musicians WHERE born < '1945-01-01' AND died IS NULL;
```

In this case, we would only get musicians born before 1945 who have not died.

The `SELECT` command can also do operations on fields, or re-order the results by certain columns:

```
SELECT name, age(born), (died - born)/365 AS "age at death" FROM musicians OR
```

In this example, we're using the `age()` function to determine the age of the musicians from their birth dates. We're also doing math on the `died` and `born` dates to determine the age at death for those who have passed. Notice that we're using the `AS` keyword to rename, or alias, the generated column.

When you run this query, notice that `age at death` is `NULL` for those without a date of death. Mathematical or logical operations on a `NULL` value always return an answer of `NULL`.

The `ORDER BY` clause specifies a column or list of columns by which the results should be ordered. It also takes an argument of `DESC` or `ASC` to specify descending or ascending order. We have ordered the output here by date of birth in descending order. Note that each data type has its own rules for sorting data, just like in Python. Dates are ordered by their calendar position, strings by alphabetical order, and numbers by their numeric value.

Updating rows, deleting rows, and more WHERE clauses

To update or delete existing rows, we use the `UPDATE` and `DELETE FROM` keywords in conjunction with a `WHERE` clause to select the affected rows.

Deleting is fairly simple looks like this:

```
DELETE FROM instruments WHERE id=4;
```

The `DELETE FROM` command will delete any rows that match the `WHERE` conditions. In this case, we match the primary key to ensure only one row is deleted. If no rows match the `WHERE` conditions, no rows will be deleted. Note, however, that the `WHERE` clause is technically optional: `DELETE FROM instruments` will simply delete all rows in the table.

Updating is similar, except it includes a `SET` clause to specify new column values as follows:

```
UPDATE musicians SET main_instrument=3 WHERE id=1;
UPDATE musicians SET main_instrument=2 WHERE name='Bill Bruford';
```

Here, we are setting `main_instrument` to the corresponding `instruments` primary key value for two musicians. We can select our musician records to update by primary key, name, or any valid set of conditions. Like `DELETE`, omitting the `WHERE` clause would affect all rows.

Any number of columns can be updated in the `SET` clause:

```
UPDATE musicians SET main_instrument=4, name='Keith Noel Emerson' WHERE name
```

Additional column updates are just separated by commas. Note that we've also matched the record using the `LIKE` operator in tandem with the `%` wildcard character. `LIKE` can be used with text and string data types to match partial values. Standard SQL supports two wildcard characters: `%`, which matches any number of characters, and _, which matches a single character.

We can also match against transformed column values:

```
UPDATE musicians SET main_instrument=1 WHERE LOWER(name) LIKE '%lake';
```

Here, we've used the `LOWER` function to match our string against the lowercase version of the column value. This doesn't permanently change the data in the table; it just temporarily changes the value for the check.

Standard SQL specifies that `LIKE` is a case-sensitive match. PostgreSQL offers an `ILIKE` operator which does case-insensitive matching as well as a `SIMILAR TO` operator that matches using more advanced regular expression syntax.

Subqueries

Rather than using the raw primary key values of our `instruments` table each time, we can use a subquery as shown in the following SQL query:

```
UPDATE musicians SET main_instrument=(SELECT id FROM instruments WHERE name='
```

A subquery is a SQL query within a SQL query. If your subquery can be guaranteed to return a single value, it can be used anywhere you would use a literal value. In this case, we're letting our database do the work of figuring out what the primary key of `guitar` is, and inserting that for our `main_instrument` value.

In the `WHERE` clause, we've also used the `IN` operator to match against a list of values. This allows us to match against a list of values.

`IN` can be used with a subquery as well as follows:

```
SELECT name FROM musicians WHERE main_instrument IN (SELECT id FROM instrumen
```

Since `IN` is meant to be used with a list of values, any query that returns a single column with any number of rows is valid.

Subqueries that return multiple rows and multiple columns can be used anywhere a table can be used:

```
SELECT name FROM (SELECT * FROM musicians WHERE died IS NULL) AS living_music
```

Note that subqueries in a `FROM` clause require an alias; we've aliased the subquery as `living_musicians`.

Joining tables

Subqueries are one way of using multiple tables together, but a more flexible and powerful way is to use `JOIN`.

`JOIN` is used in the `FROM` clause of an SQL statement as follows:

```
SELECT musicians.name, instruments.name as main_instrument FROM musicians JOI
```

A `JOIN` statement requires an `ON` clause that specifies the conditions used to match rows in each table. The `ON` clause acts like a filter, much like the `WHERE` clause does; you can imagine that the `JOIN` creates a new table containing every possible combination of rows from both tables, then filters out the ones that don't match the `ON` conditions. Tables are typically joined by matching the values in common fields, such as those specified in a foreign key constraint. In this case, our `musicians.main_instrument` column contains the `id` values from the `instrument` table, so we can join the two tables based on this.

Joins are used to implement the following four types of table relationships:

- One-to-one joins match exactly one row in the first table to exactly one row in the second.
- Many-to-one joins match multiple rows in the first table to exactly one row in the second.
- One-to-many joins match one row in the first table to multiple rows in the second.
- Many-to-many joins match multiple rows in both tables. This kind of join requires the use of an intermediary table.

The earlier query shows a many-to-one join, since many musicians can have the same main instrument. Many-to-one joins are often used when a column's value should be limited to a set of options, such as fields that our GUI might represent with a `ComboBox` widget. The table joined is called a **lookup table**.

If we were to reverse it, it would be one-to-many:

```
SELECT instruments.name AS instrument, musicians.name AS musician FROM instru
```

One-to-many joins are commonly used when a record has a list of sub-records associated with it; in this case, each instrument has a list of musicians who consider it their main instrument. The joined table is often called a **detail table**.

The preceding SQL query will give you the following output:

instrument	musician
drums	Bill Bruford
keyboards	Keith Emerson
bass	Greg Lake
guitar	Robert Fripp
guitar	David Gilmour

Notice that `guitar` is duplicated in the instrument list. When two tables are joined, the rows of the result no longer refer to the same type of object. One row in the instrument table represents an instrument. One row in the `musician` table represents one musician. One row in this table represents an `instrument-musician` relationship.

But suppose we wanted to keep the output such that one row represented one instrument but could still include information about associated musicians in each row. To do this, we'll need to aggregate the matched musician rows using an aggregate function and the `GROUP BY` clause as shown in the following SQL query:

```
SELECT instruments.name AS instrument, count(musicians.id) as musicians FROM 
```

The `GROUP BY` clause specifies which column or columns describe what each row in the output table represents. Output columns not in the `GROUP BY` clause must then be reduced to single values using an aggregate function. In this case, we're using the `count()` function to count the total number of musician records associated with each instrument. Standard SQL contains several more aggregate functions, such as `min()`, `max()`, and `sum()`, and most SQL implementations extend this with their own functions as well.

Many-to-one and one-to-many joins don't quite cover every possible situation that databases need to model; quite often, a many-to-many relationship is required.

To demonstrate a many-to-many join, let's create a new table called `bands` as follows:

```
CREATE TABLE bands (id SERIAL PRIMARY KEY, name TEXT NOT NULL);
INSERT INTO bands(name) VALUES ('ABWH'), ('ELP'), ('King Crimson'), ('Pink Fl
```

A band has multiple musicians, and musicians can be part of multiple bands. How can we create a relationship between musicians and bands? If we added a `band` field to the `musicians` table, this would limit each musician to one band. If we added a `musician` field to the `band` table, this would limit each band to one musician. To make the connection, we need to create a **junction table**, in which each row represents a musician's membership in a band.

By convention, we call this `musicians_bands`:

```
CREATE TABLE musicians_bands (musician_id INT REFERENCES musicians(id), band_
INSERT INTO musicians_bands(musician_id, band_id) VALUES (1, 3), (2, 2), (3,
```

The `musicians_bands` table simply contains two foreign key fields, one to point to a musician's ID and one to point to the band's ID. Notice that instead of creating or specifying one field as the primary key, we use the combination of both fields as the primary key. It wouldn't make sense to have multiple rows with the same two values in them, so the combination makes an acceptable primary key. To write a query that uses this relationship, our `FROM` clause needs to specify two `JOIN` statements: one from `musicians` to `musicians_bands` and one from `bands` to `musicians_bands`.

For example, let's get the names of the bands each musician has been in:

```
SELECT musicians.name, array_agg(bands.name) AS bands FROM musicians JOIN mus
```

This query ties `musicians` to `bands` using the junction table, then displays musician names next to an aggregated list of the bands they've been in, and orders it by the musician's name.

The preceding SQL query gives you the following output:

name	bands
Bill Bruford	{ABWH,"King Crimson",Yes}
David Gilmour	{"Pink Floyd"}
Greg Lake	{ELP,"King Crimson"}
Keith Emerson	{ELP}
Robert Fripp	{"King Crimson"}

The `array_agg()` function used here aggregates string values into an array structure. This method and the `ARRAY` data type are specific to PostgreSQL. There is no SQL standard function for aggregating string values, but most SQL implementations have a solution for it.

Learning more

This has been a quick overview of SQL concepts and syntax; we've covered most of what you need to know to write a simple database application, but there's much more to learn. The PostgreSQL manual, available at `https://www.postgresql.org/docs/manuals/`, is a great resource and reference for SQL syntax and the specific features of PostgreSQL.

Modeling relational data

Our application currently stores data in a single CSV file; a file like this is often called a **flat file**, because the data has been flattened to two dimensions. While this format works acceptably for our application and could be translated directly to an SQL table, a more accurate and useful data model requires more complexity.

Normalization

The process of breaking out a flat data file into multiple tables is called **normalization**. Normalization is a process involving a series of levels called **normal forms** which progressively remove duplication and create a more precise model of the data we're storing. Although there are many normal forms, most issues encountered in common business data can be handled by conforming to the first three.

Roughly speaking, that requires the following conditions:

- The **first normal form** requires that each field contains only one value, and that repeating columns must be eliminated.
- The **second normal form** additionally requires that every value must be dependent on the entire primary key. In other words, if a table has primary key fields `A`, `B`, and `C`, and the value of column of `X` depends solely on the value of column `A` without respect to `B` or `C`, the table violates the second normal form.
- The **third normal form** additionally requires every value in the table to be dependent only on the primary key. In other words, given a table with primary key `A`, and data fields `X` and `Y`, the value of `Y` can't depend on the value of `X`.

Conforming data to these forms eliminates the potential for redundant, conflicting, or undefined data situations.

The entity-relationship diagrams

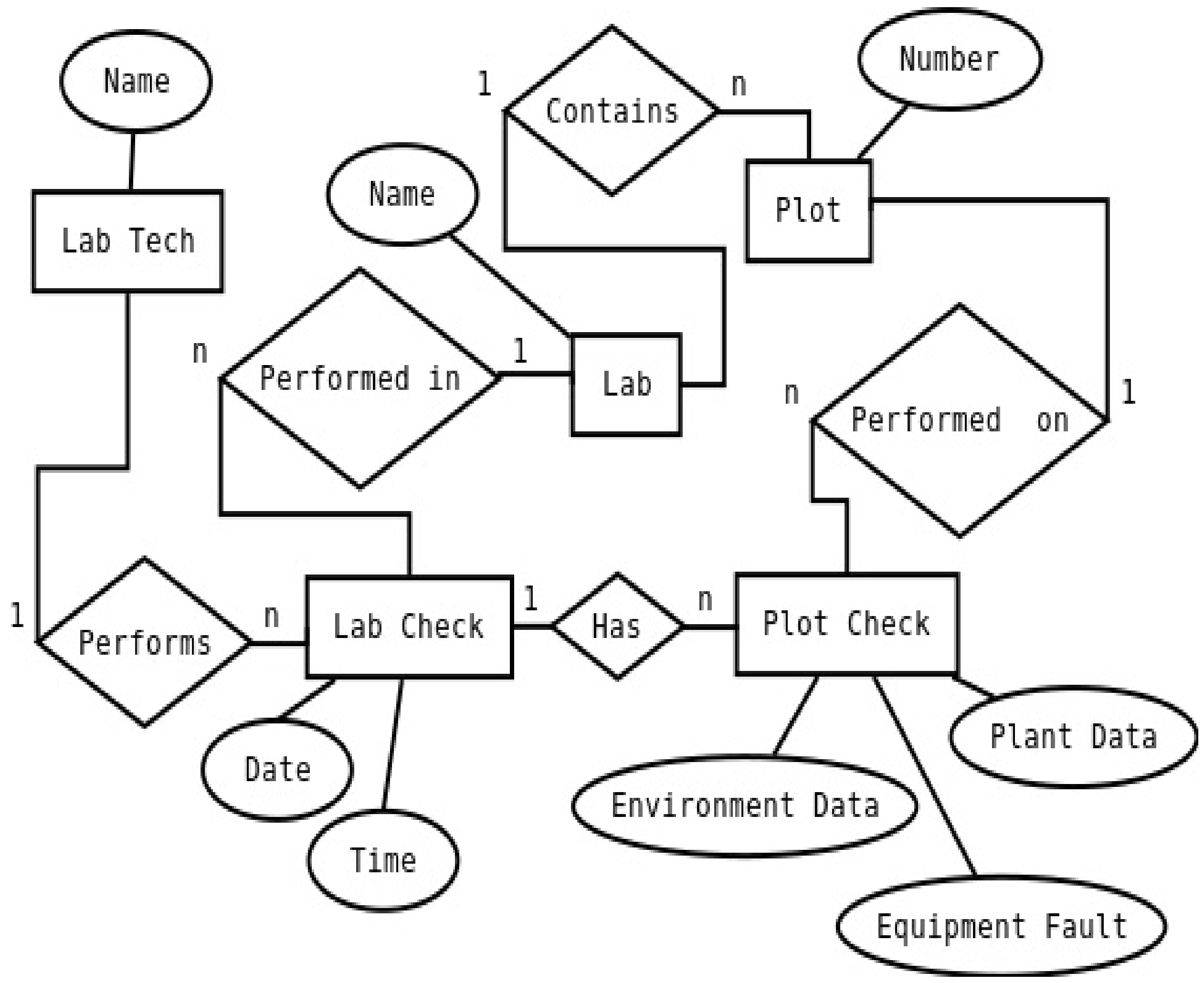
One effective way to help normalize our data and prepare it for a relational database is to analyze it and create an **entity-relationship diagram**, or **ERD**. An ERD is a way of diagramming the things which our database is storing information about and the relationships between those things.

Those things are called **entities**. An **entity** is a uniquely identifiable object; it corresponds to a single row of a single table. Entities have attributes, which correspond to the columns of its table. Entities have relationships with other entities, which correspond to the foreign key relationships we define in SQL.

Let's consider the entities in our lab scenario with their attributes and relationships:

- There are labs. Each lab has a name.
- There are plots. Each plot belongs to a lab and has a number. A seed sample is planted in the plot.
- There are lab technicians, who each have a name.
- There are lab checks, which are performed by a lab tech at a given lab. Each one has a date and time.
- There are plot checks, which is the data gathered at a plot during a lab check. Each plot check has various plant and environmental data recorded on it.

The following diagram of these entities and relationships is as follows:



In the preceding diagram, the entities are represented by rectangles. We have five entities: **Lab**, **Plot**, **Lab Tech**, **Lab Check**, and **Plot Check**. Each entity has attributes, represented by the ovals. The relationships are represented by diamonds, with the words describing the left-to-right relationship. For example, **Lab Tech** performs **Lab Check**, and **Lab Check** is performed in **Lab**. Note the small **1** and **n** characters around the relationship: these show whether a relationship is one-to-many, many-to-one, or many-to-many.

This diagram represents a reasonably normalized structure for our data. To implement it in SQL, we'd just make a table for each entity, a column for each attribute, and a foreign key relationship (possibly including an intermediate table) for each relationship. Before we can do that, let's consider SQL data types.

Assigning data types

Standard SQL defines 16 data types, including types for integers and floating-point numbers of various sizes, ASCII or Unicode strings of either fixed or variable sizes, date and time types, and bit types. Nearly every SQL engine extends this with yet more types to accommodate binary data, special types of strings or numbers, and more. Many data types seem a little redundant, and several have aliases that may be different between implementations. Choosing data types for your columns can be surprisingly confusing!

For PostgreSQL, the following chart provides some reasonable choices:

Data being stored	Recommended type	Notes
Fixed-length strings	`CHAR`	Requires a length.
Short-to-medium strings	`VARCHAR`	Requires a max length argument, for example, `VARCHAR(256)`.
Long, freeform text	`TEXT`	Unlimited length, slower performance.
Smaller Integers	`SMALLINT`	Up to ±32,767.
Most Integers	`INT`	Up to around ±2.1 billion.
Larger Integers	`BIGINT`	Up to around ±922 quadrillion.
Decimals numbers	`NUMERIC`	Takes optional length and precision arguments.
Integer Primary Key	`SERIAL`, `BIGSERIAL`	Autoincrementing integer or big integers.

Boolean	`BOOLEAN`	
Date and time	`TIMESTAMP WITH TIMEZONE`	Stores date, time, and timezone. Accurate to 1 µs.
Date without time	`DATE`	
Time without date	`TIME`	Can be with or without time zone.

These types will probably meet the vast majority of your needs in most applications, and we'll be using a subset of these for our ABQ database. As we create our tables, we'll refer to our data dictionary and choose appropriate data types for our columns.

Be careful not to choose overly specific or restrictive data types. Any data can ultimately be stored in a `TEXT` *field; the purpose of choosing more specific types is mainly to enable the use of operators, functions, or sorting specific to that type. If those aren't required, consider a more generic type. For example, phone numbers and U.S. Social Security numbers can be represented purely with digits, but that's no reason to make them* `INTEGER` *or* `NUMERIC` *fields; after all, you wouldn't do arithmetic with them!*

Creating the ABQ database

Now that we've modeled our data and gotten a feel for the data types available, it's time to build our database. To begin, create a database on your SQL server called `abq` and make yourself the owner.

Next, under your project root folder, create a new directory called `sql`. Inside the `sql` folder, create a file called `create_db.sql`. We'll start writing our database creation code in this file.

Creating our tables

The order in which we create our tables is significant. Any table referred to in a foreign key relationship will need to exist before the relationship is defined. Because of this, it's best to start with your lookup tables and follow the chain of one-to-many relationships until all the tables are created. In our ERD, that takes us from roughly the upper-left to the lower-right.

Creating the lookup tables

We need to create the following three lookup tables:

- `labs`: This lookup table will contain the ID strings for our laboratories.
- `lab_techs`: This lookup table will have the names of the lab technicians, identified by their employee ID numbers.
- `plots`: This lookup table will have one row for each physical plot, identified by lab and plot numbers. It will also keep track of the current seed sample planted in the plot.

Add the SQL query for creating these tables to `create_db.sql` as follows:

```
CREATE TABLE labs (id CHAR(1) PRIMARY KEY);
CREATE TABLE lab_techs (id SMALLINT PRIMARY KEY, name VARCHAR(512) UNIQUE NOT
CREATE TABLE plots (lab_id CHAR(1) NOT NULL REFERENCES labs(id),
    plot SMALLINT NOT NULL, current_seed_sample CHAR(6),
    PRIMARY KEY(lab_id, plot),
    CONSTRAINT valid_plot CHECK (plot BETWEEN 1 AND 20));
```

Before we can use our database, the lookup tables will need to be populated:

- `labs` should have values `A` through `E` for the five labs.
- `lab_techs` needs the name and ID number for our four lab technicians: `J Simms` (`4291`), `P Taylor` (`4319`), `Q Murphy` (`4478`), and `L Taniff` (`5607`).
- `plots` needs all 100 of the plots, numbers `1` through `20` for each lab. The seed sample rotates between four values such as `AXM477`, `AXM478`, `AXM479`, and `AXM480`.

You can populate these tables by hand using pgAdmin, or using the `db_populate.sql` script included with the example code.

The lab_checks table

The `lab_check` table is an instance of a technician checking all the plots of a lab at a given time on a given date as shown in the following SQL query:

```
CREATE TABLE lab_checks(
    date DATE NOT NULL, time TIME NOT NULL,
    lab_id CHAR(1) NOT NULL REFERENCES labs(id),
    lab_tech_id SMALLINT NOT NULL REFERENCES lab_techs(id),
    PRIMARY KEY(date, time, lab_id));
```

The `date`, `time`, and `lab_id` columns together uniquely identify a lab check, and so we designate them the primary key columns. The ID of the lab technician performing the check is the lone attribute in this table.

The plot_checks table

Plot checks are the actual data records collected at individual plots. These are part of a lab check, and so must refer back to an existing lab check.

We'll begin with the primary key columns:

```
CREATE TABLE plot_checks(date DATE NOT NULL, time TIME NOT NULL,
lab_id CHAR(1) NOT NULL REFERENCES labs(id), plot SMALLINT NOT NULL,
```

This is the primary key of a `lab_check` table plus a `plot` number; its key constraints look like this:

```
PRIMARY KEY(date, time, lab_id, plot),
FOREIGN KEY(date, time, lab_id)
    REFERENCES lab_checks(date, time, lab_id),
FOREIGN KEY(lab_id, plot) REFERENCES plots(lab_id, plot),
```

Now we can add the attribute columns:

```
seed_sample CHAR(6) NOT NULL,
humidity NUMERIC(4, 2) CHECK (humidity BETWEEN 0.5 AND 52.0),
light NUMERIC(5, 2) CHECK (light BETWEEN 0 AND 100),
temperature NUMERIC(4, 2) CHECK (temperature BETWEEN 4 AND 40),
equipment_fault BOOLEAN NOT NULL,
blossoms SMALLINT NOT NULL CHECK (blossoms BETWEEN 0 AND 1000),
plants SMALLINT NOT NULL CHECK (plants BETWEEN 0 AND 20),
fruit SMALLINT NOT NULL CHECK (fruit BETWEEN 0 AND 1000),
max_height NUMERIC(6, 2) NOT NULL CHECK (max_height BETWEEN 0 AND 1000),
min_height NUMERIC(6, 2) NOT NULL CHECK (min_height BETWEEN 0 AND 1000),
median_height NUMERIC(6, 2) NOT NULL
    CHECK (median_height BETWEEN min_height AND max_height),
notes TEXT);
```

Notice our use of data types and the `CHECK` constraint to duplicate the limits from our `data` dictionary. Using these, we've leveraged the power of the database to safeguard against invalid data.

Creating a view

Before we finish our database design, we're going to create a view that will simplify access to our data. A view behaves like a table in most respects, but contains no actual data; it's really just a stored `SELECT` query. Our view will format our data for easier interaction with the GUI.

Views are created using the `CREATE VIEW` command as follows:

```
CREATE VIEW data_record_view AS (
```

Inside the parentheses, we put the `SELECT` query that will return the table data for our view:

```
SELECT pc.date AS "Date", to_char(pc.time, 'FMHH24:MI') AS "Time",
    lt.name AS "Technician", pc.lab_id AS "Lab", pc.plot AS "Plot",
    pc.seed_sample AS "Seed sample", pc.humidity AS "Humidity",
    pc.light AS "Light", pc.temperature AS "Temperature",
    pc.plants AS "Plants", pc.blossoms AS "Blossoms", pc.fruit AS
    "Fruit",
    pc.max_height AS "Max Height", pc.min_height AS "Min Height",
    pc.median_height AS "Median Height", pc.notes AS "Notes"
FROM plot_checks AS pc JOIN lab_checks AS lc ON pc.lab_id = lc.lab_id AND pc.
```

We're selecting the `plot_checks` table, and joining it to `lab_checks` and `lab_techs` by way of our foreign key relationships. Notice that we've aliased these tables by using the `AS` keyword. Short aliases like this can help make a large query more readable. We're also aliasing each field to the name used in the application's data structures. These must be enclosed in double quotes to allow for the use of spaces and to preserve case. By making the column names match the `data` dictionary keys in our application, we won't need to translate field names in our application code.

SQL database engines such as PostgreSQL are highly efficient at joining and transforming tabular data. Whenever possible, leverage this power and make the database do the work of formatting the data for the convenience of your application.

This completes our database creation script. Run this script in your PostgreSQL client and verify that the four tables and the view have been created.

Integrating SQL into our application

Converting our application to a SQL backend will be no small task. The application was built around the assumption of the CSV files, and although we've taken care to separate our concerns, many things are going to need to change.

Let's break down the steps we'll need to take:

- We'll need to write a SQL model
- Our `Application` class will need to use the SQL model
- The record form will need to be reordered to prioritize our keys, use the new lookups, and autopopulate using the database
- The record list will need to be adjusted to work with the new data model and primary keys

Along the way, we'll need to fix other bugs or implement some new UI elements as needed. Let's get started!

Creating a new model

We'll start in `models.py` by importing `psycopg2` and `DictCursor`:

```
import psycopg2 as pg
from psycopg2.extras import DictCursor
```

`DictCursor` will allow us to fetch results in Python dictionary rather than the default tuples, which is easier to work with in our application.

Begin a new model class called `SQLModel` and copy over the `fields` property from the `CSVModel`.

Start by clearing the value lists from `Technician`, `Lab`, and `Plot`, and making `Technician` an `FT.string_list` type:

```
class SQLModel:
    fields = {
        ...
        "Technician": {'req': True, 'type': FT.string_list,
                       'values': []},
        "Lab": {'req': True, 'type': FT.string_list, 'values': []},
        "Plot": {'req': True, 'type': FT.string_list,'values': []},

```

These lists will be populated from our lookup tables rather than hardcoded into the model.

We'll do that in the `__init__()` method:

```
    def __init__(self, host, database, user, password):
        self.connection = pg.connect(host=host, database=database,
            user=user, password=password, cursor_factory=DictCursor)

        techs = self.query("SELECT * FROM lab_techs ORDER BY name")
        labs = self.query("SELECT id FROM labs ORDER BY id")
        plots = self.query(
        "SELECT DISTINCT plot FROM plots ORDER BY plot")
        self.fields['Technician']['values'] = [x['name'] for x in
        techs]
        self.fields['Lab']['values'] = [x['id'] for x in labs]
        self.fields['Plot']['values'] = [str(x['plot']) for x in plots]
```

`__init__()` takes our basic database connection details and establishes a connection to the database using `psycopg2.connect()`. Because we passed in `DictCursor` as the `cursor_factory`, this connection will return lists of dictionaries for all data queries.

Then, we query the database for the pertinent columns in our three lookup tables and use a list comprehension to flatten the results of each query for the `values` list.

The `query` method used here is a wrapper that we need to write next:

```
    def query(self, query, parameters=None):
        cursor = self.connection.cursor()
        try:
            cursor.execute(query, parameters)
        except (pg.Error) as e:
            self.connection.rollback()
            raise e
        else:
            self.connection.commit()
            if cursor.description is not None:
                return cursor.fetchall()
```

Querying a database using `psycopg2` involves generating a `cursor` object from the connection, then calling its `execute()` method with the query string and optional parameter data. By default, all queries are executed in a transaction, meaning they don't take effect until we commit the changes. If the query raises an exception for any reason (SQL syntax error, constraint violation, connection issue, and so on) the transaction enters a corrupt state and must be rolled back (reverted to the beginning state of the transaction) before we can use our connection again. Therefore, we will execute our queries in a `try` block and rollback the transaction using `connection.rollback()` in the event of any `psycopg2`-related exceptions (which all descend from `pg.Error`).

To retrieve data from a cursor after the query is executed, we're using the `fetchall()` method, which retrieves all results as a list. However, if the query wasn't a data-returning query (such as `INSERT`, for example), `fetchall()` will throw an exception. To avoid this, we first check `cursor.description`: if the query returned data (even an empty set of data), `cursor.description` will contain metadata about the returned table (column names, for example). If not, it will be `None`.

Let's test our `query()` method by writing the `get_all_records()` method:

```
    def get_all_records(self, all_dates=False):
        query = ('SELECT * FROM data_record_view '
            'WHERE NOT %(all_dates)s OR "Date" = CURRENT_DATE '
            'ORDER BY "Date", "Time", "Lab", "Plot"')
        return self.query(query, {'all_dates': all_dates})
```

Since our users are used to working with only the current day's data, we'll only show that data by default, but add an optional flag should we ever need to retrieve all data. We can get the current date in most SQL implementations using the `CURRENT_DATE` constant, which we've used here. To use our `all_dates` flag, we're employing a prepared query.

The syntax `%(all_dates)s` defines a parameter; it tells `psycopg2` to check the included parameter dictionary for the key `all_dates` and substitute its value into the query. The `psycopg2` library will automatically do this in a way that's both safe and works correctly with various data types like `None` or Boolean values.

Always use prepared queries to pass data into a SQL query. Never use string formatting or concatenation! Not only is it harder than you think to get it right, it can leave you open to accidental or malicious database corruption.

Next, let's create `get_record()`:

```
def get_record(self, date, time, lab, plot):
    query = ('SELECT * FROM data_record_view '
        'WHERE "Date" = %(date)s AND "Time" = %(time)s '
        'AND "Lab" = %(lab)s AND "Plot" = %(plot)s')
    result = self.query(
        query, {"date": date, "time": time, "lab": lab, "plot": plot})
    return result[0] if result else {}
```

We're no longer dealing in row numbers like our `CSVModel` did, so this method needs all four key fields to retrieve a record. Once again, we're using a prepared query, specifying parameters for the four fields. Take note of the `s` after the closing parenthesis of the parameter; this is a required format specifier, and should always be `s`.

Even with a single row, `query()` is going to return results in a list. Our application expects a single row dictionary from `get_record()`, so our `return` statement extracts the first item in `result` if the list is not empty, or an empty `dict` if it is.

Retrieving a lab check record is very similar:

```
    def get_lab_check(self, date, time, lab):
        query = ('SELECT date, time, lab_id, lab_tech_id, '
            'lt.name as lab_tech FROM lab_checks JOIN lab_techs lt '
            'ON lab_checks.lab_tech_id = lt.id WHERE '
            'lab_id = %(lab)s AND date = %(date)s AND time = %(time)s')
        results = self.query(
            query, {'date': date, 'time': time, 'lab': lab})
        return results[0] if results else {}
```

In this query, we're using a join to make sure we have the technician name available and not just the ID. This method will come in handy in our `save_record()` method and form data autofill methods.

The `save_record()` method will need four queries: an `INSERT` and `UPDATE` query for each of `lab_checks` and `plot_checks`. To keep the method reasonably concise, let's create the query strings as class properties.

We'll start with the lab check queries:

```
    lc_update_query = ('UPDATE lab_checks SET lab_tech_id = '
        '(SELECT id FROM lab_techs WHERE name = %(Technician)s) '
        'WHERE date=%(Date)s AND time=%(Time)s AND lab_id=%(Lab)s')
    lc_insert_query = ('INSERT INTO lab_checks VALUES (%(Date)s, '
        '%(Time)s, %(Lab)s,(SELECT id FROM lab_techs '
        'WHERE name=%(Technician)s))')
```

These queries are fairly straightforward, though note our use of a subquery to populate `lab_tech_id` in each case. Our application will have no idea what a lab tech's ID is, so we'll need to look the ID up by name. Also, take note that our parameter names match the names used in our application's fields. This will save us having to reformat the record data acquired from our form.

The plot check queries are longer but no more complicated:

```
    pc_update_query = (
        'UPDATE plot_checks SET seed_sample = %(Seed sample)s, '
        'humidity = %(Humidity)s, light = %(Light)s, '
        'temperature = %(Temperature)s, '
        'equipment_fault = %(Equipment Fault)s, '
        'blossoms = %(Blossoms)s, plants = %(Plants)s, '
        'fruit = %(Fruit)s, max_height = %(Max Height)s, '
        'min_height = %(Min Height)s, median_height = '
        '%(Median Height)s, notes = %(Notes)s '
        'WHERE date=%(Date)s AND time=%(Time)s '
        'AND lab_id=%(Lab)s AND plot=%(Plot)s')

    pc_insert_query = (
        'INSERT INTO plot_checks VALUES (%(Date)s, %(Time)s, %(Lab)s,'
        ' %(Plot)s, %(Seed sample)s, %(Humidity)s, %(Light)s,'
        ' %(Temperature)s, %(Equipment Fault)s, %(Blossoms)s,'
        ' %(Plants)s, %(Fruit)s, %(Max Height)s, %(Min Height)s,'
        ' %(Median Height)s, %(Notes)s)')
```

With the queries in place, we can start the `save_record()` method:

```
    def save_record(self, record):
        date = record['Date']
        time = record['Time']
        lab = record['Lab']
        plot = record['Plot']
```

The `CSVModel.save_record()` method took a `record` dictionary and a `rownum`, but we no longer need the `rownum` since it's meaningless. All our key information is already in the record. For convenience, we'll extract those four fields and assign them local variable names.

There are three possibilities when we try to save a record in this database:

- Neither a lab check or plot check record exists. Both will need to be created.
- The lab check exists but the plot check does not. The lab check will need to be updated, in case the user wants to correct the technician value, and the plot check will need to be added.
- Both the lab check and plot check exist. Both will need to be updated with the submitted values.

To determine which possibility is true, we'll make use of our `get_` methods:

```
        if self.get_lab_check(date, time, lab):
            lc_query = self.lc_update_query
        else:
            lc_query = self.lc_insert_query
        if self.get_record(date, time, lab, plot):
            pc_query = self.pc_update_query
        else:
            pc_query = self.pc_insert_query
```

For both the lab check and plot check, we attempt to retrieve a record from the respective table using our key values. If one is found, we'll use our update queries; otherwise, we'll use our insert queries.

Now, we just run those queries with `record` as the parameter list:

```
        self.query(lc_query, record)
        self.query(pc_query, record)
```

Note that `psycopg2` has no problem with us passing a dictionary with extra parameters that aren't referenced in the query, so we don't need to bother with filtering unneeded items from `record`.

There is one more thing we need to do here: remember that our `Application` needs to keep track of updated and inserted rows. Since we are no longer dealing with row numbers, only the database model knows whether an insert or update was performed.

Let's create an instance property to share that information:

```
        if self.get_record(date, time, lab, plot):
            pc_query = self.pc_update_query
            self.last_write = 'update'
        else:
            pc_query = self.pc_insert_query
            self.last_write = 'insert'
```

Now `Application` can check the value of `last_write` after calling `save_record()` to determine which operation was done.

There is one last method this model needs; since our database knows what seed sample is currently in each plot, we want our form to populate this automatically for the user. We'll need a method that takes a `lab` and `plot_id` and returns the seed sample name.

We'll call it `get_current_seed_sample()`:

```
    def get_current_seed_sample(self, lab, plot):
        result = self.query('SELECT current_seed_sample FROM plots '
            'WHERE lab_id=%(lab)s AND plot=%(plot)s',
            {'lab': lab, 'plot': plot})
        return result[0]['current_seed_sample'] if result else ''
```

This time, our `return` statement is not just extracting the first row of results, but the value of the `current_seed_sample` column from that first row. If there's no `result`, we return an empty string.

That completes our model class; now let's incorporate it into the application.

Adjusting the Application class for the SQL backend

The first thing the `Application` class will need is the database connection information to pass to the model.

For the host and database name, we can just add settings to our `SettingsModel`:

```
    variables = {
        ...
        'db_host': {'type': 'str', 'value': 'localhost'},
        'db_name': {'type': 'str', 'value': 'abq'}
```

These can be saved in our JSON `config` file, which can be edited to switch from development to production, but our username and password will need to be entered by the user. For that, we'll need to build a login dialog.

Building a login window

Tkinter does not provide us with a ready-made login dialog, but it does provide us with a generic `Dialog` class which can be subclassed to create custom dialogs.

Import this class from `tkinter.simpledialog` into our `views.py` file:

```
from tkinter.simpledialog import Dialog
```

Let's start with our class declaration and `__init__()` method:

```
class LoginDialog(Dialog):

    def __init__(self, parent, title, error=''):
        self.pw = tk.StringVar()
        self.user = tk.StringVar()
        self.error = tk.StringVar(value=error)
        super().__init__(parent, title=title)
```

Our class will take a `parent` as usual, a window `title`, and an optional `error`, which will be used in case we need to re-display the dialog with an `error` message (for example, if the password is wrong). The rest of `__init__()` sets up some Tkinter variables for the password, username, and `error` string; then, it finishes with the customary call to `super()`.

The form itself is not defined in `__init__()`; instead, we need to override the `body()` method:

```
    def body(self, parent):
        lf = tk.Frame(self)
        ttk.Label(lf, text='Login to ABQ', font='Sans 20').grid()
```

The first thing we do is make a frame and add a title label to the first row using a large font.

Next, we'll check for an `error` string and, if there is one, display it in an appropriate style:

```
        if self.error.get():
            tk.Label(lf, textvariable=self.error,
                     bg='darkred', fg='white').grid()
```

Now we'll add the username and password fields and `pack` our frame into the dialog:

```
        ttk.Label(lf, text='User name:').grid()
        self.username_inp = ttk.Entry(lf, textvariable=self.user)
        self.username_inp.grid()
        ttk.Label(lf, text='Password:').grid()
        self.password_inp = ttk.Entry(lf, show='*',
        textvariable=self.pw)
        self.password_inp.grid()
        lf.pack()
        return self.username_inp
```

Notice our use of the `show` option in the password entry, which replaces any typed text with the character we specify, to create a hidden text field. Also, note that we return the username input widget from the method. `Dialog` will focus whichever widget is returned here when it's displayed.

`Dialog` automatically supplies the OK and Cancel buttons; we'll want to know which button was clicked, and if it was the OK button, retrieve the entered information.

Clicking OK calls the `apply()` method, so we can override it to set up a `result` value:

```
        def apply(self):
            self.result = (self.user.get(), self.pw.get())
```

`Dialog` creates a property by default called `result` which is set to `None`. But now, if our user clicks OK, `result` will be a tuple containing a username and password. We'll use this property to determine what was clicked and what was entered.

Using the login window

To use the dialog, our application needs a method that will display the dialog in an infinite loop until either the user clicks Cancel or the provided credentials successfully authenticate.

Start a new `database_login()` method in `Application`:

```
        def database_login(self):
            error = ''
            db_host = self.settings['db_host'].get()
            db_name = self.settings['db_name'].get()
            title = "Login to {} at {}".format(db_name, db_host)
```

We begin by setting up an empty `error` string and a `title` string to pass to our `LoginDialog` class.

Now we'll start the infinite loop:

```
        while True:
            login = v.LoginDialog(self, title, error)
            if not login.result:
                break
```

Inside the loop, we create a `LoginDialog`, which will block until the user clicks one button or the other. After the dialog returns, if `login.result` is `None`, the user has clicked Cancel, so we break out of the loop and exit the method.

If we have a non-`None` `login.result`, we'll attempt to log in with it:

```
        else:
            username, password = login.result
            try:
                self.data_model = m.SQLModel(
                 db_host, db_name, username, password)
            except m.pg.OperationalError:
                error = "Login Failed"
            else:
                break
```

After extracting the `username` and `password` from the `result` tuple, we try to create a `SQLModel` instance with it. If the credentials fail, `psycopg2.connect` will raise an

`OperationalError`, in which case we'll simply populate our `error` string and let the infinite loop iterate again.

If the data model creation succeeded, we simply break out of the loop and exit the method.

Back in `__init__()`, just after setting up our settings, let's put `database_login()` to work:

```
        self.database_login()
        if not hasattr(self, 'data_model'):
            self.destroy()
            return
```

After our call to `self.database_login()`, `Application` either has a `data_model` attribute (because the login succeeded) or doesn't (because the user clicked Cancel). If it doesn't, we'll quit the application by destroying the main window and returning immediately from `__init__()`.

Of course, before this logic will work, we need to delete the creation of the `CSVModel`:

```
        # Delete this line:
        self.data_model = m.CSVModel(filename=self.filename.get())
```

Fixing some model incompatibilities

In theory, we should be able to swap in a new model with the same method calls and our application object will just work, but this isn't quite the case. There are a few small fixes we need to make to get `Application` working with our new model.

DataRecordForm creation

First, let's fix our `DataRecordForm` instantiation in `Application.__init__()`:

```
        # The data record form
        self.recordform = v.DataRecordForm(
            self, self.data_model.fields, self.settings,
            self.callbacks)
```

Previously, we'd pulled the `fields` argument from the static class property of `CSVModel`. We need to pull it from our data model instance instead, since the instance is setting up some values.

Fixing the open_record() method

Next, we need to fix our `open_record()` method. It takes a `rownum` currently, but we no longer have row numbers; we have `date`, `time`, `lab`, and `plot`.

To reflect this, replace all instances of `rownum` with `rowkey`:

```
    def open_record(self, rowkey=None):
        if rowkey is None:
        # ...etc
```

Finally, expand `rowkey` in the `get_record()` call, since it expects four positional arguments:

```
            record = self.data_model.get_record(*rowkey)
```

Fixing the on_save() method

The error handling portion of `on_save()` is fine, but after the `if errors:` block, we'll start changing things:

```
        data = self.recordform.get()
        try:
            self.data_model.save_record(data)
```

We no longer need to extract the row number or pass it into `save_record()`, and we can delete the handling of `IndexError` since `SQLModel` will not raise that exception. We also need to rewrite the updating of `inserted_rows` and `updated_rows`.

Remove all the code in this method after the call to `self.status.set()`, and replace it with this:

```
        key = (data['Date'], data['Time'], data['Lab'], data['Plot'])
        if self.data_model.last_write == 'update':
            self.updated_rows.append(key)
        else:
            self.inserted_rows.append(key)
        self.populate_recordlist()
        if self.data_model.last_write == 'insert':
            self.recordform.reset()
```

After building the primary key tuple from `data` passed into the method, we use the value of `last_write` to append it to the proper list. Finally, we reset the record form in the case of an insert.

Creating new callbacks

There are two callbacks we want to have for our record form. When the user enters a `lab` and `plot` value, we want to automatically populate the correct `seed` value that is currently planted in that `plot`. Also, when the `date`, `time`, and `lab` values have been entered, and we have an existing lab check that matches, we should populate the name of the lab tech who did that check.

Of course, if our user prefers not to have data autofilled, we shouldn't do either of these things.

Let's start with the `get_current_seed_sample()` method:

```
    def get_current_seed_sample(self, *args):
        if not (hasattr(self, 'recordform')
            and self.settings['autofill sheet data'].get()):
            return
        data = self.recordform.get()
        plot = data['Plot']
        lab = data['Lab']
        if plot and lab:
            seed = self.data_model.get_current_seed_sample(lab, plot)
            self.recordform.inputs['Seed sample'].set(seed)
```

We begin by checking whether we have a record form object created, and whether the user wants data autofilled. If not, we exit the method. Next, we fetch the `plot` and `lab` from the form's current data. If we have both, we use them to fetch the `seed` sample value from the model and set the form's `Seed sample` value accordingly.

We'll do something similar with the lab tech value:

```
    def get_tech_for_lab_check(self, *args):
        if not (hasattr(self, 'recordform')
            and self.settings['autofill sheet data'].get()):
            return
        data = self.recordform.get()
        date = data['Date']
        time = data['Time']
        lab = data['Lab']

        if all([date, time, lab]):
            check = self.data_model.get_lab_check(date, time, lab)
            tech = check['lab_tech'] if check else ''
            self.recordform.inputs['Technician'].set(tech)
```

This time, we need the `date`, `time`, and `lab` arguments to fetch the lab check record. Because we can't be sure if a check matching the values exists, we'll set `tech` to a blank string if we can't find a matching lab check.

Add these two methods to the `callbacks` dictionary and the `Application` class should be ready to go.

Updating our views for the SQL backend

Let's review the changes we need to make in our views:

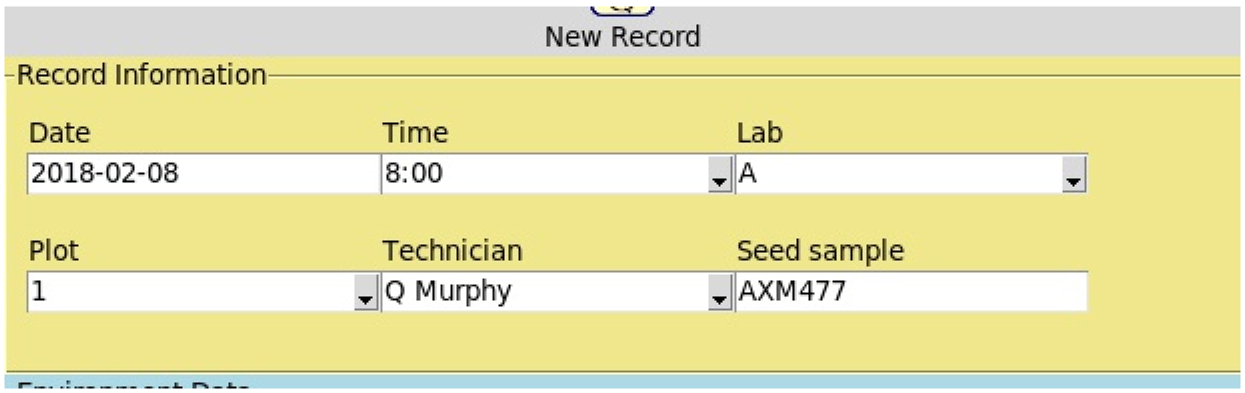
- Re-arrange our fields to put all the primary keys upfront
- Fix our form's `load_record()` method to work with the new key structure
- Add triggers to our form to populate `Technician` and `Seed sample`
- Fix our record list to work with the new keys

Let's start with our record form.

The data record form

The first task we have is to move the fields around. This is really just a matter of cutting and pasting code and then fixing our `grid()` arguments. Place them in the proper key order: Date, Time, Lab, Plot. Then, leave Technician and Seed sample at the end of the Record Information section.

It should look like this:



New Record

Record Information

Date	Time	Lab
2018-02-08	8:00	A
Plot	Technician	Seed sample
1	Q Murphy	AXM477

The reason for this change is so that all the fields which could trigger autofilling of Technician or Seed sample will come before those fields. If any of them came after, we'd be uselessly autofilling a field the user had already filled.

At the end of `__init__()`, let's add our triggers to populate Technician and Seed sample:

```
        for field in ('Lab', 'Plot'):
            self.inputs[field].variable.trace(
                'w', self.callbacks['get_seed_sample'])
        for field in ('Date', 'Time', 'Lab'):
            self.inputs[field].variable.trace(
                'w', self.callbacks['get_check_tech'])
```

We're putting a trace on the key variables for lab check and plot; should any of them change, we'll call the appropriate callback to auto-populate the form.

In `load_record()`, replace `rownum` with `rowkey` for clarity, then fix the label `text` so that it makes sense:

```
        self.record_label.config(
            text='Record for Lab {2}, Plot {3} at {0} {1}'
            .format(*rowkey))
```

The last change of all for `DataRecordForm` deals with a small usability issue. As we auto-populate the form, it gets more and more confusing to determine which field we need to focus next. We're going to address this by creating a method that finds and focuses the first empty field in the form.

We'll call it `focus_next_empty()`:

```
    def focus_next_empty(self):
        for labelwidget in self.inputs.values():
            if (labelwidget.get() == ''):
                labelwidget.input.focus()
                break
```

In this method, we're just iterating all the inputs and checking their current value. When we find one returns an empty string, we focus it, then break through the loop so that no more are checked. We can remove any calls to focus fields from `DataRecordForm.reset()` and replace them with a call to this method. You can also add it to our application's autofill methods, `get_current_seed_sample()` and `get_tech_for_lab_check()`.

The record list

In `RecordList`, the `Row` column no longer contains useful information we wish to display.

We can't remove it, but we can hide it with this code:

```
self.treeview.config(show='headings')
```

The `show` configuration option takes any or both of two values: `tree` and `headings`. The `tree` argument represents the `#0` column since it's used to expand `tree`. The `headings` argument represents the remaining columns. By specifying only `headings` here, the `#0` column is hidden.

We also need to deal with our `populate()` method, which relies heavily on `rownum`.

We'll start by changing the `for` loop that populates the values:

```
        for rowdata in rows:
            rowkey = (str(rowdata['Date']), rowdata['Time'],
            rowdata['Lab'], str(rowdata['Plot']))
            values = [rowdata[key] for key in valuekeys]
```

We can remove the `enumerate()` call and just deal with the row data, extracting the `rowkey` tuple from it by getting `Date`, `Time`, `Lab`, and `Plot`. These need to be cast to string, because they come out of the database as Python objects like `date` and `int`, and we need to match them against the keys in `inserted` and `updated` which are all string values (since they were pulled from our form).

Let's do that comparison and set our row tags:

```
        if self.inserted and rowkey in self.inserted:
            tag = 'inserted'
        elif self.updated and rowkey in self.updated:
            tag = 'updated'
        else:
            tag = ''
```

Now, we need to decide how to handle our row's `iid` value. The `iid` values must be strings; this wasn't a problem when our primary key was an integer (easily castable to and from a string), but our tuple must be serialized in some way that we can easily reverse.

A simple way to address this is to turn our tuple into a delimited string:

```
        stringkey = '{}|{}|{}|{}'.format(*rowkey)
```

Any character that isn't going to appear in the data will work fine as a delimiter; we've chosen to use the pipe character in this case.

Now we can use the string version of the key in `treeview`:

```
        self.treeview.insert('', 'end', iid=stringkey,
            text=stringkey, values=values, tag=tag)
```

The last part of this method focuses the first row for keyboard users. To focus the first row before, we relied on the fact that the first `iid` was always `0`. Now it will be some data-dependent tuple, so we'll have to retrieve the first `iid` before we can set the selection and focus.

We can do this by using the `Treeview.identify_row()` method:

```
        if len(rows) > 0:
            firstrow = self.treeview.identify_row(0)
            self.treeview.focus_set()
            self.treeview.selection_set(firstrow)
            self.treeview.focus(firstrow)
```

The `identify_row()` method takes a row number and returns the `iid` of that row. Once we have that, we can pass it to `selection_set()` and `focus()`.

Our final change is to the `on_open_record()` method. Since we've used our serialized tuple as an `iid` value, we obviously need to translate this back to a tuple that can be passed back to the `on_open_record()` method.

This is as easy as calling `split()`:

```
        self.callbacks['on_open_record'](selected_id.split('|'))
```

That fixes all our view code, and our program is ready to run!

Last changes

Phew! That was quite a journey, but you're not quite done yet. As homework, you'll need to update your unit tests to accommodate the database and login. The best approach would be to mock out the database and login dialog.

There are also still some remnants of the CSV backend sitting around, such as the Select target… item in the file menu. You can delete those UI elements, but leave the backend code as it may come in handy in the near future.

Summary

In this chapter, you learned about relational databases and SQL, the language used to work with them. You learned to model and normalize data to reduce the possibility of inconsistencies, and how to convert flat files into relational data. You learned how to work with the `psycopg2` library, and went through the arduous task of converting the application to use a SQL backend.

In the next chapter, we'll be reaching out to the cloud. We'll need to contact some remote servers using different networking protocols to exchange data. You'll learn about the Python standard library's modules for working with HTTP and FTP, and use them to download and upload data.

Connecting to the Cloud

It seems that nearly every application needs to talk to the outside world sooner or later, and your `ABQ data entry` application is no exception. You've received some new feature requests that will require some interactions with remote servers and services. First, the quality assurance division is doing a study of how local weather conditions are impacting the environmental data in each lab; they've requested a way to download and store local weather data in the database on demand. The second request is from your boss, who is still required to upload daily CSV files to the central corporate servers. She would like this process streamlined and available at a mouse click.

In this chapter, you will learn the following topics:

- Connecting to web services and downloading data using `urllib`
- Managing more complex HTTP interactions using the `requests` library
- Connecting and uploading to FTP services using `ftplib`

HTTP using urllib

Every time you open a website in your browser, you're using the **Hyper Text Transfer Protocol, or HTTP**. HTTP was created over 25 years ago as a way for web browsers to download HTML documents, but has evolved into one of the most popular client-server communication protocols for any number of purposes. Not only can we use it to move everything from plain text to streaming video across the Internet, but applications can also use it to transfer data, initiate remote procedures, or distribute computing tasks.

A basic HTTP transaction includes a client and a server, which function as follows:

- **Client**: The client creates a request. The request specifies an operation called a **method**. The most common methods are `GET`, for retrieving data, and `POST`, for submitting data. The request has a URL, which specifies the host, port, and path to which the request is being made, and headers which include metadata like the data-type or authorization tokens. Finally, it has a payload, which may contain serialized data in key-value pairs.
- **Server**: The server receives the request and returns a response. The response has a header containing metadata such as the status code or content-type of the response. It also has a payload containing the actual content of the response, such as HTML, XML, JSON, or binary data.

In a web browser, these operations take place in the background, but our application will deal directly with request and response objects in order to talk to remote HTTP servers.

Basic downloading with urllib.request

The `urllib.request` module is a Python module for generating HTTP requests. It contains a number of functions and classes for generating HTTP requests, the most basic of which is the `urlopen()` function. The `urlopen()` function can create a `GET` or `POST` request and send it to a remote server.

Let's explore how `urllib` works; open a Python shell and execute the following commands:

```
>>> from urllib.request import urlopen
>>> response = urlopen('http://packtpub.com')
```

The `urlopen()` function takes, at a minimum, a URL string. By default, it makes a `GET` request to the URL and returns an object that wraps the response received from the server. This `response` object exposes metadata or content received from the server, which we can use in our application.

Much of the response's metadata is found in the header, which we can extract using `getheader()` as follows:

```
>>> response.getheader('Content-Type')
'text/html; charset=utf-8'
>>> response.getheader('Server')
'nginx/1.4.5'
```

Responses have a status, indicating the error conditions encountered (if any) during the request process; the status has both a number and a text explanation, called `reason`.

We can extract both from our `response` object as follows:

```
>>> response.status
200
>>> response.reason
'OK'
```

In the preceding code, a `200` status means the transaction was a success. Client-side errors, such as sending a bad URL or incorrect permissions, are indicated by statuses in the 400s, while server-side problems are indicated by statuses in the 500s.

The payload of the `response` object can be retrieved using an interface similar to a file handle as follows:

```
>>> html = response.read()
>>> html[:15]
b'<!DOCTYPE html>'
```

Just like a file handle, the response can only be read once, using the `read()` method; unlike a file handle, it can't be "rewound" using `seek()`, so it's important to save the response data in another variable if it needs to be accessed more than once. The output of `response.read()` is a bytes object, which should be cast or decoded into an appropriate object.

In this case, we have a `utf-8` string as follows:

```
>>> html.decode('utf-8')[:15]
'<!DOCTYPE html>'
```

In addition to the `GET` requests, `urlopen()` can also generate `POST` requests.

To do this, we include a `data` argument as follows:

```
>>> response = urlopen('http://duckduckgo.com', data=b'q=tkinter')
```

The `data` value needs to be a URL-encoded bytes object. The URL-encoded data string consists of key-value pairs separated by ampersand (`&`) symbols, with certain reserved characters encoded to URL-safe alternatives (for example, the space character is `%20`, or sometimes just `+`).

A string like this can be created by hand, but it's easier to use the `urlencode` function provided by the `urllib.parse` module. Take a look at the following code:

```
>>> from urllib.parse import urlencode
>>> data = {'q': 'tkinter, python', 'ko': '-2', 'kz': '-1'}
>>> urlencode(data)
```

```
'q=tkinter%2C+python&ko=-2&kz=-1'
>>> response = urlopen('http://duckduckgo.com', data=urlencode(data).encode()
```

The `data` argument must be bytes, not a string, so `encode()` must be called on the URL-encoded string before `urlopen` will accept it.

Let's try downloading the weather data needed for our application. The site we'll be using is `http://weather.gov`, which provides weather data within the United States. The actual URL we'll be downloading is `http://w1.weather.gov/xml/current_obs/STATION.xml`, where `STATION` is replaced by the call-sign of the local weather station. In the case of ABQ, we'll be using KBMG, located in Bloomington, Indiana.

The QA team wants you to record the temperature (in degrees Celsius), relative humidity, air pressure (in millibars), and sky conditions (a string, like overcast or fair). They also need the date and time at which the weather was observed by the station.

Creating a download function

We're going to be creating several functions that access network resources for our application. These functions won't be tied to any particular class, so we'll just put them in their own file called `network.py`. Let's take a look at the following steps:

1. Create `network.py` in the `abq_data_entry` module directory.
2. Now, let's open `network.py` and start our weather download function:

```
from urllib.request import urlopen

def get_local_weather(station):
    url = (
        'http://w1.weather.gov/xml/current_obs/{}.xml'
        .format(station))
    response = urlopen(url)
```

   Our function will take a `station` string as an argument, in case we need to change that later or if someone wants to use this application at a different facility. The function begins by building the URL for the weather data and requests it using `urlopen()`.

3. Assuming things went okay, we just need to parse out this `response` data and put it into a form the `Application` class can pass to the database model. To determine how we'll handle the response, let's go back to the Python shell and examine the data in it:

```
>>> response = urlopen('http://w1.weather.gov/xml/current_obs/KBMG
>>> print(response.read().decode())
<?xml version="1.0" encoding="ISO-8859-1"?>
<?xml-stylesheet href="latest_ob.xsl" type="text/xsl"?>
<current_observation version="1.0"
         xmlns:xsd="http://www.w3.org/2001/XMLSchema"
         xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
         xsi:noNamespaceSchemaLocation="http://www.weather.gov/vie
        <credit>NOAA's National Weather Service</credit>
        <credit_URL>http://weather.gov/</credit_URL>
....
```

4. As the URL indicated, the payload of the response is an XML

document, most of which we won't need. After some searching, though, we can find the fields we're after as follows:

```
<observation_time_rfc822>Wed, 14 Feb 2018 14:53:00
-0500</observation_time_rfc822>
<weather>Fog/Mist</weather>
<temp_c>11.7</temp_c>
<relative_humidity>96</relative_humidity>
<pressure_mb>1018.2</pressure_mb>
```

Good, the data we need is there, so we just need to extract it from the XML string into a format our application can use. Let's take a moment to learn about parsing XML data.

Parsing XML weather data

The Python standard library contains an `xml` package, which consists of several submodules for parsing or creating XML data.
The `xml.etree.ElementTree` submodule is a simple, lightweight parser that should meet our needs.

Let's import `ElementTree` into our `network.py` file as follows:

```
from xml.etree import ElementTree
```

Now, back at the end of our function, we'll parse the XML data in our `response` object as follows:

```
    xmlroot = ElementTree.fromstring(response.read())
```

The `fromstring()` method takes an XML string and returns an `Element` object. To get at the data we need, we'll need to understand what an `Element` object represents, and how to work with it.

XML is a hierarchical representation of data; an element represents a node in this hierarchy. An element begins with a tag, which is a text string inside angle brackets. Each tag has a matching closing tag, which is just the tag with a forward-slash prepended to the tag name. Between the opening and closing tags, an element may have other child elements or it may have text. An element can also have attributes, which are key-value pairs placed inside the angle brackets of the opening tag, just after the tag name.

Take a look at the following example of XML:

```
<star_system starname="Sol">
  <planet>Mercury</planet>
  <planet>Venus</planet>
  <planet>Earth
    <moon>Luna</moon>
    </planet>
  <planet>Mars
    <moon>Phobos</moon>
    <moon>Deimos</moon>
    </planet>
  <dwarf_planet>Ceres</dwarf_planet>
</star_system>
```

This is an (incomplete) XML description of the solar system. The root element has a tag of `<star_system>` with an attribute of `starname`. Under this root element, we have four `<planet>` elements and a `<dwarf_planet>` element, each of which contains a text node with the planet's name. Some of the planet nodes also have child `<moon>` nodes, each containing a text node with the moon's name.

Arguably, this data could have been structured differently; for example, planet names could have been in a child `<name>` node inside the planet elements, or listed as an attribute of the `<planet>` tag. While XML syntax is well-defined, the actual structure of an XML document is up to the creator, so fully parsing XML data requires a knowledge of the way the data is laid out in the document.

If you look at the XML weather data that we downloaded in the shell earlier, you'll notice it's a fairly shallow hierarchy. Under the `<current_observations>` node, there are a number of child elements whose tags represent specific data fields like temperature, humidity, windchill, and so on.

To get at these child elements, `Element` offers us the following variety of methods:

Method	**Returns**
`iter()`	An iterator of all child nodes (recursively)
`find(tag)`	The first element matching the given tag
`findall(tag)`	A list of elements matching the given tag
`getchildren()`	A list of the immediate child nodes
`iterfind(tag)`	An iterator of all child nodes matching the given tag (recursive)

When we downloaded the XML data earlier, we identified five tags containing the data we want to extract from this document: `<observation_time_rfc822>`, `<weather>`, `<temp_c>`, `<relative_humidity>`, and `<pressure_mb>`. We'll want our `get_local_weather()` function to return a Python `dict` containing each of these keys.

Let's add the next lines in the `network.py` file as follows:

```
    xmlroot = ElementTree.fromstring(response.read())
    weatherdata = {
        'observation_time_rfc822': None,
        'temp_c': None,
        'relative_humidity': None,
        'pressure_mb': None,
        'weather': None
    }
```

Our first line extracts the raw XML from the response and parses it into an `Element` tree, returning the root node to `xmlroot`. Then, we've set up `dict` containing the tags we want to extract from our XML data.

Now, let's get the values by executing the following code:

```
    for tag in weatherdata:
        element = xmlroot.find(tag)
        if element is not None:
            weatherdata[tag] = element.text
```

For each of our tag names, we're going to use the `find()` method to try to locate the element with a matching tag in `xmlroot`. This particular XML document does not use duplicate tags, so the first instance of any tag should be the only one. If the tag is matched, we'll get back an `Element` object; if not, we get back `None`, so we need to make sure `element` is not `None` before trying to access its `text` value.

To finish the function just return `weatherdata` .

You can test this function in the Python shell; from a command line, navigate to the `ABQ_Data_Entry` directory and start a Python shell:

```
>>> from abq_data_entry.network import get_local_weather
>>> get_local_weather('KBMG')
{'observation_time_rfc822': 'Wed, 14 Feb 2018 16:53:00 -0500',
 'temp_c': '11.7', 'relative_humidity': '96', 'pressure_mb': '1017.0',
 'weather': 'Drizzle Fog/Mist'}
```

You should get back a `dict` with the current weather conditions in Bloomington, Indiana. You can find the station codes for other cities inside the U.S. at `http://w1.weather.gov/xml/current_obs/`.

Now that we have our weather function, we just need to build the table for storing the data and the interface for triggering the operation.

Implementing weather data storage

To store our weather data, we'll start by creating a table in the ABQ database to hold the individual observation data, then build a `SQLModel` method to store data in it. We don't need to worry about writing code to retrieve data from it, since our laboratory's QA team has their own reporting tools which they'll use to access it.

Creating the SQL table

Open the `create_db.sql` file, and add a new `CREATE TABLE` statement as follows:

```
CREATE TABLE local_weather (
        datetime TIMESTAMP(0) WITH TIME ZONE PRIMARY KEY,
        temperature NUMERIC(5,2),
        rel_hum NUMERIC(5, 2),
        pressure NUMERIC(7,2),
        conditions VARCHAR(32)
        );
```

We're using the `TIMESTAMP` data type on the record as a primary key; there's no point in saving the same timestamped observation twice, so this makes an adequate key. The `(0)` size after the `TIMESTAMP` data type indicates how many decimal places we need for the seconds' measurement. Since these measurements are taken approximately hourly, and we only need one every four hours or so (when the lab checks are done), we don't need fractions of seconds in our timestamp.

Notice that we're saving the time zone; always store time zone data with timestamps when it's available! It may not seem necessary, especially when your application will be run in a workplace that will never change time zones, but there are many edge cases such as daylight-saving time changes where the lack of a time zone can create major problems.

Run this `CREATE` query in your database to build the table, and let's move on to creating our `SQLModel` method.

Implementing the SQLModel.add_weather_data() method

Over in `models.py`, let's add a new method to the `SQLModel` class called `add_weather_data()`, which takes a data `dict` as its only argument.

Let's start this method by writing an `INSERT` query as follows:

```
    def add_weather_data(self, data):
        query = (
            'INSERT INTO local_weather VALUES '
            '(%(observation_time_rfc822)s, %(temp_c)s, '
            '%(relative_humidity)s, %(pressure_mb)s, '
            '%(weather)s)'
        )
```

This is a straightforward parameterized `INSERT` query using variable names that match the `dict` keys that the `get_local_weather()` function extracts from the XML data. We should only need to pass this query and the data `dict` into our `query()` method.

There is one problem, however; if we get a duplicate timestamp, our query will fail due to a duplicate primary key. We could do another query to check first, but that would be slightly redundant, since PostgreSQL itself checks for duplicate keys before inserting a new row. When it detects such an error, `psycopg2` raises an `IntegrityError` exception, so we just need to catch this exception and, if it gets raised, do nothing.

To do this, we'll wrap our `query()` call in the `try...except` blocks as follows:

```
        try:
            self.query(query, data)
        except pg.IntegrityError:
            # already have weather for this datetime
            pass
```

Now, our data entry staff can call this method as often as they wish, but it will only save a record when there is a fresh observation to save.

Updating the SettingsModel class

Before leaving `models.py`, we will need to add a new application setting to store the preferred weather station. Add a new entry in the `SettingsModel.variables` dictionary as follows:

```
    variables = {
        ...
        'weather_station': {'type': 'str', 'value': 'KBMG'},
        ...
```

We won't add a GUI for this setting, since users won't need to update it. It'll be up to us, or the system admin at other lab sites, to make sure this is properly set on each workstation.

Adding the GUI elements for weather download

The `Application` object now needs to connect the weather download method from `network.py` to the database method in `SQLModel` with an appropriate callback method that the main menu classes can call. Follow these steps:

1. Open `application.py` and start a new method as follows:

```
            def update_weather_data(self):

              try:
                   weather_data = n.get_local_weather(
                       self.settings['weather_station'].get())
```

2. Recall that in an error scenario, `urlopen()` can raise any number of exceptions, depending on what went wrong with the HTTP transaction. There isn't really anything the application can do to handle such exceptions other than inform the user and exit the method. Therefore, we'll catch the generic `Exception` and display the text in `messagebox` as follows:

```
                    except Exception as e:
                        messagebox.showerror(
                            title='Error',
                            message='Problem retrieving weather data',
                            detail=str(e)
                        )
                        self.status.set('Problem retrieving weather data')
```

3. In the event that `get_local_weather()` succeeds, we simply need to pass the data on to our model method as follows:

```
                else:
                    self.data_model.add_weather_data(weather_data)
                    self.status.set(
                        'Weather data recorded for {}'
                        .format(weather_data['observation_time_rfc822']))
```

   In addition to saving the data, we've notified the user in the status bar that the weather was updated and displayed the timestamp of the update.

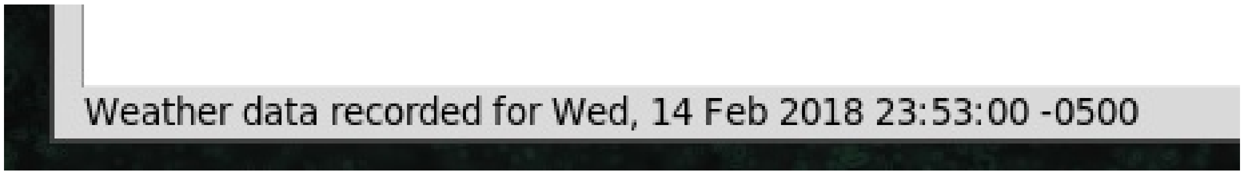
4. With the callback method done, let's add it to our `callbacks` dictionary:

```
        self.callbacks = {
            ...
            'update_weather_data': self.update_weather_data,
            ...
```

5. Now we can now add a command item for the callback in the main menu. On Windows, functionality like this goes in the `Tools` menu, and since neither the Gnome nor macOS guidelines seem to indicate a more appropriate location, we'll implement a `Tools` menu in the `LinxMainMenu` and `MacOsMainMenu` classes to hold this command, just to be consistent. In `mainmenu.py`, starting in the generic menu class, add a new menu as follows:

```
        #Tools menu
        tools_menu = tk.Menu(self, tearoff=False)
        tools_menu.add_command(
            label="Update Weather Data",
            command=self.callbacks['update_weather_data'])
        self.add_cascade(label='Tools', menu=tools_menu)
```

6. Add this same menu to the macOS and Linux menu classes, and add the command to the Windows main menu's `tools_menu`. After updating the menus, you can run the application and try the new command from the `Tools` menu. If all went well, you should see an indication in the status bar as shown in the following screenshot:



Weather data recorded for Wed, 14 Feb 2018 23:53:00 -0500

7. You should also connect to the database with your PostgreSQL client and check that the table contains some weather data now by executing the following SQL command:

```
        SELECT * FROM local_weather;
```

That SQL statement should return output similar to the following:

datetime	temperature	rel$_{hum}$	pressure	conditions
2018-02-14 22:53:00-06	15.00	87.00	1014.00	Overcast

HTTP using requests

You've been asked to create a function in your program to upload a CSV extract of the daily data to ABQ's corporate web services, which uses an authenticated REST API. While `urllib` is easy enough to use for simple one-off `GET` and `POST` requests, complex interactions involving authentication tokens, file uploads, or REST services can be frustrating and complicated using `urllib` alone. To get this done, we'll turn to the `requests` library.

__REST__ stands for __REpresentational State Transfer__, and is the name used for web services built around advanced HTTP semantics. In addition to `GET` and `POST`, REST APIs use additional HTTP methods like `DELETE`, `PUT`, and `PATCH`, along with data formats like XML or JSON, to present an API with a complete range of interactions.

The third-party `requests` library is highly recommended by the Python community for any serious work involving HTTP (even the `urllib` documentation recommends it). As you'll see, `requests` removes many of the rough edges and outdated assumptions left in `urllib`, and provides convenient classes and wrapper functions for more modern HTTP transactions. Complete documentation on `requests` can be found at `http://docs.python-requests.org`, but the next section will cover most of what you need to know to use it effectively.

Installing and using requests

The `requests` package is written in pure Python, so installing it with `pip` requires no compiling or binary downloads. Simply type `pip install --user requests` in the terminal and it will be added to your system.

Open your Python shell, and let's make some requests as follows:

```
>>> import requests
>>> response = requests.request('GET', 'http://www.alandmoore.com')
```

`requests.request` requires, at minimum, an HTTP method and a URL. Just like `urlopen()`, it constructs the appropriate request packet, sends it to the URL, and returns an object representing the server's response. Here, we're making a `GET` request to this author's website.

In addition to the `request()` function, `requests` has shortcut functions that correspond to the most common HTTP methods.

Thus, the same request can be made as follows:

```
response = requests.get('http://www.alandmoore.com')
```

The `get()` method requires only the URL and performs a `GET` request. Likewise, the `post()`, `put()`, `patch()`, `delete()`, and `head()` functions send requests using the corresponding HTTP method. All of the request functions take additional optional arguments.

For example, we can send data with a `POST` request as follows:

```
>>> response = requests.post(
    'http://duckduckgo.com',
    data={'q': 'tkinter', 'ko': '-2', 'kz': '-1'})
```

Notice that, unlike `urlopen()`, we can use a Python dictionary directly as a `data` argument; `requests` does the job of converting it to the proper bytes object for us.

Some of the more common arguments used with request functions are as follows:

Argument	**Purpose**
`params`	Like `data`, but added to the query string rather than the payload
`json`	JSON data to include in the payload
`headers`	A dictionary of header data to use for the request
`files`	A dictionary of `{fieldnames: file objects}` to send as a multipart form data request
`auth`	Username and password tuple to use for basic HTTP digest authentication

The requests.session() fucntion

Web services, particularly privately owned ones, are often password protected. Sometimes, this is done using the older HTTP digest authentication system, which we can address using the `auth` argument of the request functions. More commonly these days though, authentication involves posting credentials to a REST endpoint to obtain a session cookie or authentication token that is used to validate subsequent requests.

An endpoint is simply a URL that corresponds to data or functionality exposed by the API. Data is sent to or retrieved from an endpoint.

The `requests` method makes all of this simple by providing the `Session` class. A `Session` object allows you to persist settings, cookies, and connections across multiple requests.

To create a `Session` object, use the `requests.session()` factory function as follows:

```
s = requests.session()
```

Now, we can call request methods like `get()`, `post()`, and others on our `Session` object as follows:

```
# Assume this is a valid authentication service that returns an auth token
s.post('http://example.com/login', data={'u': 'test', 'p': 'test'})
# Now we would have an auth token
response = s.get('http://example.com/protected_content')
# Our token cookie would be listed here
print(s.cookies.items())
```

Token and cookie handling like this happens in the background, without any explicit action from us. Cookies are stored in a `CookieJar` object stored as our `Session` object's `cookies` property.

We can also set values on our `Session` object that will persist across requests as in this example:

```
s.headers['User-Agent'] = 'Mozilla'
```

```
# will be sent with a user-agent string of "Mozilla"
s.get('http://example.com')
```

In this example, we've set the user-agent string to `Mozilla`, which will be used for all requests made from this `Session` object. We can also set default URL parameters using the `params` property or callback functions using the `hooks` property.

The response objects

The response objects returned from these request functions are not the same as those returned by `urlopen()`; they contain all the same data, but in a slightly different (and generally more convenient) form.

For example, the response headers are already translated into a Python `dict` for us, as follows:

```
>>> r = requests.get('http://www.alandmoore.com')
>>> r.headers
{'Date': 'Thu, 15 Feb 2018 21:13:42 GMT', 'Server': 'Apache',
 'Last-Modified': 'Sat, 17 Jun 2017 14:13:49 GMT',
 'ETag': '"20c003f-19f7-5945391d"', 'Content-Length': '6647',
 'Keep-Alive': 'timeout=15, max=200', 'Connection': 'Keep-Alive',
 'Content-Type': 'text/html'}
```

Another difference is that `requests` does not automatically raise an exception on HTTP errors. However, the `.raise_for_status()` response method can be called to do so.

For example, this URL will give an HTTP `404` error, as shown in the following code:

```
>>> r = requests.get('http://www.example.com/does-not-exist')
>>> r.status_code
404
>>> r.raise_for_status()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "/usr/lib/python3.6/site-packages/requests/models.py", line 935, in ra
    raise HTTPError(http_error_msg, response=self)
requests.exceptions.HTTPError: 404 Client Error: Not Found for url: http://ww
```

This gives us the option of dealing with HTTP errors using exception handling or more traditional flow control logic.

Implementing API upload

To start implementing our upload function, we need to figure out what kind of requests we're going to send. We've been provided with some documentation from the corporate office that describes how to interact with the REST API.

The documentation tells us the following things:

- We first need to obtain an authentication token. We do this by submitting a `POST` request to the `/auth` endpoint. The parameters of the `POST` request should include `username` and `password`.
- With the authentication token acquired, we'll need to submit our CSV file. The request is a `PUT` request sent to the `/upload` endpoint. The file is uploaded as multipart form data specified in a `file` parameter.

We already know enough to implement our REST upload function using `requests`, but before we do, let's create a service that we can use to test our code against it.

Creating a test HTTP service

Developing code that interoperates with an outside service can be frustrating. We're going to need to send a lot of bad or test data to the service while writing and debugging our code; we don't want to do so against a production service, and a "test mode" is not always available. Automated tests can use a `Mock` object to patch out network requests altogether, but during development, it's nice to be able to see what's actually going to be sent out to the web service.

Let's implement a very simple HTTP server that will accept our requests and print out information about what it receives. We can do this using the Python standard library's `http.server` module.

The module documentation shows the following example of a basic HTTP server:

```
from http.server import HTTPServer, BaseHTTPRequestHandler
def run(server_class=HTTPServer, handler_class=BaseHTTPRequestHandler):
    server_address = ('', 8000)
    httpd = server_class(server_address, handler_class)
    httpd.serve_forever()
run()
```

The server class, `HTTPServer`, defines an object that listens for HTTP requests on the configured address and port. The handler class, `BaseHTTPRequestHandler`, defines an object that receives the actual request data and returns response data. We'll use this code as a starting point, so save it outside the `ABQ_Data_Entry` directory in a file called `sample_http_server.py`.

If you run this code, you'll have a web service running on port `8000` on your local computer; however, if you make any requests to this service either using `requests`, a tool like `curl`, or just a web browser, you'll find it only returns an HTTP `501` (`unsupported method`) error. To make a server that works sufficiently, like our target API for testing purposes, we'll need to create our own handler class that can respond to the necessary HTTP methods.

To do that, we'll create our own handler class called `TestHandler` as follows:

```
class TestHandler(BaseHTTPRequestHandler):
    pass

def run(server_class=HTTPServer, handler_class=TestHandler):
    ...
```

Our corporate API uses the `POST` method to receive login credentials, and the `PUT` method to receive files, so both of those need to work. To make an HTTP method work in a request handler, we need to implement a `do_VERB` method, where `VERB` is our HTTP method name in all uppercase.

So, for `PUT` and `POST` add the following code:

```
class TestHandler(BaseHTTPRequestHandler):
    def do_POST(self, *args, **kwargs):
        pass

    def do_PUT(self, *args, **kwargs):
        pass
```

This alone doesn't address the problem, because these methods need to result in our handler sending some kind of response. We don't need any particular response for our purposes; just something with a status of `200` (`OK`) will do fine.

Since both methods need this, let's add a third method we can call from the other two as follows:

```
    def _send_200(self):
        self.send_response(200)
        self.send_header('Content-type', 'text/html')
        self.end_headers()
```

This is about the most minimal response required to satisfy most HTTP clients: a status of `200` and a header with a valid `Content-type`. This won't send any actual data back to the client, but will tell the client its request was received and successfully processed.

Something else we'd like to do in our methods is print out any data that was sent, so we can make sure our client is sending the right data.

We'll implement the following method that does this:

```
    def _print_request_data(self):
        content_length = self.headers['Content-Length']
        print("Content-length: {}".format(content_length))
        data = self.rfile.read(int(content_length))
        print(data.decode('utf-8'))
```

The handler object's `headers` property is a `dict` object containing the request headers, which includes the number of bytes sent (`content-length`). Apart from printing that information, we can also use it to read the data sent. The handler's `rfile` property is a file-like object containing the data; its `read()` method requires a length argument to specify how much data should be read, so we use our extracted `content-length` value. The returned data is a `bytes` object, so we decode it to `utf-8`.

Now that we have these two methods, let's update `do_POST()` and `do_PUT()` to call them as follows:

```
    def do_POST(self, *args, **kwargs):
        print('POST request received')
        self._print_request_data()
        self._send_200()

    def do_PUT(self, *args, **kwargs):
        print("PUT request received")
        self._print_request_data()
        self._send_200()
```

Now, each method will print out the length and data it receives to `POST` or `PUT` as well as any data. Run this script in a terminal window so you can monitor its output.

Now, open a shell and let's test it as follows:

```
>>> import requests
>>> requests.post('http://localhost:8000', data={1: 'test1', 2: 'test2'})
<Response[200]>
```

In the web server terminal, you should see the following output:

```
POST request received
Content-length: 15
1=test1&2=test2
127.0.0.1 - - [15/Feb/2018 16:22:41] "POST / HTTP/1.1" 200 -
```

We could implement additional functionality, like actually checking credentials and returning an authentication token, but for now this server does enough to help us write and test our client code.

Creating our network function

Now that our test service is up and running, let's start working on the network function that will interact with the REST API:

1. We'll start by creating a function in `network.py` that will take a path to the CSV file, the upload and authentication URLs, and a username and password:

```
    import requests

    ...

    def upload_to_corporate_rest(
        filepath, upload_url, auth_url, username, password):
```

2. Since we're going to have to deal with authentication tokens, the first thing we should do is create a session. We'll call it `session` as follows:

```
    session = requests.session()
```

3. After creating the session, we post our username and password to the authentication endpoint like so:

```
    response = session.post(
        auth_url,
        data={'username': username, 'password': password})
    response.raise_for_status()
```

   The `session` object will automatically store the token we receive if we're successful. In the event of a problem, we've called `raise_for_status()`, so that the function will abort and the calling code can handle any exceptions raised by network or data problems.

4. Assuming we haven't raised an exception, we must be authenticated at this point and can now submit the file. This will be done with a `put()` call as follows:

```
        files = {'file': open(filepath, 'rb')}
        response = session.put(
            upload_url,
            files=files
        )
```

To send a file, we have to actually open it and pass it into `put()` as a file handle; notice we open it in binary-read mode (`rb`). The `requests` documentation recommends this as it ensures the correct `content-length` value will be calculated for the header.

5. After sending the request, we close the file and check again for a failed status before ending the function, like so:

```
            files['file'].close()
            response.raise_for_status()
```

Updating application

Before we can call our new function from `Application`, we need to implement a way to create a CSV extract of the daily data. This will be used by more than one function, so we'll implement it separately from the function that calls the upload code. Follow along with these steps:

1. To begin, we'll need a temporary location to store our generated CSV file. The `tempfile` module includes functions to work with temporary files and directories; we'll import `mkdtemp()`, which will give us a name for a platform-specific temporary directory.:

```
from tempfile import mkdtemp
```

Note that `mdktemp()` doesn't actually create a directory; it merely provides an absolute path to a randomly named directory in the platform's preferred `temp` file location. We'll have to create the directory ourselves.

2. Now, let's start our new `Application` method as follows:

```
    def _create_csv_extract(self):
        tmpfilepath = mkdtemp()
        csvmodel = m.CSVModel(
            filename=self.filename.get(), filepath=tmpfilepath)
```

   After creating a temporary directory name, we've created an instance of our `CSVModel` class; even though we're no longer storing our data in the CSV files, we can still use the model to export a CSV file. We've passed the `Application` object's default filename, which is still set to `abq_data_record-CURRENTDATE.csv`, and also the temporary directory's path as `filepath`. Of course, our `CSVModel` doesn't currently take a `filepath`, but we'll fix that in a moment.

3. After creating the CSV model, we'll extract our records from the database as follows:

```
        records = self.data_model.get_all_records()
        if not records:
            return None
```

   Remember that our `SQLModel.get_all_records()` method returns a list of all records for the current day by default. If we don't happen to have any records for the day, it's probably best to stop right away and alert the user, rather than sending an empty CSV file to corporate, so we return `None` from the method if there are no records. Our calling code can test for a `None` return value and display the appropriate warning.

4. Now all we need to do is iterate through the records and save each one to the CSV, then return the `CSVModel` object's filename, like this:

```
    for record in records:
        csvmodel.save_record(record)

    return csvmodel.filename
```

5. Now that we have a way to create a CSV extract file, we can write the callback method as follows:

```
        def upload_to_corporate_rest(self):

            csvfile = self._create_csv_extract()

            if csvfile is None:
                messagebox.showwarning(
                    title='No records',
                    message='There are no records to upload'
                )
                return
```

   To begin, we created a CSV extract file and checked if it's `None`. If it is, we'll display an error message and exit the method.

6. Before we can upload, we need to get a username and password from the user. Fortunately, we have the perfect class for this:

```
            d = v.LoginDialog(
                self,
                'Login to ABQ Corporate REST API')
            if d.result is not None:
                username, password = d.result
            else:
                return
```

   Our login dialog serves us well here. Unlike with our database login, we're not going to run this in an endless loop; if the password is wrong, the user can just rerun the command. Recall that `result` will be

`None` if the user clicks Cancel, so we'll just exit the callback method in that case.

7. Now, we can execute our network function as follows:

```
        try:
            n.upload_to_corporate_rest(
                csvfile,
                self.settings['abq_upload_url'].get(),
                self.settings['abq_auth_url'].get(),
                username,
                password)
```

   We're executing `upload_to_corporate_rest()` in a `try` block since there are a number of exceptions it might raise. We're passing in the upload and authentication URLs from our settings object; we haven't added those yet, so that will need to happen before we're done.

8. Now, let's catch a few exceptions, starting with the `RequestException`. This exception would happen if there were some problem with the data we were sending to the API, most likely a wrong username and password. We'll attach the exception string to the message we show the user, like so:

```
        except n.requests.RequestException as e:
            messagebox.showerror('Error with your request', str(e))
```

9. Next we'll catch `ConnectionError`; this exception is going to be the result of a network problem, such as the internet connection at the lab being down, or the server not responding:

```
        except n.requests.ConnectionError as e:
            messagebox.showerror('Error connecting', str(e))
```

10. Any other exception will just be displayed as `General Exception`, like so:

```
        except Exception as e:
            messagebox.showerror('General Exception', str(e))
```

11. Let's wrap up the method with a success dialog as follows:

```
        else:
            messagebox.showinfo(
                'Success',
                '{} successfully uploaded to REST API.'
                .format(csvfile))
```

12. Let's finish our changes to `Application` by adding this method to `callbacks` as follows:

```
                self.callbacks = {
                    ...
                    'upload_to_corporate_rest':
                   self.upload_to_corporate_rest,
                    ...
```

Updating the models.py file

There are a couple of things to fix in the `models.py` file before we can test our new functionality. We'll go through these steps to address them:

1. First, our `CSVModel` class needs to be able to take `filepath`:

```
    def __init__(self, filename, filepath=None):
        if filepath:
            if not os.path.exists(filepath):
                os.mkdir(filepath)
            self.filename = os.path.join(filepath, filename)
        else:
            self.filename = filename
```

   If `filepath` is specified, we need to first make sure the directory exists. Since the `mkdtmp()` method called in the `Application` class does not actually create a temporary directory, we'll create it here. Once that's done, we'll join the `filepath` and `filename` values and store it in the `CSVModel` object's `filename` property.

2. The other thing we need to do in `models.py` is add our new settings. Scroll down to the `SettingsModel` class, and add two more `variables` entries as follows:

```
            variables = {
                ...
                'abq_auth_url': {
                    'type': 'str',
                    'value': 'http://localhost:8000/auth'},
                'abq_upload_url': {
                    'type': 'str',
                    'value': 'http://localhost:8000/upload'},
                 ...
```

We won't be building a GUI to set these settings they'll need to be manually created in a user's configuration file, though for testing, we can use the defaults.

Finishing up

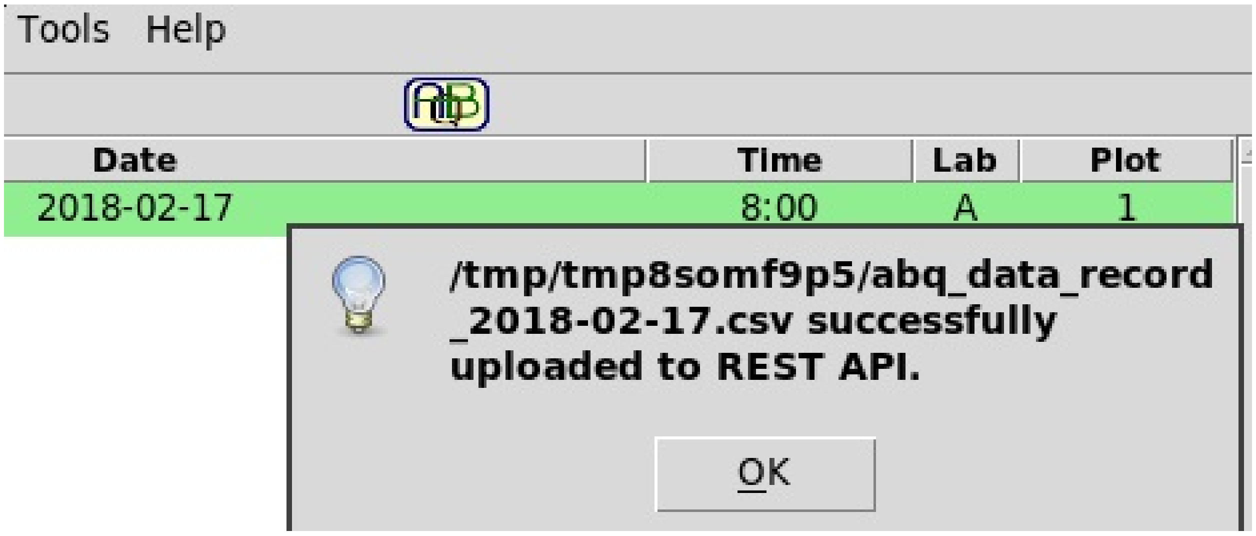
The last thing to do is add the command to our main menu.

Add a new entry to the `tools_menu` in each menu class:

```
        tools_menu.add_command(
            label="Upload CSV to corporate REST",
            command=self.callbacks['upload_to_corporate_rest'])
```

Now, run the application and let's try it out. To make it work, you'll need to have at least one data entry, and you'll need to start up the `sample_http_server.py` script.

If all goes well, you should get a dialog like this:



Date	Time	Lab	Plot
2018-02-17	8:00	A	1

/tmp/tmp8somf9p5/abq_data_record_2018-02-17.csv successfully uploaded to REST API.

Your server should also have printed some output to the terminal similar to this:

```
POST request received
Content-length: 27
username=test&password=test
127.0.0.1 - - [16/Feb/2018 10:17:22] "POST /auth HTTP/1.1" 200 -
PUT request received
Content-length: 397
--362eadeb828747769e75d5b4b6d32f31
Content-Disposition: form-data; name="file"; filename="abq_data_record_2018-0
```

```
Date,Time,Technician,Lab,Plot,Seed sample,Humidity,Light,Temperature,Equipmen
2018-02-16,8:00,Q Murphy,A,1,AXM477,10.00,10.00,10.00,,1,2,3,1.00,3.00,2.00,"
"

--362eadeb828747769e75d5b4b6d32f31--

127.0.0.1 - - [16/Feb/2018 10:17:22] "PUT /upload HTTP/1.1" 200 -
```

Notice the POST and PUT requests, as well as the raw text of the CSV file in the payload of PUT. We have successfully met the API requirements for this function.

FTP using ftplib

While HTTP and REST APIs are the current trend in client-server interactions, it's not unusual for businesses to rely on older, time tested, and sometimes obsolete technology to implement data transfers. ABQ is no exception: in addition to the REST upload, you need to implement support for ABQ corporate's legacy system that relies on FTP.

Basic concepts of FTP

File Transfer Protocol, or **FTP**, dates back to the early 1970s, predating HTTP by almost 20 years. Nevertheless, it's still commonly used by many organizations to exchange large files over the internet. FTP is considered somewhat obsolete in many circles due in part to the fact that it transmits data and credentials in clear text, though SSL-encrypted variants of FTP are also available.

Like HTTP, FTP clients send requests containing plain text commands similar to HTTP methods, and the FTP server returns a response packet containing header and payload information.

There are, however, many significant differences between the two protocols:

- FTP is a **stateful connection**, meaning the client and server maintain a constant connection over the course of the session. In other words, FTP is more like a live telephone call, whereas HTTP is like two people having a dialog over voicemail.
- FTP requires a session to be authenticated before any other commands or data are sent, even for anonymous users. FTP servers also implement a more complex set of permissions.
- FTP has separate modes for transferring text and binary data (the main difference being that text mode transfers automatically correct line endings and encoding for the receiving OS).
- FTP servers are less consistent in their implementation of commands.

Creating a test FTP service

Before we implement our FTP upload functionality, it's helpful to have a test FTP service, just as we did with our test HTTP service. You can, of course, download any of a number of free FTP servers such as FileZilla, PureFTPD, ProFTPD, or others.

Rather than going to the trouble of installing, configuring, and later removing an FTP service on your system just for testing one function of an application, we can instead build a rudimentary server in Python. The third-party `pyftpdlib` package offers us an easy way to implement a quick-and-dirty FTP server adequate for test needs.

Install `pyftpdlib` using `pip`:

```
pip install --user pyftpdlib
```

Just like our simple HTTP server, the FTP service consists of a *server* object and a *handler* object. It also needs an *authorizer* object to handle authentication and permissions.

We'll start our `basic_ftp_server.py` file by importing those:

```
from pyftpdlib.authorizers import DummyAuthorizer
from pyftpdlib.handlers import FTPHandler
from pyftpdlib.servers import FTPServer
```

To make sure our authentication code works properly, let's set up our `DummyAuthorizer` class with a test user:

```
auth = DummyAuthorizer()
auth.add_user('test', 'test', '.', perm='elrw')
```

The `perm` argument takes a string of characters, each of which represents a specific permission on the server. In this case, we have `e` (connect), `l` (list), `r` (read), and `w` (write new file). There are many other permissions available, all of which are off by default until granted, but this is sufficient for our needs.

Now, let's set up the handler:

```
handler = FTPHandler
handler.authorizer = auth
```

Notice we're not instantiating the handler, just aliasing the class. The server class will manage the creation of handler classes. We can, however, assign our `auth` object as the handler's `authorizer` class, so that any created handlers will use our authorizer.

Finally, let's set up and run the server portion:

```
address = ('127.0.0.1', 2100)
server = FTPServer(address, handler)

server.serve_forever()
```

This is simply a matter of instantiating an `FTPServer` object with an address tuple and handler class, then calling the object's `server_forever()` method. The address tuple is in the form `(ip_address, port)`, so a tuple of `('127.0.0.1', 2100)` means we'll be serving on our computer's loopback address on port `2100`. The default port for FTP is usually 21, but on most operating systems, starting a service that listens on a port under `1024` requires root or system-admin privileges. For simplicity's sake, we'll just use a higher port.

TIP *While it's possible to build production quality FTP servers with `pyftpdlib`, we haven't done that here. This script is adequate for testing, but please don't use it in production if you value security.*

Implementing the FTP upload function

Now that the test server is up and running, let's build our FTP upload function and the logic for the GUI. While the standard library doesn't contain an FTP server library, it does contain an FTP client library in the form of the `ftplib` module.

Begin by importing `ftplib` into our `network.py` file:

```
import ftplib as ftp
```

An FTP session can be created using the `ftplib.FTP` class. Because this is a stateful session, it needs to be closed after we're done; to make sure we do this, `FTP` can be used as a context manager.

Let's start our function by connecting to the FTP server:

```
def upload_to_corporate_ftp(
        filepath, ftp_host,
        ftp_port, ftp_user, ftp_pass):

    with ftp.FTP() as ftp_cx:
        ftp_cx.connect(ftp_host, ftp_port)
        ftp_cx.login(ftp_user, ftp_pass)
```

The `upload_to_corporate()` function takes the CSV filepath and the `FTP` host, port, user, and password, much like our `upload_to_corporate_rest()` function did. We begin by creating our `FTP` object and calling `FTP.connect()` and `FTP.login`.

Next, `connect()` takes the host and port that we're going to talk to and starts a session with the server. We aren't yet authenticated at this point, but we do have a connection going.

Then, `login()` takes a username and password and attempts to authenticate our session. If our credentials check out, we're logged in to the server and can begin sending more commands; if not, an `error_perm` exception is raised.

However, our session is still alive until we close it, and we can send additional login attempts if we wish.

To actually upload a file, we use the `storbinary()` method:

```
        filename = path.basename(filepath)
        with open(filepath, 'rb') as fh:
            ftp_cx.storbinary('STOR {}'.format(filename), fh)
```

To send the file, we have to open it in binary-read mode, then call `storbinary` (yes, it's "stor", not "store"—programmers in the 1970s had a thing about dropping letters from words).

The first argument to `storbinary` is a valid FTP `STOR` command, usually `STOR filename`, where "filename" is what you want the uploaded data to be called on the server. It seems a little counter-intuitive to have to include the actual command string; presumably this must be specified in case the server uses slightly different commands or syntax.

The second argument is the file object itself. This should be opened in binary mode since we're sending it as binary data. This may seem odd since the CSV file we're sending is essentially a plain text file, but sending it as binary data guarantees that the server won't change the file in any way during transit; this is nearly always what you want when transferring files, regardless of the nature of the data being exchanged.

This is all our network function needs to do for FTP upload. Although we only needed the `storbinary()` method for our program, it's worth noting a few other common `ftp` methods in case you find yourself having to work with an FTP server.

Listing files

There are three methods for listing files on an FTP server. The `mlsd()` method calls the `MLSD` command, which is typically the best and most complete output available. It can take an optional `path` argument, specifying the path to list (otherwise it lists the current directory), and a list of `facts` , such as "size", "type", or "perm", reflecting which data you'd like included with the filenames. The `mlsd()` command returns a generator object which can be iterated or cast to another sequence type.

`MLSD` is a newer command and not always available, so there are two other methods available, `nlst()` and `dir()`, which correspond to the older `NLST` and `DIR` commands. Both methods accept an arbitrary number of arguments that will be appended verbatim to the command string sent to the server.

Retrieving files

Downloading files from an FTP server involves either one of the `retrbinary()` or `retrlines()` methods, depending on whether we wish to use binary or text mode (as mentioned before, you should probably always use binary). Like `storbinary`, each method takes a command string as its first argument, but in this case it should be a valid `RETR` command (usually "RETR filename" will suffice).

The second argument is a callback function which will be called on every line (for `retrlines()`) or chunk (for `retrbinary()`). This callback can be used to store the downloaded data.

For example, take a look at the following code:

```
from ftplib import FTP
from os.path import join

filename = 'raytux.jpg'
path = '/pub/ibiblio/logos/penguins'
destination = open(filename, 'wb')
with FTP('ftp.nluug.nl', 'anonymous') as ftp:
    ftp.retrbinary(
        'RETR {}'.format(join(path, filename)),
        destination.write)
destination.close()
```

The return value of each function is a result string containing some statistics about the download as follows:

```
'226-File successfully transferred\n226 0.000 seconds (measured here), 146.96
```

Deleting or renaming files

Deleting and renaming files using `ftplib` is mercifully simple by comparison. The `delete()` method takes only a filename and attempts to delete the given file on the server. The `rename()` method takes only a source and destination, and attempts to rename the source to the destination name.

Naturally, the success of either method depends on the permissions granted to the login account used.

Adding FTP upload to the GUI

Our FTP upload function is ready to go, so let's add the necessary bits to the rest of our application to make it all work together.

We'll start by adding the FTP host and port to the `SettingsModel` in `models.py`:

```
    variables = {
        ...
        'abq_ftp_host': {'type': 'str', 'value': 'localhost'},
        'abq_ftp_port': {'type': 'int', 'value': 2100}
        ...
```

Remember that our test FTP uses port `2100`, not the usual port `21`, so we'll make `2100` the default for now.

Now, we'll move over to `application.py` and create the callback method that will create the CSV file and pass it to the FTP upload function.

Create a new method in the `Application` object:

```
    def upload_to_corporate_ftp(self):
        csvfile = self._create_csv_extract()
```

The first thing we do is create our CSV file, using the method we created for the `REST` upload.

Next, we'll ask the user for the FTP username and password:

```
        d = v.LoginDialog(
            self,
            'Login to ABQ Corporate FTP')
```

And now, we'll call our network function:

```
        if d.result is not None:
            username, password = d.result
            try:
                n.upload_to_corporate_ftp(
                    csvfile,
                    self.settings['abq_ftp_host'].get(),
                    self.settings['abq_ftp_port'].get(),
                    username,
                    password)
```

We call the FTP upload function in a `try` block because there are several exceptions that can be raised by our FTP process.

Rather than catching them individually, we can catch `ftplib.all_errors`:

```
            except n.ftp.all_errors as e:
                messagebox.showerror('Error connecting to ftp', str(e))
```

Note that `ftplib.all_errors` is the base class for all exceptions defined in `ftplib`, which include, among other things, authentication errors, permission errors, and connectivity errors.

To end this method, we'll show a success message:

```
            else:
                messagebox.showinfo(
                    'Success',
                    '{} successfully uploaded to FTP'.format(csvfile))
```

With the callback method written, we need to add it to the `callbacks` dictionary:

```
        self.callbacks = {
            ...
            'upload_to_corporate_ftp': self.upload_to_corporate_ftp
        }
```

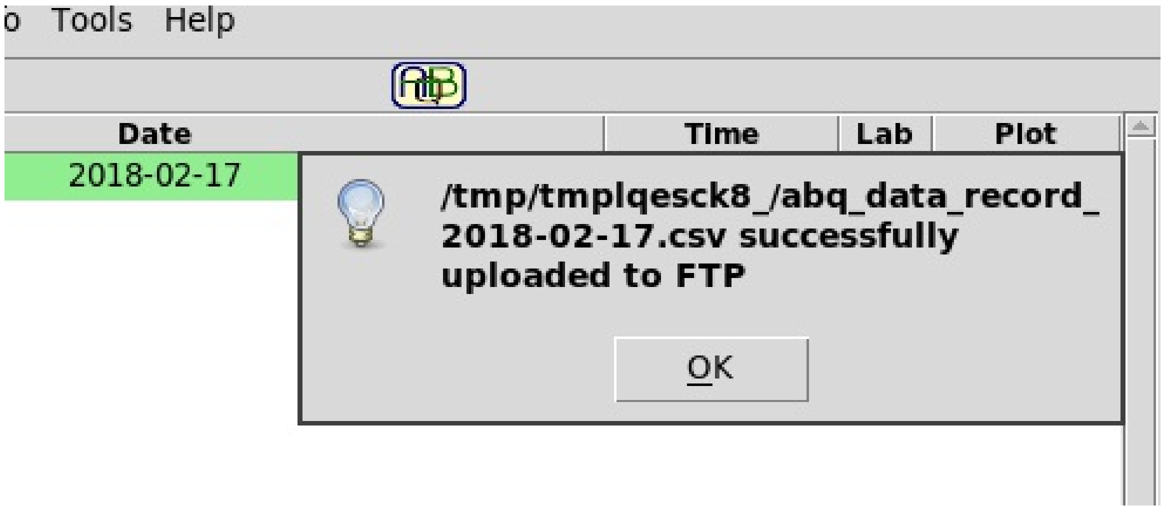
The last thing we need to do is to add our callback to the main menu classes.

Over in `mainmenu.py`, add a new command to the `tools_menu` in each class:

```
        tools_menu.add_command(
            label="Upload CSV to corporate FTP",
            command=self.callbacks['upload_to_corporate_ftp'])
```

Launch the sample FTP server in a terminal, then run your application and try out the FTP upload. Remember to enter `test` for the username and password!

You should see a success dialog like this:



/tmp/tmplqesck8_/abq_data_record_2018-02-17.csv successfully uploaded to FTP

Likewise, there should be a new CSV file in whatever directory you ran the sample FTP server from.

The FTP server should have printed out some information like this:

```
127.0.0.1:32878-[] FTP session opened (connect)
127.0.0.1:32878-[test] USER 'test' logged in.
127.0.0.1:32878-[test] STOR /home/alanm/FTPserver/abq_data_record_2018-02-17.
127.0.0.1:32878-[test] FTP session closed (disconnect).
```

Looks like our FTP upload works great!

Summary

In this chapter, we reached out to the cloud using HTTP and FTP. You learned how to download data using `urllib` and parse XML using `ElementTree`. You also discovered the `requests` library and learned the basics of interacting with a REST API. Finally, we learned how to download and upload files to FTP using Python's `ftplib`.

In the next chapter, we'll stop long-running processes from freezing up our application and improve our application's performance by learning about asynchronous programming. We'll learn the asynchronous commands built in to Tkinter as well as advanced asynchronous programming using Python's `threading` library.

Asynchronous Programming with Thread and Queue

Many times, code that works flawlessly in the simplicity of a test environment encounters problems in the real world; unfortunately, this seems to be the case for your application. While your network functions ran instantaneously in your localhost-only test environment, the lab's slow VPN uplink has exposed some shortcomings in your programming. Users report that the application freezes or becomes unresponsive when network transactions are taking place. Although it does work, it looks unprofessional and is an annoyance to users.

To solve this problem, we're going to learn about the following topics:

- How to control Tkinter's event queue
- How to write multithreaded applications using Python's `threading` module
- How to pass messages between threads using queues

Tkinter's event queue

As we discussed in `Chapter 10`, *Creating Automated Tests with unittest*, many tasks in Tkinter, such as drawing and updating widgets, are done asynchronously, rather than taking immediate action when called in code. More specifically, the actions you perform in Tkinter—clicking a button, triggering a key bind or trace, resizing a window—place an event in the event queue. On each iteration of the main loop, Tkinter pulls one event from the queue and executes it.

Tasks in the event queue are roughly prioritized as regular or do-when-idle (often just called **idle tasks**), meaning they are to be run when every regular task in the queue has been done. Most drawing or widget-updating tasks are idle tasks, while actions like callbacks are, by default, regular priority.

Because of this, a callback task that blocks for an extended period of time can cause the program to seem frozen or stuck at an awkward point, since draw events and other idle tasks are waiting for it to complete.

For this reason, it's sometimes helpful to be able to control the event queue manually to delay long-running tasks to a more opportune moment.

The after() and after_idle() methods

Tkinter widgets have two methods for adding arbitrary code to the event queue on a delay: `after()` and `after_idle()`.

Basic use of `after()` looks like this:

```
import tkinter as tk
root = tk.Tk()
root.after(1000, root.quit)
root.mainloop()
```

In this example, we're setting `root.quit` to run after 1 second (1,000 milliseconds). In the background, `root.quit` is added to the event loop, but with the condition that it shouldn't be executed until at least 1 second from when `after()` was called. During that 1 second, any other events in the queue will be executed first. The command might be executed later than 1 second, depending on what's being processed already in the event queue, but no sooner.

The `after_idle()` method also adds a Python callable to the event loop, but simply adds it as an idle task, rather than adding it on a delay. This ensures the code will be run after any other explicit callbacks.

In both methods, additional arguments are simply passed to the callable:

```
root.after(1000, print, 'hello', 'Python', 'programmers!')
```

In this example, we're passing the arguments `'hello'`, `'Python'`, and `'programmers'` to a `print()` call. This statement will schedule the `print('hello', 'Python', 'programmers!')` command to be run after 1 second.

TIP *Note that `after()` and `after_idle()` cannot take keyword arguments for the passed callable, only positional arguments.*

The update() and update_idletasks() methods

In `Chapter 10`, *Creating Automated Tests with unittest*, you also learned about the `update()` and `update_idletasks()` methods. To review, these methods will cause Tkinter to execute any tasks currently in the event queue; `update()` runs tasks currently waiting in the queue until it's entirely clear, while `update_idletasks()` only runs the idle tasks. This is generally less important and safer code, so it's recommended to use `update_idletasks()` unless it doesn't do the job.

Eliminating freezes with after() and update_idletasks ()

To better understand the use of these widget methods, we'll build a simple application that uses `after()` and `update()` to keep the UI responsive during a long-running task.

This is our initial application:

```
import tkinter as tk
from time import sleep


class App(tk.Tk):

    def __init__(self):
        super().__init__()
        self.status = tk.StringVar()
        tk.Label(self, textvariable=self.status).pack()
        tk.Button(self, text="Run Process",
            command=self.run_process).pack()

    def run_process(self):
        self.status.set("Starting process")
        for phase in range(1, 5):
            self.status.set(f"Phase {phase}")
            self.process_phase(phase, 2)
        self.status.set('Complete')

    def process_phase(self, n, length):
        # some kind of heavy processing here.
        sleep(length)

App().mainloop()
```

This application uses `time.sleep()` to simulate some heavy processing task done in multiple phases. The GUI presents the user with a button, which launches the processes, and a status indicator to show progress.

When the user clicks the button, the status indicator is supposed to show `Starting process`, then `Phase 1`, `Phase 2`, and so on, through all the phases until it finishes, when it should read `Complete`.

If you try it, though, you'll see it does no such thing. Instead, it freezes up the moment the button goes down and does not unfreeze until all the phases are complete and the status reads `Complete`. When the button is clicked, the `run_process()` callback is immediately sent to the event queue as a regular priority task and executed, blocking the main loop until the callback returns. All tasks, especially the do-when-idle drawing tasks that would update the status, are delayed until it finishes. When the `run_process()` finally returns, all the updates to `status` that were queued up are executed in a fraction of a second.

To make this a bit better, let's schedule `run_process()` using `after()`:

```
    def run_process(self):
        self.status.set("Starting process")
        self.after(50, self._run_processes)

    def _run_processes(self):
        for phase in range(1, 5):
            self.status.set(f"Phase {phase}")
            self.process_phase(phase, 2)
        self.status.set('Complete')
```

This time, the loop part of `run_process()` is split off into a separate method. The remaining setup section sets the starting status, then schedules the loop method to run 50 milliseconds later. This delay gives Tkinter time to finish up any drawing tasks and to update the status before jumping into the long blocking loop.

We still aren't seeing individual phase status messages with this version, though; it goes directly from `Starting process` to `Complete` because the `_run_processes()` method is still blocking the event loop when it eventually runs.

To fix this, we'll use `update_idletasks()`:

```
    def _run_processes(self):
        for phase in range(1, 5):
            self.status.set(f"Phase {phase}")
            self.update_idletasks()
            self.process_phase(phase, 2)
        self.status.set('Complete')
```

By forcing Tkinter to run the remaining idle tasks in the queue before starting the long blocking method, our GUI kept is up to date. Unfortunately, the individual tasks still block the application while they're running. We can't fix that simply by manipulating the event loop; instead, we need to use `threading`.

Running code in the background with threading

All of the code we have written up to this point in the book can be described as **single threaded**; that is, every statement is executed one at a time, the prior statement finishing before the next one is begun. Even asynchronous elements such as our Tkinter event queue, though they may change the order in which tasks are executed from how they are written, still execute only one task at a time. This means that a long-running procedure like a slow network transaction or file read will freeze up our application while it runs.

To get around this problem, we need to create a multithreaded application, in which multiple sections of code can be run concurrently without needing to wait for one another.

The threading module

Multithreaded application programming can be quite challenging to grasp fully, but the standard library's `threading` module makes working with threads about as simple as it can be.

To demonstrate the basic use of `threading`, let's create a slow function:

```
from time import sleep

def print_slowly(string):
    words = string.split()
    for word in words:
        sleep(1)
        print(word)
```

This function takes a string and prints it at a rate of one word per second. This will simulate a long-running, computationally expensive process and give us some feedback that it's running.

Let's create a Tkinter GUI frontend for this function:

```
import tkinter as tk
...

class App(tk.Tk):
    def __init__(self):
        super().__init__()
        self.text = tk.StringVar()
        tk.Entry(self, textvariable=self.text).pack()
        tk.Button(self, text="Run unthreaded",
        command=self.print_unthreaded).pack()
    def print_unthreaded(self):
        print_slowly(self.text.get())

App().mainloop()
```

This simple application has a `text` entry and a button; when the button is pushed, the text in the entry is sent to the `print_slowly()` function. If you run this code, enter a long sentence into the `Entry` widget and click the button, you'll see that the entire application freezes up as the words are printed to the console. That's because it's all running in a single execution thread.

Now let's add the threading code:

```
from threading import Thread
...
    def __init__(self):
        ...
        tk.Button(self, text="Run threaded",
            command=self.print_threaded).pack()

    def print_threaded(self):
        thread = Thread(target=print_slowly, args=(self.text.get(),))
        thread.start()
```

This time, we've imported the `Thread` class and created a new callback called `run_threaded()`. This callback uses a `Thread` object to run `print_slowly()` in its own execution thread.

A `Thread` object takes a `target` argument that points to the callable which will be run in `Thread`. It can also take an `args` tuple, which contains arguments to be passed into the `target` argument, and a `**kwargs` dictionary, which will also be expanded in the `target` argument.

To execute the `thread` object, we call its `start()` method. This method does not block, so the callback immediately returns allowing Tkinter to resume its event loop while `thread` executes in the background.

If you try this code, you'll see that the GUI no longer freezes while the sentence is printed. No matter how long the sentence, the GUI remains responsive the whole time.

Converting our network functions to threads

Passing a function to a `Thread` object as `target` is one way of running code in a thread; a more flexible and powerful approach is to subclass `Thread` and override its `run()` method with the code you want to execute. We're going to take this approach with our corporate REST upload function.

First, we'll subclass `Thread` to a new class called `CorporateRestUploader`:

```
class CorporateRestUploader(Thread):

    def __init__(self, filepath, upload_url, auth_url,
                 username, password):
        self.filepath = filepath
        self.upload_url = upload_url
        self.auth_url = auth_url
        self.username = username
        self.password = password
        super().__init__()
```

The `__init__()` method takes the same arguments that `upload_to_corporate_rest()` took and assigns them to instance properties. Then it calls `super().__init__()` to set up the parent `Thread` object.

Next, let's implement `run()`:

```
    def run(self, *args, **kwargs):
        session = requests.session()
        response = session.post(
            self.auth_url,
            data={'username': self.username,
                  'password': self.password}
        )
        response.raise_for_status()
        files = {'file': open(self.filepath, 'rb')}
        response = session.put(
            self.upload_url,
            files=files
        )
        files['file'].close()
        response.raise_for_status()
```

This is exactly the code from `upload_to_corporate_rest()` except that the function arguments have been changed to instance properties. That's all there is to convert a function to a `thread` object. All we'll need to do to use this is instantiate a `CorporateRestUploader` object and call its `start()` method.

Simulating a slow server

Testing this code with our lightning-fast local web server won't show us whether the `threading` module actually works, so we need to sabotage our test server to make it simulate a slow connection.

Import `sleep()` into the `sample_http_server.py` script, then edit the `TestHandler` methods:

```
    def do_POST(self, *args, **kwargs):
        print('POST request received')
        self._print_request_data()
        sleep(2)
        self._send_200()

    def do_PUT(self, *args, **kwargs):
        print("PUT request received")
        self._print_request_data()
        sleep(10)
        self._send_200()
```

We're adding a 2 second delay to the `POST` response and a 10 second delay to `PUT`. This should adequately demonstrate the effect of a slow server.

Demonstrating the threaded versus non-threaded uploader

Before editing `Application` to use our new threaded uploader, let's see how the traditional single-threaded version behaves with the slowed-down test server. Start the server, launch your application, make sure there are some entries for the current date, then run the REST upload. Notice how the application freezes hard for at least 12 seconds before returning control.

Now, let's make the necessary adjustments to `Application` to use our multithreaded uploader.

Replace the call to the `upload_to_corporate_rest()` function with this:

```
        self.uploader = n.CorporateRestUploader(
            csvfile, self.settings['abq_upload_url'].get(),
            self.settings['abq_auth_url'].get(),
            username, password)
        self.uploader.start()
```

It's a simple matter of creating a threaded uploader object and calling its `start()` method. Try the upload again, and you'll see that there is no freezing whatsoever. You can verify that the process completed by checking the output of the HTTP server.

TIP *Remember, you override the `run()` method, but call the `start()` method. Mixing these up will cause your code to either do nothing or block like a normal single-threaded call.*

Passing messages using a queue

We've solved the problem of the program freezing up, but now we have some new problems. The most obvious problem is that our callback immediately shows a message box claiming that we've successfully uploaded the file, even though the process is still ongoing in the background. A subtler and far worse problem is that we aren't alerted to errors. If you try running the callback without the test service running, it will still immediately claim that the upload succeeded, even though you can see on the terminal that exceptions are being raised. What's going on here?

The root problem here is that the `Thread.start()` method doesn't block, nor does it pass on exceptions caused in the thread's `run()` method. Those exceptions are raised within the new thread, and can only be caught in the new thread. As far as our main thread is concerned, the code in the `try` block executed just fine.

What we need in order to solve these problems is a way for the two threads to communicate, so that the upload thread can send error or progress messages back to the main thread to be handled appropriately. We can do this using a queue.

The Queue object

Python's `queue.Queue` is a **first-in first-out** (**FIFO**) data structure. Items can be placed into a `Queue` object using the `put()` method, and retrieved using the `get()` method. Let's take a look at the following example:

```
>>> from queue import Queue
>>> q = Queue()
>>> q.put('My item')
>>> q.get()
'My item'
```

This may not seem terribly exciting, but what makes `Queue` useful is that it has been specially designed to work safely as a channel for asynchronous communication between threads (programmers refer to this as **thread-safe**). One thread can place messages on `queue`, and another can retrieve them and respond appropriately.

By default, `get()` will block until an item is received. This behavior can be altered by passing `False` as its first argument, or using the `get_nowait()` method; in that case, it will raise an exception if `Queue` is empty. Let's take a look at the following example:

```
>>> q = Queue()
>>> q.get_nowait()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
  File "/usr/lib/python3.6/queue.py", line 192, in get_nowait
  return self.get(block=False)
  File "/usr/lib/python3.6/queue.py", line 161, in get
  raise Empty
queue.Empty
```

We can also check whether `queue` is empty using the `empty()` or `qsize()` methods:

```
>>> q.empty()
True
>>> q.qsize()
0
>>> q.put(1)
>>> q.empty()
False
>>> q.qsize()
```

`Queue` has several other methods that are useful in more advanced multithreading situations, but `get()`, `put()`, and `empty()` will be sufficient to solve our problems.

Using queues to communicate between threads

Before editing our application code, let's create a simpler example application to make sure we understand how to use `Queue` to communicate between threads.

Start with a long-running thread:

```
from threading import Thread
from time import sleep

class Backend(Thread):

    def __init__(self, queue, *args, **kwargs):
        super().__init__(*args, **kwargs)
        self.queue = queue

    def run(self):
        self.queue.put('ready')
        for n in range(1, 5):
            self.queue.put(f'stage {n}')
            print(f'stage {n}')
            sleep(2)
        self.queue.put('done')
```

The `Backend` object is a subclass of `Thread` that takes a `Queue` object as an argument and saves it as an instance property. Its `run` method simulates a long-running four-phase process using `print()` and `sleep()`. At the beginning, at the end, and before each phase, we use `queue.put()` to place a status message into the `queue` module.

Now we'll create a frontend for this process in Tkinter:

```
import tkinter as tk
from queue import Queue

class App(tk.Tk):

    def __init__(self, *args, **kwargs):
        super().__init__(*args, **kwargs)
        self.status = tk.StringVar(self, value='ready')
        tk.Label(self, textvariable=self.status).pack()
        tk.Button(self, text="Run process", command=self.go).pack()
        self.queue = Queue()
```

This simple application contains a `Label` object tied to a `status` variable and a `Button` widget that launches a method called `go()` when clicked. It also has a `Queue` object stored as `self.queue`.

Let's create the `go()` method:

```
    def go(self):
        p = Backend(self.queue)
        p.start()
```

The `go()` method creates an instance of the `Backend` class, passing in our `Queue` object, and starts it. Because both threads now have a reference to `queue`, we can use it to communicate between them. We've already seen how `Backend` places status messages on the `queue` module so how does `App()` retrieve them?

Maybe we could start a loop:

```
while True:
    status = self.queue.get()
    self.status.set(status)
    if status == 'done':
        break
```

That won't work, of course, because the loop will block, freezing up `App()` and defeating the purpose of using a second thread. Instead, we need a way to periodically poll the `queue` module for status messages and respond whenever one is received.

We can do that using `after()`:

```
        self.after(100, self.check_queue)
```

After 100 milliseconds, we'll call a `check_queue()` method. It will be up to that method to read the `queue` module and determine how to respond.

It starts like this:

```
    def check_queue(self):
        if not self.queue.empty():
            self.status.set(self.queue.get())
```

The `Queue.empty()` method, as you might expect, tells us whether the `queue` module is empty or not. If the `queue` module is empty, we don't want to do anything, because `get()` will, by default, block until it receives a message, and we don't want to block. If there is something in the `queue` module, we'll want to get it and send it to our `status` variable.

This only performs one check, of course; we want to keep polling the `queue` module until the process is done. Thus, if our status is not `done`, we need to schedule another `queue` check.

That can be done with another call to `after()` at the end of `check_queue()`:

```
        if self.status.get() != 'done':
            self.after(100, self.check_queue)
```

Now `check_queue()` will do its job, then schedule itself to run again every `100` milliseconds until the status is `done`. If you run this application, you'll see that we get status messages in (relatively) real time. Unlike the single-threaded application we created earlier in the chapter, there is no freezing, even while the tasks are running.

Adding a communication queue to our threaded uploader

Create a copy of `CorporateResUploader` and call it `CorporateRestUploaderWithQueue`:

```
class CorporateRestUploaderWithQueue(Thread):

    def __init__(self, filepath, upload_url, auth_url,
                 username, password, queue):
        ...
        self.queue = queue
        ...
```

The only difference in `__init__()` is the addition of a `queue` argument, which we store as an instance property. Just as in our example application, the `Queue` object will be created in the `Application` object and passed into the thread constructor.

Back in `Application`, update the call to the `uploader` class:

```
        self.rest_queue = Queue()
        self.uploader = n.CorporateRestUploaderWithQueue(
            csvfile, self.settings['abq_upload_url'].get(),
            self.settings['abq_auth_url'].get(),
            username, password,
            self.rest_queue)
```

Now both `Application` and `CorporateRestUploaderWithQueue` have a reference to the same `Queue` object, and they can communicate.

Creating a communications protocol

Now that we have established a channel for inter-thread communication, we have to decide how our two threads will communicate. In other words, what exactly will our uploader thread place on the queue, and how should our application thread respond to it? We could just throw anything into the queue and keep writing cases on the app-side to deal with whatever shows up, but a better approach is to create a mini-protocol that standardizes communications.

Our uploader thread will mainly be sending status-related information back to the application so that it can display updates about what's happening in message boxes or on the status bar. Let's create a message format that we can use to determine what the thread is doing and communicate that to the user.

The message structure will look like this:

Field	**Description**
`status`	One word indicating the type of message, such as info or error
`subject`	A short sentence summarizing the message
`body`	A longer string with details about the message

We could create a structure like this using `dict` or `class`, but simple collections of named fields like this are a great use-case for `namedtuple()`. The `collections.namedtuple()` function allows us to quickly create mini-classes that contain only named properties.

Creating a `namedtuple` class looks like this:

```
from collections import namedtuple
MyClass = namedtuple('MyClass', ['prop1', 'prop2'])
```

This is roughly equivalent to writing:

```
class MyClass():
    def __init__(self, prop1, prop2):
        self.prop1 = prop1
        self.prop2 = prop2
```

The `namedtuple()` method is much faster to create than a class, and unlike a`dict` it enforces uniformity.

At the top of the `network.py` file, let's define a `namedtuple` class called `Message`:

```
from collections import namedtuple

Message = namedtuple('Message', ['status', 'subject', 'body'])
```

Creating a new `Message` object is just like instantiating any other class:

```
message = Message('info', 'Testing the class', 'We are testing the Message cl
```

Sending messages from the uploader

To make sure that the `Message` objects are the only thing that get put in our queue, let's create a wrapper method in `CorporateRestUploaderWithQueue` that will create the object and place it in the queue. We'll use this for all communications to the queue.

Call it `_putmessage()`:

```
    def _putmessage(self, status, subject, body):
        self.queue.put(Message(status, subject, body))
```

Now, in the `run()` method, let's add some status messages:

```
    def run(self, *args, **kwargs):
        session = requests.session()
        self._putmessage(
            'info', 'Authenticating',
            'Authenticating to {} as {}'.format(
                self.auth_url, self.username))
        ...
        # Before upload request
        self._putmessage(
            'info', 'Starting Upload',
            'Starting upload of {} to {}'.format(
                self.upload_url, self.filepath))
```

Previously, our function raised exceptions and expected the calling code to catch and handle them. Our thread, however, has to deal with its own exceptions, so we'll move our `requests` calls to a `try` block and convert any exceptions to queue messages.

The code is the same with both requests:

```
        # Authentication request
        try:
            response = session.post(
                self.auth_url,
                data={'username': self.username,
                      'password': self.password})
            response.raise_for_status()
        except Exception as e:
            self._putmessage(
                'error', 'Authentication Failure', str(e))
            return
         ...
         # Upload request
        try:
            response = session.put(
                self.upload_url,
                files=files
            )
            files['file'].close()
            response.raise_for_status()
        except Exception as e:
            self._putmessage(
                'error', "Upload Failure", str(e))
            return
        ....
```

Note that `return` in each of the exception handling blocks; since we can't rely on exceptions to abort the process when something goes wrong, the code explicitly returns from this method after sending the exception to the queue.

Finally, at the end of the method, add a success message:

```
        self._putmessage(
            'done', 'Complete',
            "File {} uploaded to ABQ REST".format(self.filepath))
```

Handling queue messages

Back in the `Application` object, we need to create a method that will poll the queue and handle any messages sent from the upload thread.

Let's call it `check_queue()`:

```
    def check_queue(self, queue):
        if not queue.empty():
            item = queue.get()
```

The method starts by checking to see whether the queue has any items, and if so it retrieves one. Once we have one, we need to examine it and determine what to do with it based on the `status` value.

First, let's handle a `done` status:

```
            if item.status == 'done':
                messagebox.showinfo(
                    item.status,
                    message=item.subject,
                    detail=item.body
                )
                self.status.set(item.subject)
                return
```

When our upload finishes successfully, we want to show a message box and set the status, then return without doing anything else. Our `status`, `subject`, and `body` map nicely to the `title`, `message`, and `detail` sections of the message box.

Next, we'll handle error conditions:

```
            elif item.status == 'error':
                messagebox.showerror(
                    item.status,
                    message=item.subject,
                    detail=item.body
                )
                self.status.set(item.subject)
                return
```

Once again, we show a message box, but this time an error message box. We also want to exit the method, since the thread has presumably quit.

Finally, let's handle the `info` statuses:

```
            else:
                self.status.set(item.body)
```

For the `info` messages, we won't show a message box, just set `status`. The last thing we need to do in this method is make sure it gets called again if the thread is still going.

We do this with a call to `after()`:

```
        self.after(100, self.check_queue, queue)
```

This has to be done if either the message was an `info` message or if there was no message, so it's unindented to the leftmost level inside the method. It won't happen if we got a `done` or `error` message, since we returned from the method in each of those cases.

With `check_queue()` written, we just need to call it at the end of `upload_to_corporate_rest()`:

```
        self.check_queue(self.rest_queue)
```

It doesn't really need to be called as an `after()` callback since there will most likely not be a message on the first call, causing `check_queue()` to just schedule it's next call and return.

Now launch the application and try the REST upload again. Watch the status bar, and you'll see the progress getting displayed, ending with a message box when the process completes. Try it with the HTTP server turned off, and you should see an error message pop up right away.

Summary

In this chapter, you learned how to use asynchronous and multithreaded programming techniques to remove freezing and unresponsive behavior from your program. You learned how to work with and control Tkinter's event queue, how to use Python's `threading` module, and how to utilize queues to communicate between threads.

In the next chapter, we're going to explore the most powerful widget in Tkinter: `Canvas`. We'll learn how to draw images and animate them, and create useful and informative charts.

Visualizing Data Using the Canvas Widget

With months of experimental data logged in the database, it's time to begin the process of visualizing and interpreting it. Rather than exporting data into a spreadsheet to create charts and graphs, your fellow analysts have asked whether the program itself can create graphical data visualizations. To implement this feature, you're going to need to learn about Tkinter's `Canvas` widget.

In this chapter, you'll learn the following topics:

- Using the `Canvas` widget for drawing and animation
- Building a simple line graph using `Canvas`
- Incorporating more advanced graphs and charts using Matplotlib

Drawing and animation with Tkinter's Canvas

The `Canvas` widget is undoubtedly the most powerful widget available in Tkinter. It can be used to build anything from custom widgets and views to complete user interfaces. As the name implies, `Canvas` is a blank area on which figures and images can be drawn.

A `Canvas` object can be created like any other widget:

```
root = tk.Tk()
canvas = tk.Canvas(root, width=1024, height=768)
canvas.pack()
```

`Canvas` accepts the usual widget configuration arguments, as well as `width` and `height` for setting its size. Once created, we can start adding items to `canvas` using its many `create_()` methods.

For example, we can add a rectangle with this code:

```
canvas.create_rectangle(100, 100, 200, 200, fill='orange')
```

The first four arguments are the coordinates of the upper-left and lower-right corners, in pixels from the upper-left corner of the canvas. Each `create_()` method begins like this, with coordinates defining the shape. The `fill` option specifies the color of the inside of the object.

Coordinates can also be specified as tuple pairs, like so:

```
canvas.create_rectangle((600, 100), (700, 200), fill='#FF8800')
```

Although this is more characters, it improves readability considerably. Also note that, just like colors elsewhere in Tkinter, we can use names or hex codes.

We can also create ovals, as shown in the following:

```
canvas.create_oval((350, 250), (450, 350), fill='blue')
```

An oval, like a rectangle, takes the coordinates of the upper-left and lower-right corners of its **bounding box**. A bounding box is the smallest rectangle that will contain an item, so in the case of this oval, you can imagine a circle inside a square with corners at `(350, 250)` and `(450, 350)`.

We can create lines using `create_line()`, like so:

```
canvas.create_line((100, 400), (400, 500),
    (700, 400), (100, 400), width=5, fill='red')
```

Lines can consist of any number of points, between which Tkinter will connect the dots. We've specified the width of the line as well as its color (using the `fill` argument). Additional arguments can control the shape of corners and ends, the presence and style of arrows at each end of the line, whether and how the line is dashed, and whether the line is straight or curved.

In a similar fashion, we can create polygons, like this:

```
canvas.create_polygon((400, 150), (350,  300), (450, 300),
    fill='blue', smooth=True)
```

This is just like creating a line, except that Tkinter connects the last dot back to the first and fills in the interior. Setting `smooth` to `True` causes the corners to be rounded using Bezier curves.

In addition to simple shapes, we can also place text or images on the `canvas` object as follows:

```
canvas.create_text((400, 600), text='Smile!',
    fill='cyan', font='TkDefaultFont 64')
smiley = tk.PhotoImage(file='smile.gif')
image_item = canvas.create_image((400, 300), image=smiley)
```

The return value of any `create_()` method is a string that uniquely identifies the item in the context of the `Canvas` object. We can use that identification string to do things to the item after creation.

For example, we can bind events like so:

```
canvas.tag_bind(image_item, '<Button-1>', lambda e: canvas.delete(image_item)
```

Here, we've used the `tag_bind` method to bind a left-mouse click on our image object to the canvas's `delete()` method, which (when given an item identifier) deletes the item.

Animating Canvas objects

Tkinter's `Canvas` widget doesn't have a built-in animation framework, but we can still create simple animations by combining its `move()` method with our understanding of the event queue.

To demonstrate this, we'll create a bug race simulator, in which two bugs (represented by colored circles) will race haphazardly toward a finish line on the other side of the screen. Like real bugs, they won't have any notion that they're in a race and will move randomly, the winner being whichever bug incidentally hits the finish line first.

To begin, open a new Python file and start with a basic boilerplate as follows:

```
import tkinter as tk

class App(tk.Tk):
    def __init__(self):
        super().__init__()

App().mainloop()
```

Creating our objects

Let's create the objects to be used in our game:

1. In `App.__init__()`, we'll simply create our `canvas` object and add it using `pack()`:

```
        self.canvas = tk.Canvas(self, background='black')
        self.canvas.pack(fill='both', expand=1)
```

2. Next, we'll create a `setup()` method as follows:

```
    def setup(self):
        self.canvas.left = 0
        self.canvas.top = 0
        self.canvas.right = self.canvas.winfo_width()
        self.canvas.bottom = self.canvas.winfo_height()
        self.canvas.center_x = self.canvas.right // 2
        self.canvas.center_y = self.canvas.bottom // 2

        self.finish_line = self.canvas.create_rectangle(
            (self.canvas.right - 50, 0),
            (self.canvas.right, self.canvas.bottom),
            fill='yellow', stipple='gray50')
```

   In the preceding code snippet, `setup()` begins by calculating some relative locations on the `canvas` object and saving them as instance properties, which will simplify the placement of objects on the `canvas` object. The finish line, which is a rectangle across the right edge of the window, uses the `stipple` argument to specify a bitmap that will overlay the solid color to give it some texture; in this case, `gray50` is a built-in bitmap that alternates black and transparent pixels.

3. Add a call to `setup()` at the end of `__init__()` as follows:

```
        self.after(200, self.setup)
```

   Because `setup()` relies on the `width` and `height` values of the `canvas` object, we need to make sure it isn't called until the operating system's window manager has drawn and sized the window. The simplest way of doing this is to delay the call by a few hundred milliseconds.

4. Next, we need to create our players. Let's create a class to represent them as follows:

```
class Racer:

    def __init__(self, canvas, color):
        self.canvas = canvas
        self.name = "{} player".format(color.title())
        size = 50
        self.id = canvas.create_oval(
            (canvas.left, canvas.center_y),
            (canvas.left + size, canvas.center_y + size),
            fill=color)
```

   The `Racer` class will be created with a reference to `canvas` and a `color` string, from which its color and name will be derived. We'll draw the racer initially at the middle-left of the screen and make it `50` pixels in size. Finally, we save a reference to its item ID string in `self.id`.

5. Now, back in `App.setup()`, we'll create two racers by executing the following code:

```
        self.racers = [
            Racer(self.canvas, 'red'),
            Racer(self.canvas, 'green')]
```

6. At this point, all the objects in our game are set up. Run the program and you should see a yellow-stippled finish line on the right and a green circle on the left (the red circle will be hidden under the green).

Animating the racers

To animate our racers, we're going to use the `Canvas.move()` method. `move()` takes an item ID, a number of `x` pixels, and a number of `y` pixels, and moves the item by that amount. By using `random.randint()` and some simple logic, we can generate a series of moves that will send each racer on a meandering path towards the finish line.

A simple implementation may look like this:

```
def move_racer(self):
    x = randint(0, 100)
    y = randint(-50, 50)
    t = randint(500, 2000)
    self.canvas.after(t, self.canvas.move, self.id, x, y)
    if self.canvas.bbox(self.id)[0] < self.canvas.right:
        self.canvas.after(t, self.move_racer)
```

This isn't really what we want, though; the problem is that `move()` happens instantaneously, causing the bug to jump across the screen; we want our moves to take place smoothly over a period of time.

To accomplish this, we're going to take the following approach:

1. Calculate a series of linear moves, each with a random delta `x`, delta `y`, and `time`, that will reach the finish line
2. Break each move into a number of steps determined by dividing the time into a regular interval
3. Add each step of each movement to a queue
4. At our regular interval, pull the next step from the queue and pass it to `move()`

Let's start by defining our frame interval and creating our animation queue:

```
from queue import Queue
...
class Racer:
    FRAME_RES = 50

    def __init__(...):
        ...
        self.animation_queue = Queue()
```

FRAME_RES (short for frame resolution) defines the number of milliseconds between each Canvas.move() call. 50 milliseconds gives us 20 frames per second and should be sufficient for smooth movements.

Now create a method to plot the course to the finish line:

```
    def plot_course(self):
        start_x = self.canvas.left
        start_y = self.canvas.center_y
        total_dx, total_dy = (0, 0)

        while start_x + total_dx < self.canvas.right:
            dx = randint(0, 100)
            dy = randint(-50, 50)
            target_y = start_y + total_dy + dy
            if not (self.canvas.top < target_y < self.canvas.bottom):
                dy = -dy
            time = randint(500, 2000)
            self.queue_move(dx, dy, time)
            total_dx += dx
            total_dy += dy
```

This method plots a course from the left-center of canvas to the right-side by generating random x and y movements until the total x is greater than the width of the canvas object. The change in x will always be positive, keeping our bugs moving towards the finish line, but the change in y can be positive or negative. To keep our bugs on the screen, we constrain the total y movements by negating any change in y that would put the player outside the top or bottom bound of the canvas.

In addition to dx and dy, we generate a random amount of time for the move to take, between half a second and two seconds, and send the generated values to a queue_move() method.

The queue_move() command will need to break the large move into individual frames that describe how much movement should happen in one FRAME_RES interval. To do this, we need a **partition function**: a mathematical function that will break an integer n into k approximately equal integers. For example, if we wanted to break -10 into four parts, our function should return a list like [-3, -3, -2, -2].

Create `partition()` as a static method on `Racer`:

```
    @staticmethod
    def partition(n, k):
        """Return a list of k integers that sum to n"""
        if n == 0:
            return [0] * k
```

We start with the easy case: when `n` is `0`, return a list of `k` zeros.

The rest of the code looks like this:

```
        base_step = int(n / k)
        parts = [base_step] * k
        for i in range(n % k):
                parts[i] += n / abs(n)
        return parts
```

First, we create a list of length `k` that is made up of `base_step`, that is, the integer portion of `n` divided by `k`. We use a cast of `int()` here rather than floor division because it behaves more appropriately with negative numbers. Next, we need to distribute the remainder among the list as evenly as we can. To accomplish this, we add `1` or `-1` (depending on the sign of the remainder) to the first `n % k` items in the parts list.

Follow the math here using our example of `n = -10` and `k = 4`:

- -10 / 4 = -2.5, truncated to -2.
- So we have a list: [-2, -2, -2, -2].
- -10 % 4 = 2, so we add -1 (that is, -10 / 10) to the first two items in the list.
- We arrive at an answer of [-3, -3, -2, -2]. Perfect!

Now we can write `queue_move()`:

```
    def queue_move(self, dx, dy, time):
        num_steps = time // self.FRAME_RES
        steps = zip(
            self.partition(dx, num_steps),
            self.partition(dy, num_steps))

        for step in steps:
            self.animation_queue.put(step)
```

We first determine the number of steps in this move by dividing the time by `FRAME_RES` using floor division. We create a list of `x` moves and a list of `y` moves by passing `dx` and `dy` each to our `partition()` method. Those two lists are combined with `zip` to form a single list of `(dx, dy)` pairs, which then gets added to the animation queue.

To make the animation actually happen, we'll write an `animate()` method:

```
    def animate(self):
        if not self.animation_queue.empty():
            nextmove = self.animation_queue.get()
            self.canvas.move(self.id, *nextmove)
        self.canvas.after(self.FRAME_RES, self.animate)
```

The `animate()` method checks the queue for a move. If there is one, `canvas.move()` is called with the racer's ID and the moves that need to be made. Finally, the `animate()` method is scheduled to run again in `FRAME_RES` milliseconds.

The last step in animating the racers is to call `self.plot_course()` and `self.animate()` at the end of `__init__()`. If you run the game now, your two dots should wander the screen from left to right. But nobody's winning just yet!

Detecting and handling a win condition

To detect a win condition, we're going to periodically check whether a racer is overlapping with the finish line item. When one of them is, we'll declare it the winner and offer the option to play again.

Collision detection between items is slightly awkward with the Tkinter `Canvas` widget. We have to pass a set of bounding box coordinates to `find_overlapping()`, which returns a tuple of item identifiers that overlap with the bounding box.

Let's create an `overlapping()` method for our `Racer` class:

```
    def overlapping(self):
        bbox = self.canvas.bbox(self.id)
        overlappers = self.canvas.find_overlapping(*bbox)
        return [x for x in overlappers if x!=self.id]
```

This method retrieves the bounding box of the `Racer` item using the canvas's `bbox()` method. It then fetches a tuple of items overlapping this bounding box using `find_overlapping()`. Next, we'll filter this tuple to remove the `Racer` item's ID, effectively returning a list of items overlapping with the `Racer` class.

Back in our `App()` method, we'll create a `check_for_winner()` method:

```
    def check_for_winner(self):
        for racer in self.racers:
            if self.finish_line in racer.overlapping():
                self.declare_winner(racer)
                return
        self.after(Racer.FRAME_RES, self.check_for_winner)
```

This method iterates our list of racers and checks whether the `finish_line` ID is in the list returned by the racer's `overlapping()` method. If it is, `racer` has hit the finish line and will be declared the winner.

If no player was declared the winner, we'll schedule the check to run again after `Racer.FRAME_RES` milliseconds.

We handle a win condition in the `declare_winner()` method:

```
def declare_winner(self, racer):
    wintext = self.canvas.create_text(
        (self.canvas.center_x, self.canvas.center_y),
        text='{} wins!\nClick to play again.'.format(racer.name),
        fill='white',
        font='TkDefaultFont 32',
        activefill='violet')
    self.canvas.tag_bind(wintext, '<Button-1>', self.reset)
```

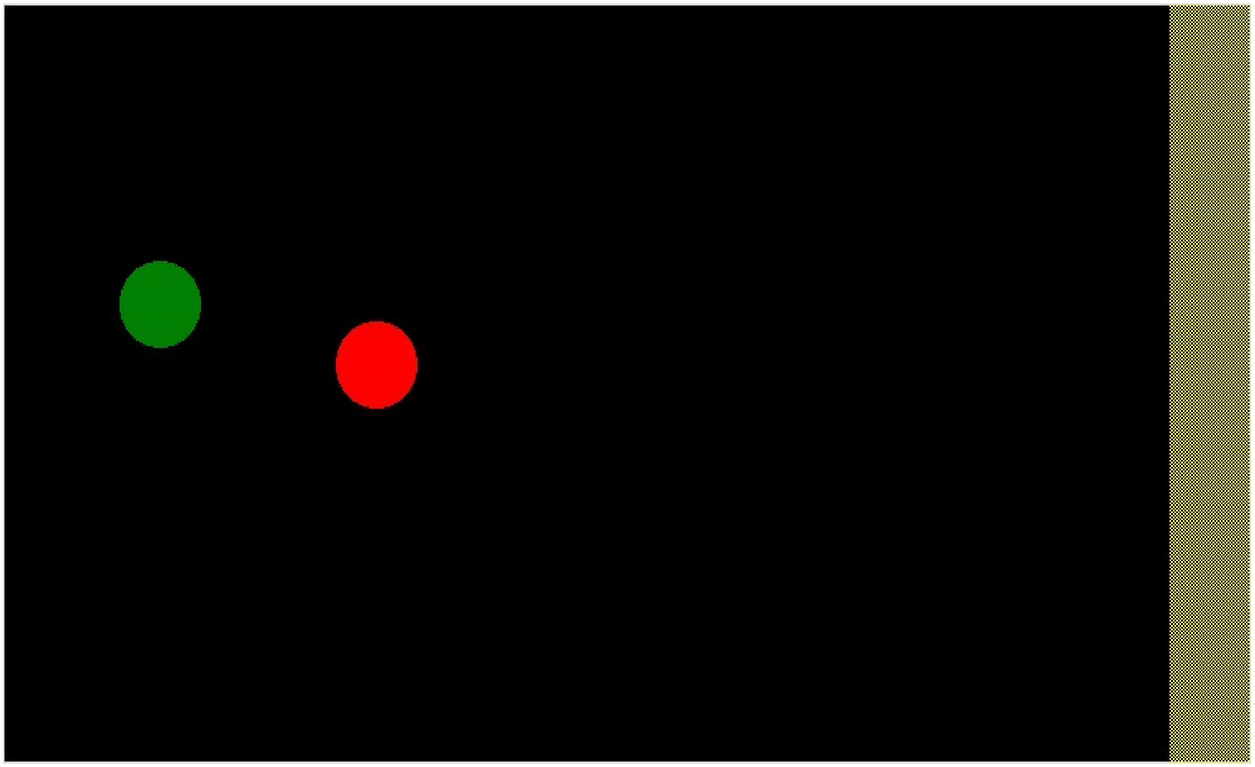
In this method, we've just created a `text` item declaring `racer.name` as the winner in the center of `canvas`. The `activefill` argument causes the color to appear violet when the mouse is hovered over it, indicating to the user that this text is clickable.

When that text is clicked, it calls the `reset()` method:

```
def reset(self, *args):
    for item in self.canvas.find_all():
        self.canvas.delete(item)
    self.setup()
```

The `reset()` method needs to clear off the canvas, so it retrieves a list of all item identifiers using the `find_all()` method, then calls `delete()` on each one. Finally, we call `setup()` to reset the game.

The game is now complete, as you can see in the following screenshot:



While not exactly simple, animation in Tkinter can provide smooth and satisfactory results with some careful planning and a bit of math.

Enough games, though; let's get back to the lab and figure out how to use the Tkinter `Canvas` widget to visualize data.

Creating simple graphs on the canvas

The first graph we want to produce is a simple line graph that shows the growth of our plants over time. Each lab has varying climate conditions, and we want to see how those conditions are affecting the growth of all plants, so the chart will have one line per lab showing the average of the median height measurements for all plots in the lab over the days of the experiment.

We'll start by creating a model method to return the raw data, then create a `Canvas`-based line-chart view, and finally create an application callback to pull the data and send it to the chart view.

Creating the model method

Suppose we have a SQL query that determines the day number of a plot check by subtracting its date from the oldest date in the `plot_checks` table, then pulls `lab_id` and the average of `median_height` for all plants in the given lab on the given day.

We'll run this query in a new `SQLModel` method called `get_growth_by_lab()`:

```
    def get_growth_by_lab(self):
        query = (
            'SELECT date - (SELECT min(date) FROM plot_checks) AS day, '
            'lab_id, avg(median_height) AS avg_height FROM plot_checks '
            'GROUP BY date, lab_id ORDER BY day, lab_id;')
        return self.query(query)
```

We'll get back a table of data that looks something like this:

Day	Lab ID	Average height
0	A	7.4198750000000000
0	B	7.3320000000000000
0	C	7.5377500000000000
0	D	8.4633750000000000
0	E	7.8530000000000000
1	A	6.7266250000000000
1	B	6.8503750000000000

We'll use this data to build our chart.

Creating the graph view

Head over to `views.py`, where we'll create the `LineChartView` class:

```
class LineChartView(tk.Canvas):

    margin = 20

    def __init__(self, parent, chart_width, chart_height,
                 x_axis, y_axis, x_max, y_max):
        self.max_x = max_x
        self.max_y = max_y
        self.chart_width = chart_width
        self.chart_height = chart_height
```

`LineChartView` is a subclass of `Canvas`, so we'll be able to draw items directly on it. We'll accept a parent widget, height, and width for the chart portion, labels for the `x` and `y` axes as arguments, and the maximum values for `x` and `y` to display. We'll save the chart dimensions and maximum values for later use, and set a class property of 20 pixels for the margin width.

Let's start setting up this `Canvas`:

```
        view_width = chart_width + 2 * self.margin
        view_height = chart_height + 2 * self.margin
        super().__init__(
            parent, width=view_width,
            height=view_height, background='lightgrey')
```

We calculate the `width` and `height` values of view by adding the margin to both sides, then call the superclass `__init__()` with them, also setting the background to `lightgrey`. We'll also save the chart `width` and `height` as instance properties.

Next, let's draw the axes:

```
        self.origin = (self.margin, view_height - self.margin)
        self.create_line(
            self.origin, (self.margin, self.margin), width=2)
        self.create_line(
            self.origin,
            (view_width - self.margin,
             view_height - self.margin))
```

Our chart's origin will be `self.margin` pixels from the bottom-left corner, and we'll draw the `x` and `y` axes as simple black lines moving left and up from it to the edge of the chart.

Next, we'll label the axes:

```
        self.create_text(
            (view_width // 2, view_height - self.margin),
            text=x_axis, anchor='n')
        # angle requires tkinter 8.6 -- macOS users take note!
        self.create_text(
            (self.margin, view_height // 2),
            text=y_axis, angle=90, anchor='s')
```

Here, we're creating the `text` items set to the labels for the `x` and `y` axes. There are a few new arguments in use here: `anchor` sets which side of the text's bounding box is attached to the coordinates provided, and `angle` rotates the text object by the given number of degrees. Note that `angle` is a Tkinter 8.6 feature, so it could be a problem for macOS users. Also, note that we've used south as `anchor` for the rotated text; even though it's rotated, the cardinal directions refer to the non-rotated sides, so south will always be the bottom of the text as it's normally printed.

Last of all, we need to create a second `Canvas` that will contain the actual chart:

```
        self.chart = tk.Canvas(
            self, width=chart_width, height=chart_height,
            background='white')
        self.create_window(
            self.origin, window=self.chart, anchor='sw')
```

While we could place widgets on `canvas` using a geometry manager like `pack()` or `grid()`, the `create_window()` method places a widget on `Canvas` as a `Canvas` item using coordinates. We're anchoring the lower-left corner of the chart to the origin point on our graph.

With the pieces in place, we'll now create a method to draw data on the chart:

```
    def plot_line(self, data, color):
        x_scale = self.chart_width / self.max_x
        y_scale = self.chart_height / self.max_y

        coords = [(round(x * x_scale),
            self.chart_height - round(y * y_scale))
            for x, y in data]

        self.chart.create_line(*coords, width=2, fill=color)
```

In `plot_line()`, we first have to convert the raw data into coordinates that can be drawn. We'll need to scale our `data` points so that they range from `0` to the height and width of the chart object. Our method calculates the scale of `x` and `y` (that is, how many pixels per unit `x` or `y`) by dividing the chart dimensions by the maximum values of `x` and `y`. We can then transform our data by using a list comprehension that multiplies each data point by the scale value.

Also, data is usually graphed with the origin in the bottom-left, but coordinates measure from the top-left, so we'll need to flip the `y` coordinates; this is done in our list comprehension as well by subtracting the new `y` value from the chart height. These coordinates can now be passed to `create_line()` along with a reasonable `width` and the `color` argument passed in by the caller.

One last thing we need is a **legend**, to tell the user what each color on the chart represents. Without legend, this chart would be meaningless.

Let's create a `draw_legend()` method:

```
    def draw_legend(self, mapping):
        y = self.margin
        x = round(self.margin * 1.5) + self.chart_width
        for label, color in mapping.items():
              self.create_text((x, y), text=label, fill=color,
              anchor='w')
              y += 20
```

Our method takes a dictionary that maps labels to colors, which will be provided by the application. For each one, we simply draw a text item containing the `label` text with the associated `fill` color. Since we know our labels will be short (only a single character), we can get away with just putting this in the margin.

Updating the application

In the `Application` class, create a new method for showing our chart:

```
    def show_growth_chart(self):
        data = self.data_model.get_growth_by_lab()
        max_x = max([x['day'] for x in data])
        max_y = max([x['avg_height'] for x in data])
```

The first order of business is to fetch data from our `get_growth_by_lab()` method and calculate the maximum values for the `x` and `y` axes. We've done this by using list comprehensions to extract values into lists and calling the built-in `max()` function on it.

Next, we'll build a widget to hold our `LineChartView` object:

```
        popup = tk.Toplevel()
        chart = v.LineChartView(popup, 600, 300, 'day',
                                'centimeters', max_x, max_y)
        chart.pack(fill='both', expand=1)
```

We're using the `Toplevel` widget in this case, which creates a new window outside our main application window. We've then created `LineChartView` that is `600` by `300` pixels with the *x*-axis and *y*-axis labels and added it to `Toplevel` using `pack()`.

Next, we'll assign colors to each lab and draw `legend`:

```
        legend = {'A': 'green', 'B': 'blue', 'C': 'cyan',
                  'D': 'yellow', 'E': 'purple'}
        chart.draw_legend(legend)
```

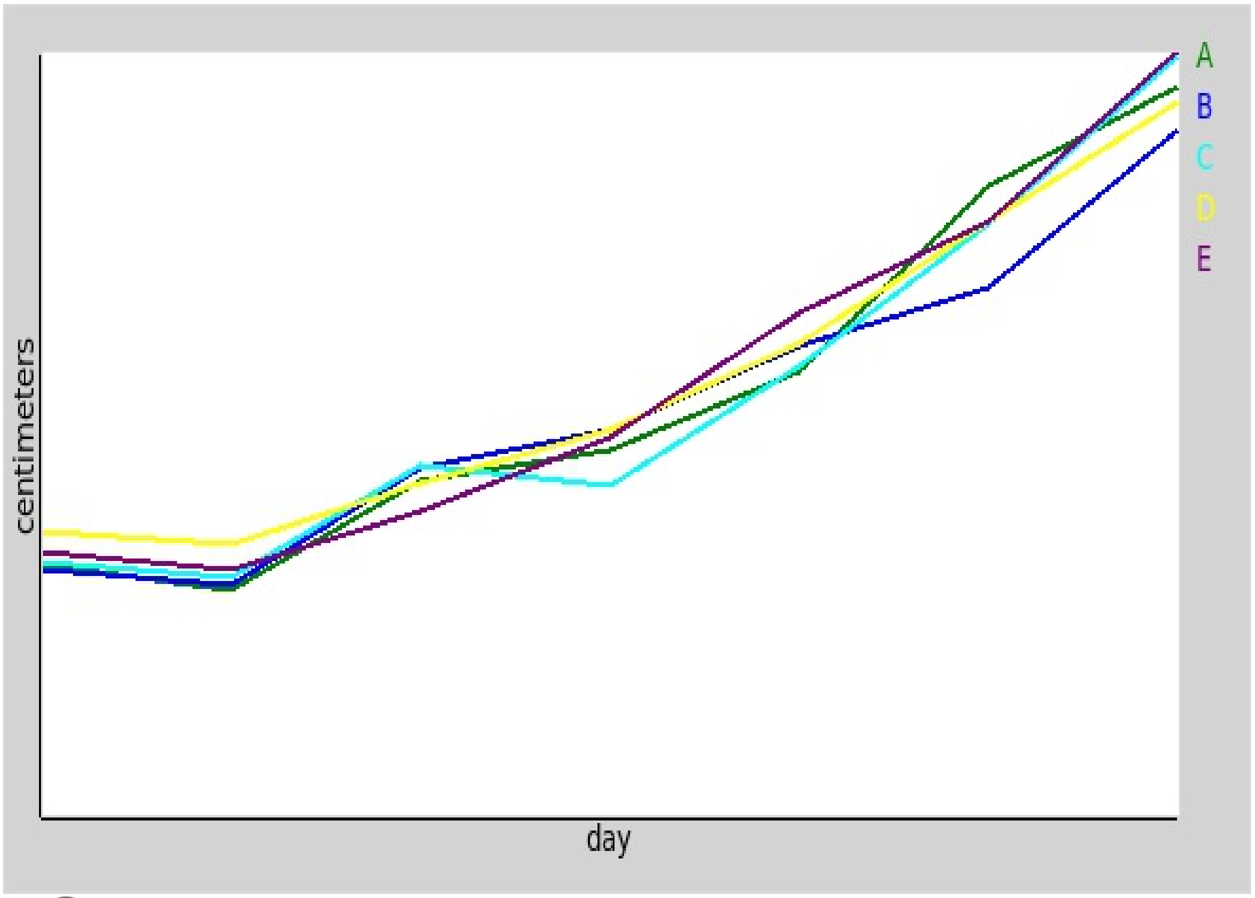
The last thing to do is to draw the actual lines:

```
        for lab, color in legend.items():
            dataxy = [(x['day'], x['avg_height'])
                for x in data
                if x['lab_id'] == lab]
            chart.plot_line(dataxy, color)
```

Remember that our data contains values for all the labs together, so we're iterating through the labs in `legend` and using a list comprehension to extract only the data for that lab. Then our `plot_line()` method does the rest.

With this method complete, add it to the `callbacks` dictionary and add a menu item to the tools menu for each platform.

When you call your function, you should see something like this:



The graph won't look like much without some sample data. Unless you just like doing data entry, there is a script for loading sample data in the `sql` directory.

Advanced graphs using Matplotlib and Tkinter

Our line graph is pretty, but it still needs considerable work to be fully functional: it lacks a scale, grid lines, and other features that would make it a completely useful chart.

We could spend a lot of time making it more complete, but there's a faster way to get much more satisfactory graphs and charts in our Tkinter application: **Matplotlib**.

Matplotlib is a third-party library for generating professional-quality, interactive graphs of all types. It's a vast library with many add-ons, and we won't cover much of its actual usage, but we should look at how to integrate Matplotlib into a Tkinter application. To do this, we'll create a bubble chart showing the yield of each plot as it relates to `humidity` and `temperature`.

You should be able to install `matplotlib` *using* `pip` *with the command* `pip install --user matplotlib`*. For complete instructions on installing, please see* `https://matplotlib.org/users/installing.html.`

Data model method

Before we can make a chart, we'll need a `SQLModel` method to extract the data:

```
    def get_yield_by_plot(self):
        query = (
            'SELECT lab_id, plot, seed_sample, MAX(fruit) AS yield, '
            'AVG(humidity) AS avg_humidity, '
            'AVG(temperature) AS avg_temperature '
            'FROM plot_checks WHERE NOT equipment_fault '
            'GROUP BY lab_id, plot, seed_sample')
        return self.query(query)
```

The purpose of this chart is to find the sweet spot of `temperature` and `humidity` for each seed sample. Therefore, we need one row per `plot` that includes the maximum `fruit` measurement, average humidity and temperature at the `plot` column, and `seed_sample`. Since we don't want any bad data, we'll filter out rows that have `Equipment Fault`.

Creating the bubble chart view

To integrate MatplotLib into a Tkinter application, there are several imports we need to make.

The first is `matplotlib` itself:

```
import matplotlib
matplotlib.use('TkAgg')
```

It may seem odd to run code in the `import` section, and your editor may even complain about it. But before we import anything else from `matplotlib` we need to tell it which backend it should use. In this case, we want the `TkAgg` backend, which is made to integrate into Tkinter.

Now we can make a few more imports from `matplotlib`:

```
from matplotlib.figure import Figure
from matplotlib.backends.backend_tkagg import (
    FigureCanvasTkAgg, NavigationToolbar2TkAgg)
```

The `Figure` class represents the basic drawing area on which `matplotlib` charts can be drawn. The `FigureCanvasTkAgg` class is an interface between the `Figure` and the Tkinter `Canvas`, and `NavigationToolbar2TkAgg` allows us to place a pre-made toolbar for `Figure` on our graph.

To see how these fit together, let's start our `YieldChartView` class in `views.py`:

```
class YieldChartView(tk.Frame):
    def __init__(self, parent, x_axis, y_axis, title):
        super().__init__(parent)
        self.figure = Figure(figsize=(6, 4), dpi=100)
        self.canvas = FigureCanvasTkAgg(self.figure, master=self)
```

After calling `super().__init__()` to create the `Frame` object, we create a `Figure` object to hold our chart. Instead of a size in pixels, the `Figure` object takes a size in **inches** and a **dots per inch** (**dpi**) setting (in this case, resulting in a 600 by 400 pixel `Figure`). Next, we create a `FigureCanvasTkAgg` object to connect our `Figure` object with a Tkinter `Canvas`. The `FigureCanvasTkAgg` object is not itself a `Canvas` object or subclass, but it has a `Canvas` object we can place in our application.

Next, we'll add the toolbar and `pack()` to our `FigureCanvasTkAgg` object:

```
        self.toolbar = NavigationToolbar2TkAgg(self.canvas, self)
        self.canvas.get_tk_widget().pack(fill='both', expand=True)
```

Our toolbar is passed our `FigureCanvasTkAgg` object and the root window (`self` in this case), attaching it to our figure and it's canvas. To place the `FigureCanvasTkAgg` object on our `Frame` object, we need to call `get_tk_widget()` to retrieve its Tkinter `Canvas` widget, which we can then pack or grid as desired using `pack()` and `grid()`.

The next step is to set up the axes:

```
        self.axes = self.figure.add_subplot(1, 1, 1)
        self.axes.set_xlabel(x_axis)
        self.axes.set_ylabel(y_axis)
        self.axes.set_title(title)
```

In Matplotlib, an `axes` object represents a single set of `x` and `y` axes on which data can be graphed, and is created using the `add_subplot()` method. The three integers passed to `add_subplot()` establish that this is the first set of `axes` out of one row of one column of subplots. Our figure could conceivably contain multiple subplots arranged in a table-like format, but we only need one. After it's created, we set the labels on the `axes` object.

To create a bubble chart, we're going to use the **scatter plot** feature of Matplotlib, but use the size of each dot to indicate the fruit yield. We'll also color code the dots to indicate the seed sample.

Let's implement a method to draw our scatter plots:

```
    def draw_scatter(self, data, color, label):
        x, y, s = zip(*data)
        s = [(x ** 2)//2 for x in s]
        scatter = self.axes.scatter(
            x, y, s, c=color, label=label, alpha=0.5)
```

The data passed in should contain three columns per record, and we're breaking those out into three separate lists containing the `x`, `y`, and `size` values. Next, we're going amplify the differences between size values to make them more apparent by squaring each value then dividing it by half. This isn't strictly necessary, but it helps make the chart more readable when differences are relatively small.

Finally, we draw the data onto the `axes` object by calling `scatter()`, also passing along the `color` and `label` values for the dots, and making them semi-transparent with the `alpha` argument.

`zip(*data)` is a Python idiom for breaking a list of n-length tuples into n lists of values, essentially the reverse of `zip(x, y, s)`.

To draw legend for our `axes` object, we need two things: a list of our `scatter` objects and list of their labels. To get these, we'll have to create a couple of blank lists in `__init__()` and append them whenever `draw_scatter()` is called.

In `__init__()`, add some empty lists:

```
        self.scatters = []
        self.scatter_labels = []
```

Now, at the end of `draw_scatter()`, append the lists and update the `legend()` method:

```
        self.scatters.append(scatter)
        self.scatter_labels.append(label)
        self.axes.legend(self.scatters, self.scatter_labels)
```

We can call `legend()` repeatedly and it will simply destroy and redraw the legend each time.

Application method

Back in `Application`, let's create the method to show our yield data.

Start by creating a `Toplevel` method and adding our chart view:

```
        popup = tk.Toplevel()
        chart = v.YieldChartView(popup,
            'Average plot humidity', 'Average Plot temperature',
            'Yield as a product of humidity and temperature')
        chart.pack(fill='both', expand=True)
```

Now let's set up the data for our scatters:

```
        data = self.data_model.get_yield_by_plot()
        seed_colors = {'AXM477': 'red', 'AXM478': 'yellow',
            'AXM479': 'green', 'AXM480': 'blue'}
```

We've retrieved the yield `data` from the data model and created a dictionary that will hold the colors we want to use for each seed sample.

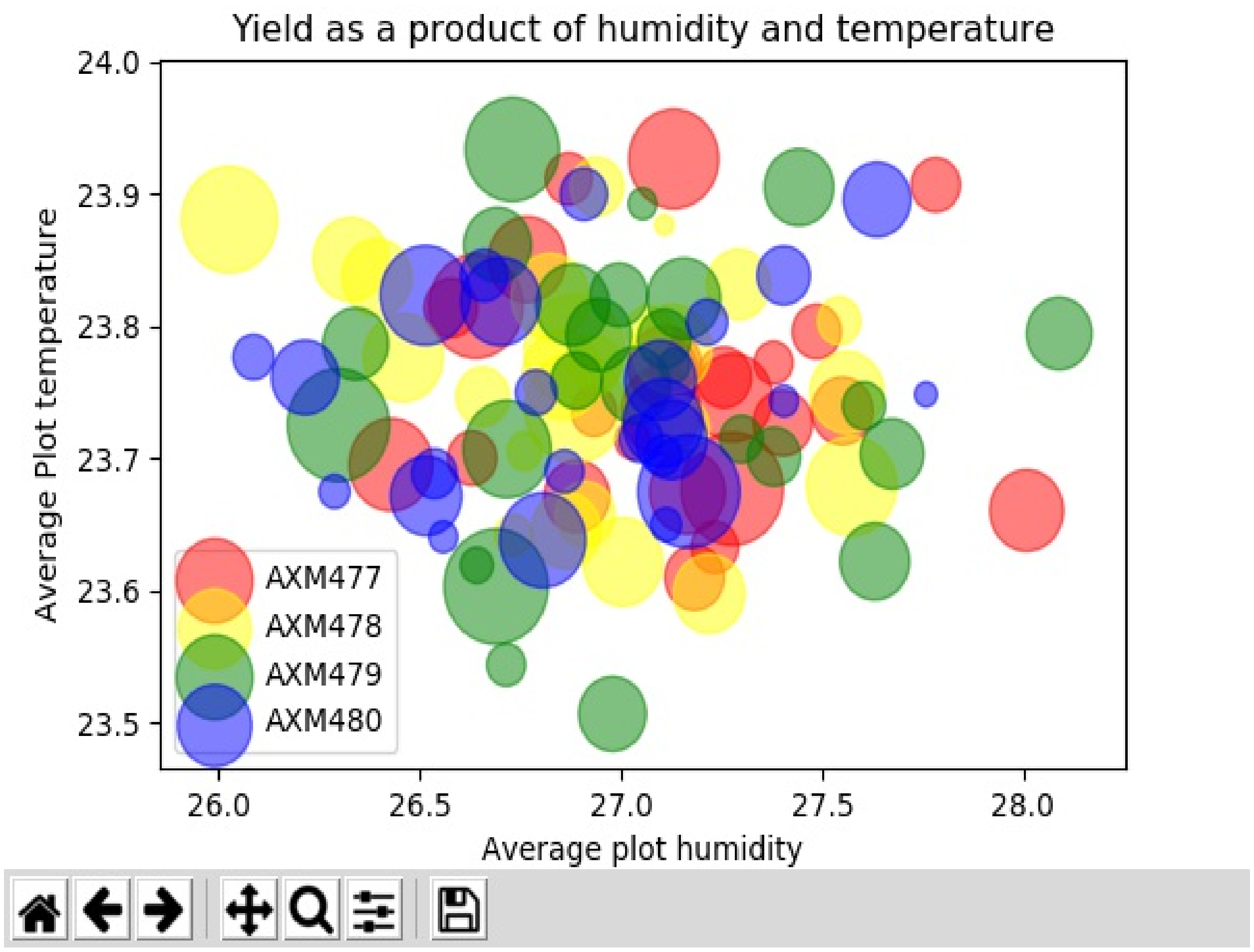
Now we just need to iterate through the seed samples and draw the scatters:

```
        for seed, color in seed_colors.items():
            seed_data = [
                (x['avg_humidity'], x['avg_temperature'], x['yield'])
                for x in data if x['seed_sample'] == seed]
            chart.draw_dots(seed_data, color, seed)
```

Once again, we're formatting and filtering down our data using a list comprehension, providing average humidity for `x`, average temperature for `y`, and yield for `s`.

Add the method to the `callbacks` dictionary and create a menu item for it just under the growth chart option.

Your bubble chart should look something like this:



Take a moment to play with this chart using the navigation toolbar. Notice how you can zoom and pan, adjust the size of the chart, and save the image. These are powerful tools that Matplotlib provides automatically.

Summary

In this chapter, you learned about Tkinter's graphical capabilities. You learned how to draw and animate figures on the Tkinter `Canvas` widget, and how to use these capabilities to visualize data. You also learned how to integrate Matplotlib figures into your application, and we implemented two charts in our application by connecting SQL queries to our chart views.

In the next chapter, we'll learn how to package up our application for distribution. We'll learn how to arrange the directory for distribution as Python code, and how to use third-party tools to create executables across Windows, macOS, and Linux.

Packaging with setuptools and cx_Freeze

Word of your application has spread throughout the ABQ corporation, and you've been asked to provide it for use at other facilities. Unfortunately, running and installing the application is not a very friendly process; you've been installing it through a tedious and error-prone copy-and-paste procedure, and users launch it from a batch or shell script you create by hand on each machine. You need to package your application in a professional way that makes it easy to install and run across Windows, macOS, and Linux.

In this chapter, you will learn the following topics:

- Creating Python source and wheel packages using `setuptools`
- Creating basic standalone binary and installer packages using `cx_Freeze`
- The specifics of creating binaries and installers for Microsoft Windows
- The specifics of creating binaries and installers for Apple macOS

Using setuptools

The standard library contains the `distutils` library, a collection of functionality related to packaging and distributing Python code. However, both the `distutils` documentation (`https://docs.python.org/3/library/distutils.html`) and the official packaging guide recommend against using it and instead direct you to use `setuptools`.

The `setuptools` library is an extension of the `distutils` library that adds some important functionality such as dependency handling; although it is not part of the standard library, it is included in the official distributions for Windows and macOS, and is readily available from the package repositories of most Linux distributions. `setuptools` is used by the `pip` package installer, and we can use it to create packages that can be installed on any system with Python and `pip`.

If you want to create packages that can be uploaded to PyPI, `setuptools` is what you need. For more information about preparing and uploading packages to PyPI, see the official Python packaging guide at `https://python-packaging.readthedocs.io`.

Configuring a setup.py script

To package our project using `setuptools`, we need to create a setup script; by convention, this is called `setup.py` and is created in the application's root directory.

The basic structure of `setup.py` is as follows:

```
from setuptools import setup

setup(
    # Arguments
)
```

The vast majority of our configuration will be passed as arguments to the `setup()` function, defining the basic metadata for our package, what will be packaged, and providing some functionality after installation.

Basic metadata arguments

To begin, let's define some basic metadata about our application using these arguments in `setup.py`:

```
setup(
    name='ABQ_Data_Entry',
    version='1.0',
    author='Alan D Moore',
    author_email='alandmoore@example.com',
    description='Data entry application for ABQ Agrilabs',
    url="http://abq.example.com",
    license="ABQ corporate license",

```

Metadata such as this will be used in naming the package as well as providing information for PyPI. Not all of the fields are necessary if you are just packaging for personal or internal use, but if you plan to upload to PyPI, you should include all these fields as well as `long_description`, which should be a reStructuredText string that provides extended information about the program.

Often, the `README.rst` file can simply be used as follows:

```
with open('README.rst', 'r') as fh:
    long_description = fh.read()

setup(
    ...
    long_description=long_description,
    ...
)
```

Packages and dependencies

Once we have specified the metadata, we need to tell `setuptools` which packages we're actually bundling using the `packages` argument.

In our case, we only have the `abq_data_entry` package, so we'll specify it as follows:

```
setup(
    #...
    packages=['abq_data_entry'],
```

Adding this will include the main package and all its submodules as well (such as our `images` and `test` modules).

For more complex cases, `setuptools` includes the `find_packages` function, which can be used instead like so:

```
from setuptools import setup, find_packages

setup(
    #...
    packages=find_packages(),
```

This will locate and include all the packages in our project directory automatically.

In addition to the modules defined in our project, our application depends on third-party modules such as `psycopg2` and `matplotlib`. We can specify these dependencies in `setup()`, and, assuming they're available from PyPI, `pip` will install them automatically when our package is installed.

This is done using the `install_requires` argument as shown here:

```
setup(
    #...
    install_requires=['psycopg2', 'requests', 'matplotlib'],
```

Our package only has three dependencies: `psycopg2`, `requests`, and `matplotlib`.

Note that these packages may have their own dependencies as well; those will also be automatically installed by `pip`.

If the package requires particular versions of these modules, we can specify that as well:

```
install_requires=['psycopg2 == 2.7.4', 'requests >= 2.18',   'matplotlib < 2.
```

Similarly, we can specify the version of Python required using the `python_requires` argument as follows:

```
setup(
    #...
    python_requires='>= 3.6',
```

The syntax for these version specifiers is laid out in PEP 440, which you can find at `https://www.python.org/dev/peps/pep-0440/`.

Adding extra files

By default, `setuptools` will only copy Python files into your package. Our package contains more than that, though: we have documentation in RST, SQL scripts, and most importantly our PNG images, without which our program won't run.

Non-Python files inside our package can be specified using the `package_data` argument as follows:

```
setup(
    #...
    package_data={'abq_data_entry.images': ['*.png']},
```

The `package_data` argument takes a dictionary that matches module paths to a list of files or globbing expressions to be included in that module. Here, we're telling `setuptools` to include all the PNG files in the `images` module.

Our project contains other files outside the `abq_data_entry` module, which aren't needed for the program to operate, but should nevertheless be distributed with the package. These cannot be specified in `setup()`, since it only deals with the in-package files.

To add these, we need to create a `MANIFEST.in` file in the project root directory with the following content:

```
include README.rst
include docs/*
include sql/*.sql
```

The `MANIFEST.in` file is a series of the `include` directives with filenames or globbing expressions that match files we want to include. Here, we're including our `docs` directory, all the `sql` files, and the `README.rst` file. Since `setup.py` relies on the `README.rst` file for the `long_description` argument, it's imperative that we include it in the package. Otherwise, our package won't be buildable on other systems.

Defining commands

Packaging the `abq_data_entry` module alone won't make our application executable after installation. Currently, we run our application from `abq_data_entry.py`, which is outside the `abq_data_entry` module that we're packaging; we could include this file in `MANIFEST.in`, but then the user would have to hunt it down somewhere in their Python libraries directory to run it.

The `setuptools` library offers a better way to add executable commands in our package using the `entry_points` argument. **Entry points** are ways for external environments to access our code. One particular entry point, `console_scripts`, defines a list of module functions that will be mapped to external commands. When the package is installed, `setuptools` will create a simple, platform-appropriate executable file for each `console_scripts` item that will run the function specified.

We can't point `console_scripts` to a Python file; it must point to a function inside the package. If we want it to create an executable file to launch our application, we'll need to add a method inside our package that duplicates the code in `abq_data_entry.py`.

Let's create this in the package's `__init__.py` file:

```
from .application import Application

def main():
    app = Application()
    app.mainloop()
```

By defining `main` in the `__init__.py` file, we make it directly available in the `abq_data_entry` namespace.

Now, we can specify this as a `console_scripts` entry point in `setup.py` as follows:

```
setup(
    #...
    entry_points={
        'console_scripts': [
            'abq = abq_data_entry:main'
        ]}
)
```

Each item in the `console_scripts` list is a string in the format `{executable_name} = {module_path}:{function_name}`. Our code here will cause `setuptools` to create an executable called `abq`, which will run the `main()` function we just defined. You could define other scripts here if there were functions in the package that could run standalone.

Creating and using source distributions

With our configuration files all set, we can create a **source distribution**. This kind of distribution bundles all the relevant files for building our package from source into a `tar.gz` archive.

To create the source distribution, run `setup.py` with the `sdist` option in the project root directory:

```
python3 setup.py sdist
```

The following two new directories will appear under the project root:

- `ABQ_Data_Entry.egg-info`: This directory contains the metadata files generated by `setuptools`. If you explore this directory, you'll find that all the information we passed to `setup()` is here in some form or another.
- `dist`: This directory contains any files generated for distribution; in this case, there is just a single `tar.gz` file that contains our source package.

To install the source distribution on another computer, it first needs to be extracted. This can be done with GUI utilities or, on Unix-like systems, the `tar` command as shown in the following example:

```
tar -xzf ABQ_Data_Entry-1.0.tar.gz
```

Now, inside the extracted directory, the `setup.py` file can be run using the `install` option as follows:

```
python3 setup.py install
```

Testing our source distribution

If you don't have a second computer handy to test your source installer on, you can use a Python virtual environment instead. A **virtual environment** is an isolated Python installation that can be activated on-demand to keep packages from polluting our system's Python environment.

First, make sure you have `virtualenv` installed using `pip`:

```
pip install --user virtualenv
```

Next, create a directory anywhere on your system and create a Python 3 environment in it as follows:

```
mkdir testenv
python3 -m virtualenv -p python3 testenv
```

This will create a copy of the Python interpreter and standard library in the `testenv` directory. This environment can be modified in any way you wish without affecting your system's Python.

To use the environment, you need to activate it by executing the following code in a terminal:

```
# On Linux, macOS, and other unix-like systems:
source testenv/bin/activate

# On Windows
testenv\Scripts\activate
```

With your test environment active now, you can now run `setup.py install` on your source distribution. You'll notice that Python will install `psycopg2`, `requests`, `matplotlib`, and many dependencies of those libraries using `pip`, even if you already have them on your system. That's because the virtual environment starts clean with no third-party packages.

If the install was successful, you should find the following two things:

- You have a command called `abq` available in your virtual environment, which launches the `ABQ Data Entry` application
- The `abq_data_entry` library can be found in `testenv/lib/python3.6/site-packages`

When finished with your virtual environment, you can use the `deactivate` script to go back to your system Python, and delete the `testenv` directory to remove the environment.

Building a wheel distribution

While a source distribution may be fine for simple software such as our application, packages with complicated build steps such as code compilation may benefit from a **built distribution**, where the building phase has already been done. The current format used by `setuptools` for built distributions is the **wheel** format.

The wheel format replaces an older `distutils` distribution format called `egg`. You will still see references to `egg` when using `setuptools` or other `distutils` derivatives.

A wheel (`.whl`) file is basically a ZIP file containing prebuilt code. They come in the following three types:

- **Universal**: This wheel file contains only Python code that will run on any platform with any major version of Python (2 or 3)
- **Pure Python:** This wheel file contains only Python code that will run on any platform, but is compatible with only one of Python 2 or Python 3
- **Platform** : This wheel file is limited to a particular OS or platform, usually because it contains compiled binary code

The default wheel file created by `setuptools` is a pure Python wheel, which is what our application should be (since we have no compiled code, but are compatible only with Python 3).

Creating one is simply a matter of calling `setup.py` with the `bdist_wheel` option as follows:

```
python3 setup.py bdist_wheel
```

Like `sdist`, this command creates a new file in the `dist` directory, only this time it's a `.whl` file. The file name will be `ABQ_Data_Entry-1.0-py3-none-any.whl`.

The segments of this file name represents the following information:

- The package name, in this case `ABQ_Data_Entry`

- The version, in this case `1.0`
- Whether it's Python 3, Python 2, or universal; in this case, `py3`
- The ABI tag, in this case `none`
- The platform, in this case `any`

Notice that it also creates a `build` directory, which is where built code is staged before it is compressed into the wheel file. You can inspect this directory to make sure that your package is being assembled correctly.

Wheel files are installed using `pip` as follows:

```
pip install ABQ_Data_Entry-1.0-py3-none-any.whl
```

As with the source install, `pip` will install any dependencies specified and then install our package to the `site-packages` directory. The `abq` file will also be created and copied to an executable location.

If you get an error when trying to use `bdist_wheel`, you may need to install the `wheel` module, as it's not always included with `setuptools`. This module can be installed with the command `pip install --user wheel`.

Using cx_Freeze

While source and wheel distributions are useful, they both require Python and any necessary library dependencies to be installed on a system before the program can be run. Often, it would be much handier if we could provide a file or set of files that can simply be copied and run on a system without installing anything else first. Better yet, we'd like to have platform-specific installation packages that set up shortcuts and other data.

There are several ways to go about this with Python code, and several projects to choose from; we're going to look at one called **cx_Freeze**.

The basic idea of cx_Freeze is to bundle up all the code and shared library files for a Python project along with a Python interpreter, and then generate a small executable file that will launch the code with the bundled interpreter. This approach works fairly well most of the time, but, as we'll see, there are some limitations and difficulties to work around. One significant limitation is that cx_Freeze can only make executables for the platform that it's running on; in other words, if you want a Windows executable, you'll need to build it on Windows; if you want a Linux executable, you'll have to build it on Linux, and so on.

Complete documentation on cx_Freeze can be found at `https://cx-freeze.readthedocs.io`.

First steps with cx_Freeze

Install cx_Freeze using `pip` as shown in the following command:

```
pip install --user cx-Freeze
```

Like `setuptools`, cx_Freeze is an extension of `distutils`; it shares many similarities with `setuptools`, but solves certain problems in different ways. Just like `setuptools`, we'll start with a script in the project directory that calls the `setup()` function.

To distinguish this script from our `setuptools` script, call it `cxsetup.py`, and enter the following code:

```
import cx_Freeze as cx

cx.setup(
    name='ABQ_Data_Entry',
    version='1.0',
    author='Alan D Moore',
    author_email='alandmoore@example.com',
    description='Data entry application for ABQ Agrilabs',
    url="http://abq.example.com",
    packages=['abq_data_entry'],
```

So far, this is nearly identical to a `setuptools` script, but from here things will diverge considerably. First, instead of generating executables using the `entry_points` argument, we have to create a list of cx_Freeze `Executable` objects.

That list is then passed to the `executables` argument, as follows:

```
    executables=[
        cx.Executable('abq_data_entry.py',
                      targetName='abq', icon='abq.ico')],
```

The `Executable` object defines the parameters of the executable files that we want cx_Freeze to generate for us. At minimum, we need to provide a Python script that should be executed when the executable will run; we're using our `abq_data_entry.py` launcher script for this purpose. By default, the generated executable will be the script name without the `.py` extension; we can override this with the `targetName` argument, as we've done here.

We can also specify an icon to use for the application. This needs to be an `.ico` file, so you'll need to convert PNG or other formats before using them. The path to the file is relative to the project directory where the `cxsetup.py` file is.

The build_exe options

Arguments to specific cx_Freeze operations can be passed into `setup()` using the `options` argument. This argument takes a `dict` object where each item is a cx_Freeze operation paired with a `dict` object of operation-specific arguments. The first operation we're going to look as is `build_exe`, which is a universal first step for all other operations. As the name implies, this is the stage where the executable and its accompanying files are built.

Among other things, this is where we specify the package dependencies:

```
    options={
        'build_exe': {
            'packages': ['psycopg2', 'requests', 'matplotlib', 'numpy'],
            'includes': ['idna.idnadata', 'zlib'],
```

In the preceding code snippet, `packages` is a list of the packages that need to be installed (including all their submodules and dependencies), while `includes` is a list of the specific modules that need to be installed. Note that we've included some things beyond our three main dependencies. Unfortunately, because cx_Freeze doesn't always do a great job at identifying all the dependencies, it's often necessary to explicitly list subdependencies.

To figure out the list, follow a basic trial-and-error procedure:

1. Build the executable
2. Run the executable
3. If you get an import error saying a module cannot be found, add it to the `includes` list and rebuild
4. If several modules from the same package are missing, add the package to the `packages` list and rebuild

Including external files

As with `setuptools`, cx_Freeze only includes Python files by default. To get other files included, we use the `include_files` argument to `build_exe`. However, there is a problem: because of the way that cx_Freeze bundles our Python module in a compressed archive, accessing file paths inside the module is problematic.

Our `images` module presents such a problem: it contains PNG files that our application accesses by calculating a relative path from its `__init__.py` file. To address the issue, the PNG files will need to be relocated to a directory outside the package during the build process. Our code will then have to find them in the new location when it's been frozen, and in the original location when not.

To make it work, modify `images/__init__.py` as follows:

```
from os import path
import sys

if getattr(sys, 'frozen', False):
    IMAGE_DIRECTORY = path.join(path.dirname(sys.executable), 'images')
else:
    IMAGE_DIRECTORY = path.dirname(__file__)
```

When running a Python script that has been frozen using cx_Freeze, `sys` has an attribute called `frozen`. We can test for the presence of this attribute to specify behavior that changes when the app is frozen. In this case, we're going to look for our images in an `images` directory located in the same directory as the executable file when the script is frozen. Otherwise, we'll look for them in the module.

To copy our images into this location, we need to update our `build_exe` options:

```
include_files = [('abq_data_entry/images', 'images')]
#...
cx.setup(
    #...
    options={
        'build_exe': {
            #...
            'include_files': include_files
```

`include_files` is a list of two-tuples. The first tuple member is a source path relative to the `cxsetup.py` script, while the second is a destination path relative to the executable file.

Note that we're defining `include_files` outside the `setup()` call, for reasons that will be apparent later.

Building executables

At this point, we can build an executable by running the following command line:

```
python3 cxsetup.py build
```

`build` runs all steps up to `build_exe`, leaving you with the built code in a platform-specific directory under `./build`. You can inspect this directory to make sure files are being copied over and created properly. cx_Freeze should have created a binary executable file called `abq`, which will launch your application when run. Note, however, that all files in this directory must be present for the program to run; cx_Freeze does not support the creation of single-file standalone executables.

For Linux and BSD, the built package is ready to go and can be zipped up and distributed as is. For Windows and macOS, we're going to need to do some more work to get it ready for distribution. In fact, you may have gotten an error, which we'll deal with in the following sections.

cx_Freeze supports the creation of the RPM files, the package format used by Linux distributions such as ***Fedora*** *or* ***SUSE****. If you're on an RPM distribution, you may want to investigate this option. Unfortunately there is no build operation to build packages for non-RPM distributions such as Debian, Ubuntu, or Arch.*

Cleaning up the build

Although we have working executables, you might have noticed that the distributable folder is extremely large for such a simple project as ours. Before calling it a day, it's worth poking around inside the build directories to see what files cx_Freeze is bundling into your application and whether you really need all of it.

If you look under `build/exe.(platform)/lib/python3.6/`, you'll find all the libraries that were pulled in as dependencies of our package. Many of these aren't actually necessary for running our application, particularly those brought in by alternate backends of `matplotlib`.

We can remove many of these using the `excludes` option of `build_exe` as follows:

```
    options={
        'build_exe': {
            'excludes': ['PyQt4', 'PyQt5', 'PySide', 'IPython',
                         'jupyter_client', 'jupyter_core', 'ipykernel',
                         'ipython_genutils'],
```

After adding this change, delete your `build` directory and rerun the build. You'll see that all these packages are no longer there, and the size of your build is significantly smaller. Knowing what can be included or excluded takes research and some trial-and-error, but with careful pruning we can bring down the size of our distributable files and the build time for our package considerably.

Building Windows executables with cx_Freeze

To get our build working correctly on Windows, we'll need to work around a couple of bugs in the current versions of cx_Freeze and Python 3.6: first, cx_Freeze relies on two environment variables pointing to the location of the Tcl and Tk libraries, which are no longer set on Windows, and, second, it fails to copy the Tcl and Tk DLL files to the program directory. Take the following steps to correct this:

1. Start by creating a conditional block for Windows builds in `cxsetup.py`:

```
import platform
import os
if platform.system() == "Windows":
    PYTHON_DIR = os.path.dirname(os.path.dirname(os.__file__))
```

   Inside the block, we're determining the directory containing our Python installation by getting the parent directory of the `os` library. We'll use this to locate the Tcl and Tk libraries.

2. Now add the environment variables as follows:

```
    os.environ['TCL_LIBRARY'] = os.path.join(PYTHON_DIR,
    'tcl', 'tcl8.6')
    os.environ['TK_LIBRARY'] = os.path.join(PYTHON_DIR,
    'tcl', 'tk8.6')
```

3. Finally, we need to append our DLL files to the `include_files` list as follows:

```
include_files += [
    (os.path.join(PYTHON_DIR, 'DLLs', 'tcl86t.dll'), ''),
    (os.path.join(PYTHON_DIR, 'DLLs', 'tk86t.dll'), '')]
```

   By specifying an empty string for the second tuple member, these files will be copied into the application's root directory.

4. That addresses the bug; the other thing we need to do for a Windows build is configure the `base` and `target` arguments to `Executable` appropriately. As we discussed in `Chapter 9`, *Maintaining Cross-Platform Compatibility*, Windows programs launch in either console or GUI mode. To make our program launch in GUI mode, we have to pass a value of `Win32GUI` for `base`. Add this to our conditional block and the `cx.setup()` call:

```
base = None
target_name = 'abq'
if platform.system() == "Windows":
    base = "Win32GUI"
    target_name = 'abq.exe'

# Inside cx.setup()
    ...
    executables=[
        cx.Executable('abq_data_entry.py', base=base,
                      targetName=target_name, icon='abq.ico')],
```

For other platforms, `base` should just be `None`. For the `target` argument, we changed the target name to `abq.exe`. Executable files on Windows need to have an extension of `.exe`, and trying to specify a target name that doesn't have this extension will result in a build error.

Building a Windows installer file

In addition to building a Windows executable, we can build a Windows installer file (`.msi`) using the `bdist_msi` operation. Apart from being ideally compact and simple to distribute, this file provides some additional capabilities for our build, such as an install wizard and shortcut generation.

One thing we can specify here is the upgrade code:

```
cx.setup(
    #...
    options = {
        #...
        'bdist_msi': {
            'upgrade_code': '{12345678-90AB-CDEF-1234-567890ABCDEF}',
```

The upgrade code is a **Globally Unique Identifier (GUID)** value that will identify this program on the OS. By specifying this, subsequent builds of this `.msi` file will remove and replace any existing installations of the same program.

Upgrade codes consist of five segments of 8, 4, 4, 4, and 12 characters from 0 to 9 and A to F. They can be created in Microsoft Visual Studio, or using the PowerShell command, `[System.Guid]::NewGuid().ToString().ToUpper()`*. Once specified, they should not change for your program.*

The installer can also create application shortcuts, which will be placed on the desktop and/or programs menu when the package is installed.

To define our shortcuts we need to create a list of shortcut table tuples as follows:

```
shortcut_data = [
    ('DesktopShortcut', 'DesktopFolder', 'ABQ Data Entry', 'TARGETDIR',
     '[TARGETDIR]' + target_name, None,
     'Data Entry application for ABQ Agrilabs', None,
     None, None, None, 'TARGETDIR'),
    ('MenuShortcut', 'ProgramMenuFolder', 'ABQ Data Entry', 'TARGETDIR',
     '[TARGETDIR]' + target_name, None,
     'Data Entry application for ABQ Agrilabs', None,
     None, None, None, 'TARGETDIR')]
```

The preceding two tuples define a shortcut for the desktop and menu, respectively. The data contained in them matches the layout defined by Microsoft at `https://msdn.microsoft.com/en-us/library/windows/desktop/aa371847.aspx`.

Those fields are described, in order, as follows:

- `Shortcut`, the type of shortcut to create; in our case either `DesktopShortcut` or `MenuShortcut`.
- `Directory_`, a special directory key into which the shortcut will be copied. Here, `DesktopFolder` points to the desktop, and `ProgramMenuFolder` points to the programs folder in the menu.
- `Name`, representing the name of the shortcut.
- `Component_`, referring to a program whose installed or uninstalled state determines whether our shortcuts are installed or uninstalled. By specifying `TARGETDIR`, the install/uninstall state of our shortcuts matches the install/uninstall state of the program directory.
- `Target`, meaning what file is executed by the shortcut. This will be our `target_name` attribute inside `TARGETDIR`.
- `Arguments`, a string of arguments passed to the command; in our case, there are none.
- `Description`, a string used in the description field of the shortcut.
- `Icon_` and `IconIndex`, which are used to locate an icon for the shortcut. These can be left as `None` since our executable's icon will be used by default.
- `ShowCmd`, specifying if the program will be launched minimized, maximized, or normally. Leaving this as `None` will launch it normally.
- Finally, `WkDir`, indicating the working directory to be used. We want this to be the program's directory, so we use `TARGETDIR` here.

Once created, these shortcut tables need to be included in the `data` argument of our `bdist_msi` options:

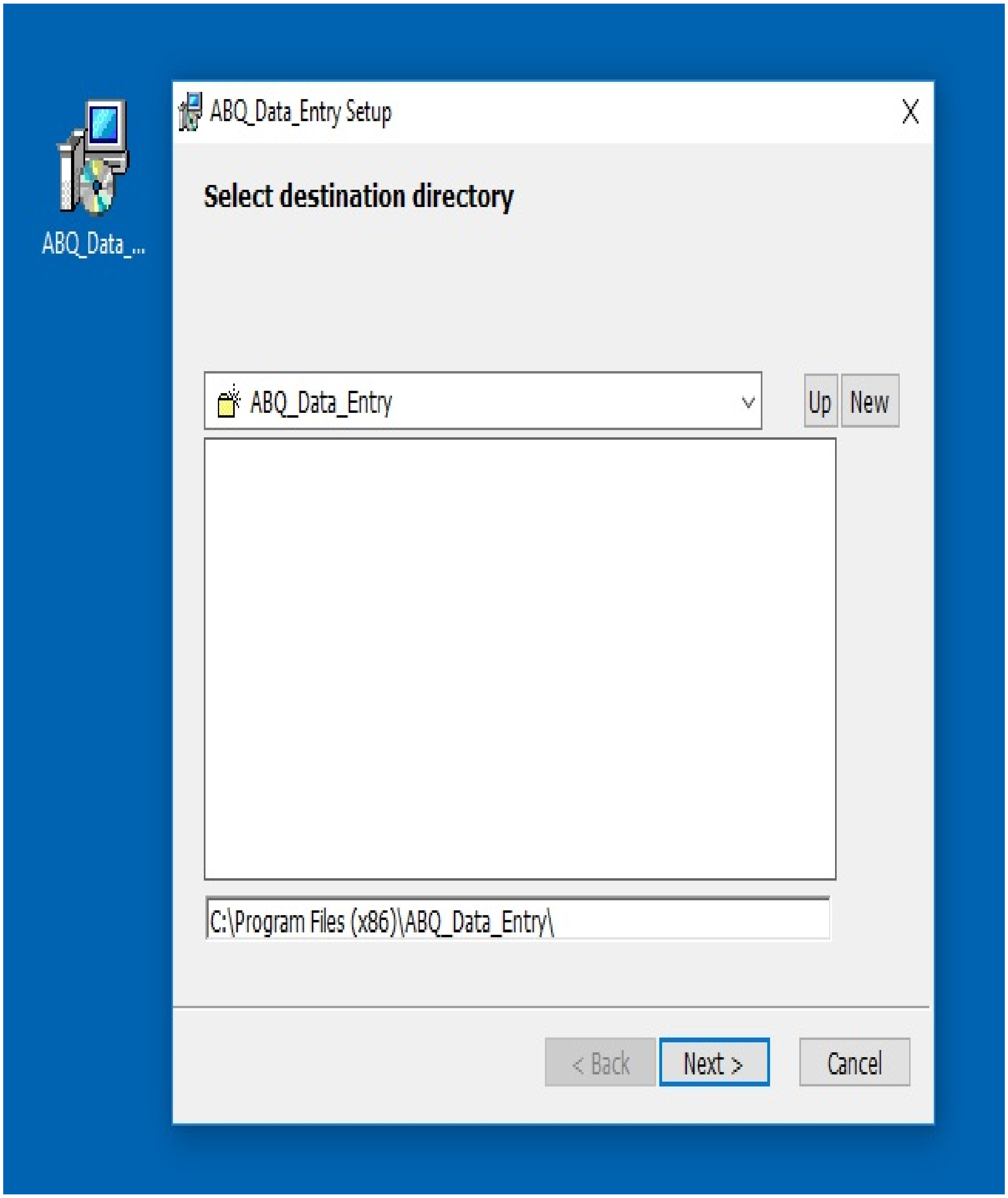
```
cx.setup(
    #...
    options={
        #...
        'bdist_msi': {
            'data': {'Shortcut': shortcut_data}
```

Currently, `data` is not documented in the cx_Freeze documentation; cx_Freeze uses the standard library's `msilib` module to build the `.msi` files, and anything passed into this argument is passed along to the `add_data()` function of `msilib`. Refer to the standard library documentation for `msilib` at `https://docs.python.org/3/library/msilib.html` if you're interested in exploring this option further.

With the `bdist_msi` options specified, let's build the `.msi` file as follows:

```
pyton3 cxsetup.py bdist_msi
```

This creates a new installer file in the `dist` directory, which you should be able to install on any compatible Windows system as shown in the following screenshot:



Keep in mind that cx_Freeze uses Python binaries from your build environment in the application build; as a result, 64-bit Python will build a 64-bit executable, and 32-bit Python will build a 32-bit executable. Additionally, builds created on newer versions of Windows may not be compatible with older versions of Windows. For maximum compatibility, build your binaries on a 32-bit version of the oldest release of Windows you plan to support.

Building macOS executables with cx_Freeze

As with Windows, we need to work around a couple of issues to use cx_Freeze on macOS.

First, there is a problem when building projects that include `numpy`, which is a dependency of `matplotlib`. To work around it, you'll need a version newer than 6.0.b1; at the time of writing, that means installing it directly from GitHub.

This can be done with by executing the following command line:

```
pip install --user git+https://github.com/anthony-tuininga/cx-freeze
```

The second issue only happens if you've installed Python using the `homebrew` package manager (currently, this is the only way to get Python working with Tk 8.6 on macOS). cx_Freeze expects Python to be in `/Library/Frameworks` where the official installer places it, but `homebrew` installs Python to `/usr/local/Cellar/Frameworks`.

This can be fixed with a symlink, by executing this command:

```
sudo ln -s /usr/local/Cellar/Frameworks/Python.Framework ~/Library/Frameworks
```

With the bugs sorted out, we can build binaries for macOS. There are two build types special to macOS: `bdist_mac` and `bdist_dmg`.

Building macOS application bundles

The `bdist_mac` build type creates an application bundle, a specially formatted directory with an `.app` extension that the Macintosh desktop treats as though it were an executable file.

`bdist_mac` has several configuration options, but we're only going to use two as follows:

```
cx.setup(
    #...
    options={
        ...
        'bdist_mac': {
            'bundle_name': 'ABQ-Data-Entry',
            'iconfile': 'abq.icns'
        }
```

Here, `bundle_name` sets the name of our application bundle. Normally, this would default to your project's name, but we're overriding it to use dashes instead of underscores. Note that using spaces in this value creates problems for cx_Freeze and is best avoided. The `iconfile` setting allows us to point to an ICNS file that macOS will use for the application's icon. The dimensions of this image file need to be a square number of pixels that is a power of two between 16 and 1,024. A compatible ABQ logo is included in the example code.

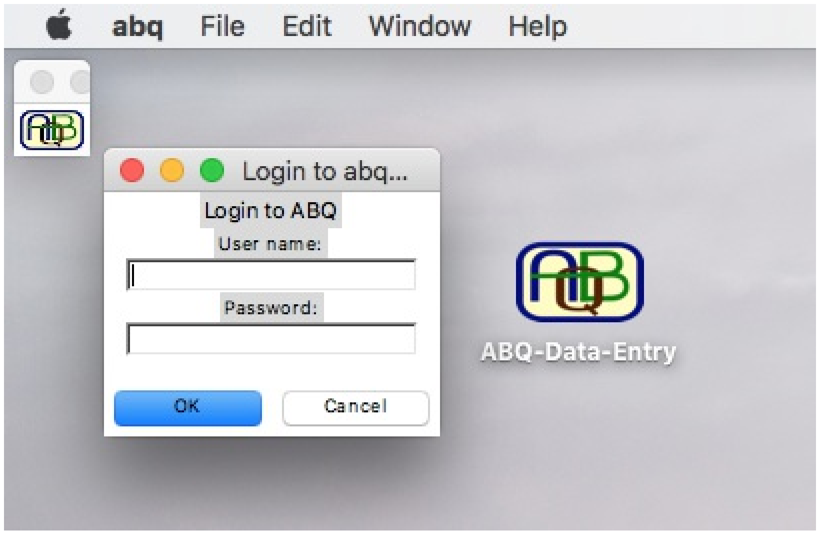
Refer to the cx_Freeze documentation for additional options here, which include code signing and explicitly specifying additional frameworks for the bundle.

Once your configuration options are added, run the `cxsetup.py` script by using the following command:

```
python3 cxsetup.py bdist_mac
```

When this process completes, `ABQ-Data-Entry.app` should appear in the `build` directory. You can double-click this directory in the macOS GUI to run it from any location, or drag it to the `/Applications` directory to install it.

It should appear something like as shown in the following screenshot:



As you can see, our application menu no longer reads Python, as we first saw in `Chapter 9`, *Maintaining Cross-platform Compatibility*; it now reads abq, the name of the executable file, which is what we want.

As with Windows, cx_Freeze-generated bundles are not necessarily backwards-compatible, so it's best to create them on the oldest version of macOS that you need to support.

Building macOS .dmg files

Applications on macOS are generally distributed inside a compressed **disk image** (`.dmg`) file. cx_Freeze allows you to go one step further and bundle your package into a DMG file directly.

This is done using `bdist_dmg` by executing the following command line:

```
python3 cxsetup.py bdist_dmg
```

This command runs `bdist_mac` and then packages the resulting bundle into a DMG file. The configuration options for `bdist_dmg` allow you to override the filename and include a shortcut to the `/Applications` directory for easy installation. The `built` file will appear in the `build` directory, and you can copy it from there to another Macintosh to be mounted and used.

Summary

In this chapter, you learned how to prepare and package your application for distribution. You learned how to package it for distribution as a Python library, either for internal use or in a public index such as PyPI. You also learned how to convert your Python script into an executable file that can be distributed to other systems without installing Python or supporting libraries.

Congratulations on finishing this book! Together we've taken a simple CSV file and turned it into a complex and robust graphical application. You now have the knowledge and confidence to create user-friendly GUI applications that work with files, databases, networks, and APIs across all major platforms.

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