Matplotlib 3.0 Cookbook

Over 150 recipes to create highly detailed interactive visualizations using Python

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Srinivasa Rao Poladi

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Preface

In the era of big data, finding valuable business insights is akin to finding a needle in a haystack. Visualization plays a critical role in finding those nuggets from an ever-increasing volume and variety of data. Matplotlib, with its rich visualization functionality, makes the process of exploratory data analysis user friendly and more productive.

Matplotlib's core functionality is vast, and it is further enhanced by many in-house and third-party toolkits. Many of the books on the market cover only a small portion of its complete functionality. In this book, we have covered Matplotlib's complete core functionality and many of its popular toolkits.

Matplotlib is popular among machine learning practitioners and researchers who use the Python ecosystem. With its rich functionality, it can be used in business intelligence and operational reporting applications. In this book, we have made an attempt to present examples from these applications.

While a recipe-based cookbook approach makes this book a reference guide for quick solutions, we have covered sufficient theoretical background to make it easy for beginners as well.

Who this book is for

This book is for data analysts, business analysts, data scientists, and Python developers who are looking for quick solutions for a wide variety of visualization applications, such as ad hoc reports, professional dashboards, exploratory data analysis, interactive analysis, embedded visualizations in selected GUI toolkits and web applications, three-dimensional plots, and geographical maps.

Those who are interested in developing business intelligence, machine learning, scientific, or engineering applications will also benefit from the recipes that are relevant for each of these disciplines.

What this book covers

`Chapter 1`, *Anatomy of Matplotlib*, explains the architecture of Matplotlib, various elements of a figure, interactive and non-interactive modes of operation, and how to customize environmental parameters.

`Chapter 2`, *Getting Started with Basic Plots*, introduces many types of graph that are commonly used in business intelligence and machine learning applications, including line, scatter, bar, stacked, histogram, box, violin, contour plots, heatmaps, and Hinton diagrams.

`Chapter 3`, *Plotting Multiple Graphs, Subplots, and Figures*, shows how to organize graphs into subplots and figures.

`Chapter 4`, *Developing Visualizations for Publishing Quality*, illustrates how to customize various attributes of a figure, including color, fonts, labels, titles, legend, spines, styles, markers, and annotation.

`Chapter 5`, *Plotting with the Object-Oriented API*, introduces the object-oriented API and compares it with the pyplot API. The object-oriented API gives flexibility in designing complex dashboards as required, but requires Python programming experience if you want to write code. The pyplot API comes with pre-packaged graphs that require simple commands to plot, without needing to write much Python code.

`Chapter 6`, *Plotting with Advanced Features*, covers how to develop complex visualization applications by using the advanced customization of legends, artist, and layout, as well as cycling object properties, origin and extent in images, transforms, animations, event handling, and path effects.

`Chapter 7`, *Embedding Text and Expressions*, covers how to add text to plots with regular text, annotations and mathematical expressions.

`Chapter 8`, *Saving the Figure in Different Formats*, explains how to save figures to external output files in PNG, PDF, SVG, and PS formats.

`Chapter 9`, *Developing Interactive Plots*, explains how to develop interactive plots using event handling, animations, and widgets. These features enable the users to perform interactive analysis.

`Chapter 10`, *Embedding Plots in Graphical User Interface*, explains how to embed Matplotlib plots into other graphical user interfaces used for developing applications.

`Chapter 11`, *Plotting 3D Graphs Using the mplot3d Toolkit*, covers how to use the mplot3D toolkit to plot 3D graphs, and the next two chapters cover two more toolkits.

`Chapter 12`, *Using the axisartist Toolkit*, explains that while the standard Matplotlib axes uses a traditional Cartesian coordinate system, it can't handle special features such as curved or floating axes that are useful in plotting geographical or planetary systems. This chapter explains how to create special applications using the `axisartist` toolkit.

`Chapter 13`, *Using the axes_grid1 Toolkit*, covers the `axes_grid1` toolkit. This toolkit enables you to plot images in a grid with an associated color bar that aligns well with the image and also enables anchor images as legends, zoom in/out effects, and more.

`Chapter 14`, *Plotting Geographical Maps Using the Cartopy Toolkit*, explains wide variety of features that cater to many different user communities. We will cover most of the features typically used in business applications.

`Chapter 15`, *Exploratory Data Analysis Using the Seaborn Toolkit*, explains the process of exploratory data analysis using exhaustive features of seaborn toolkit.

To get the most out of this book

Basic knowledge of Python is enough to understand the content in this book, except for `Chapters 9`, *Developing Interactive Plots* and `Chapter 10`, *Embedding Plots in a Graphical User Interface*. These two chapters deal with interactive plotting and embedded applications that need medium-level Python programming experience.

Many Python distributions automatically include Matplotlib, along with all its dependencies. If you have not installed any standard Python distributions, you can follow the installation process at `https://matplotlib.org/users/installing.html` to install Matplotlib and its associated dependencies.

Download the example code files

You can download the example code files for this book from your account at `www.packt.com`. If you purchased this book elsewhere, you can visit `www.packt.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.packt.com`.
2. Select the **SUPPORT** tab.
3. Click on **Code Downloads & Errata**.
4. Enter the name of the book in the **Search** box and follow the onscreen instructions.

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
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The code bundle for the book is also hosted on GitHub at `https://github.com/PacktPublishing/Matplotlib-3.0-Cookbook`. 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!

Download the color images

We also provide a PDF file that has color images of the screenshots/diagrams used in this book. You can download it here: `https://www.packtpub.com/sites/default/files/downloads/9781789135718_ColorImages.pdf`.

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: "We will follow the order of `.txt`, `.csv`, and `.xlsx` files, in three separate sections."

A block of code is set as follows:

```
import matplotlib.pyplot as plt
import pandas as pd
import numpy as np
from matplotlib import cm
```

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: "When you run the program and click **Next** and **Next**, you will see the following three figures, representing each of the clusters, as shown in the header of each figure."

Warnings or important notes appear like this.

Tips and tricks appear like this.

Sections

In this book, you will find several headings that appear frequently (*Getting ready*, *How to do it...*, *How it works...*, *There's more...*, and *See also*).

To give clear instructions on how to complete a recipe, use these sections as follows:

Getting ready

This section tells you what to expect in the recipe and describes how to set up any software or any preliminary settings required for the recipe.

How to do it…

This section contains the steps required to follow the recipe.

How it works…

This section usually consists of a detailed explanation of what happened in the previous section.

There's more…

This section consists of additional information about the recipe in order to make you more knowledgeable about the recipe.

See also

This section provides helpful links to other useful information for the recipe.

Get in touch

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1 Anatomy of Matplotlib

This chapter begins with an introduction to Matplotlib, including the architecture of Matplotlib and the elements of a figure, followed by the recipes. The following are the recipes that will be covered in this chapter:

- Working in interactive mode
- Working in non-interactive mode
- Reading from external files and plotting
- How to change and reset default environment variables

Introduction

Matplotlib is a cross-platform Python library for plotting two-dimensional graphs (also called **plots**). It can be used in a variety of user interfaces such as Python scripts, IPython shells, Jupyter Notebooks, web applications, and GUI toolkits. It can be used to develop professional reporting applications, interactive analytical applications, complex dashboard applications or embed into web/GUI applications. It supports saving figures into various hard-copy formats as well. It also has limited support for three-dimensional figures. It also supports many third-party toolkits to extend its functionality.

Please note that all the examples in this book are tested with Matplotlib 3.0 and Jupyter Notebook 5.1.0.

Architecture of Matplotlib

Matplotlib has a three-layer architecture: **backend**, **artist**, and **scripting**, organized logically as a stack. Scripting is an API that developers use to create the graphs. Artist does the actual job of creating the graph internally. Backend is where the graph is displayed.

Backend layer

This is the bottom-most layer where the graphs are displayed on to an output device. This can be any of the user interfaces that Matplotlib supports. There are two types of backends: **user interface backends** (for use in `pygtk`, `wxpython`, `tkinter`, `qt4`, or `macosx`, and so on, also referred to as **interactive backends**) and **hard-copy** backends to make image files (`.png`, `.svg`, `.pdf`, and `.ps`, also referred to as **non-interactive backends**). We will learn how to configure these backends in later `Chapter 9`, *Developing Interactive Plots* and `Chapter 10`, *Embedding Plots in a Graphical User Interface*.

Artist layer

This is the middle layer of the stack. Matplotlib uses the `artist` object to draw various elements of the graph. So, every element (see elements of a figure) we see in the graph is an artist. This layer provides an **object-oriented API** for plotting graphs with maximum flexibility. This interface is meant for seasoned Python programmers, who can create complex dashboard applications.

Scripting layer

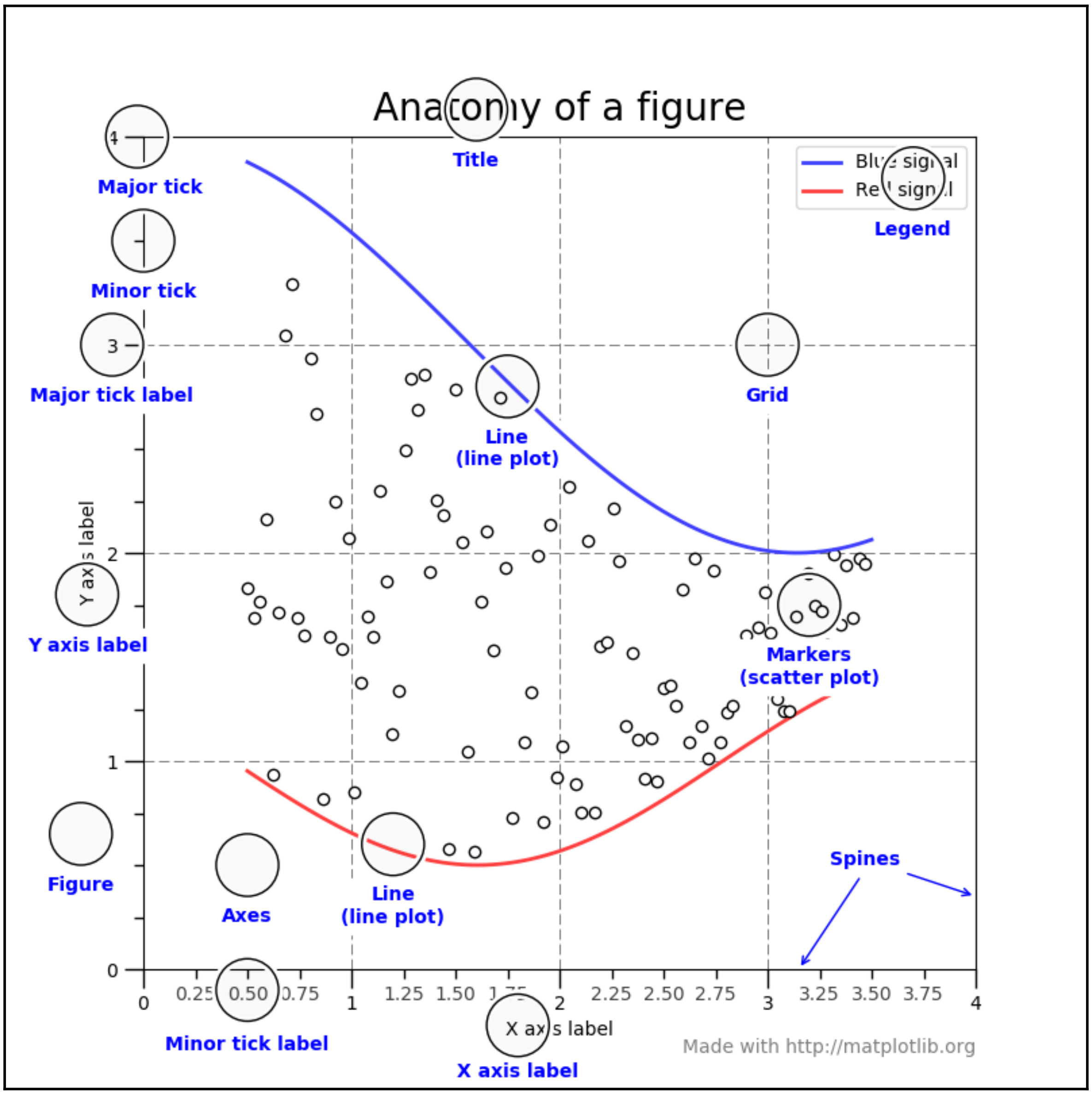
This is the topmost layer of the stack. This layer provides a simple interface for creating graphs. This is meant for use by end users who don't have much programming expertise. This is called a `pyplot` API.

Elements of a figure

The high-level Matplotlib object that contains all the elements of the output graph is called a `figure`. Multiple graphs can be arranged in different ways to form a figure. Each of the figure's elements is customizable.

Figure

The following diagram is the anatomy of a `figure`, containing all its elements:



Anatomy of a figure (Source : http://diagramss.us/plotting-a-graph-in-matlab.html)

Axes

`axes` is a sub-section of the figure, where a graph is plotted. `axes` has a **title**, an **x-label** and a **y-label**. A `figure` can have many such `axes`, each representing one or more graphs. In the preceding figure, there is only one `axes`, two line graphs in blue and red colors.

Axis

These are number lines representing the scale of the graphs being plotted. Two-dimensional graphs have an *x* axis and a *y* axis, and three-dimensional graphs have an *x* axis, a *y* axis, and a *z* axis.

Don't get confused between axes and axis. Axis is an element of axes. Grammatically, axes is also the plural for axis, so interpret the meaning of axes depending on the context, whether multiple axis elements are being referred to or an axes object is being referred to.

Label

This is the name given to various elements of the figure, for example, *x* axis label, *y* axis label, graph label (blue signal/red signal in the preceding figure *Anatomy of a figure*), and so on.

Legend

When there are multiple graphs in the `axes` (as in the preceding figure *Anatomy of a figure*), each of them has its own label, and all these labels are represented as a legend. In the preceding figure, the legend is placed at the top-right corner of the figure.

Title

It is the name given to each of the `axes`. The `figure` also can have its own title, when the figure has multiple axes with their own titles. The preceding figure has only one axes, so there is only one title for the axes as well as the figure.

Ticklabels

Each axis (*x*, *y*, or *z*) will have a range of values that are divided into many equal bins. Bins are chosen at two levels. In the preceding figure *Anatomy of a figure*, the *x* axis scale ranges from 0 to 4, divided into four major bins (0-1, 1-2, 2-3, and 3-4) and each of the major bins is further divided into four minor bins (0-0.25, 0.25-0.5, and 0.5-0.75). Ticks on both sides of major bins are called **major ticks** and minor bins are called **minor ticks**, and the names given to them are **major ticklabels** and **minor ticklabels**.

Spines

Boundaries of the figure are called **spines**. There are four spines for each axes(top, bottom, left, and right).

Grid

For easier readability of the coordinates of various points on the graph, the area of the graph is divided into a grid. Usually, this grid is drawn along major ticks of the *x* and *y* axis. In the preceding figure, the grid is shown in dashed lines.

Working in interactive mode

Matplotlib can be used in an **interactive** or **non-interactive** modes. In the interactive mode, the graph display gets updated after each statement. In the non-interactive mode, the graph does not get displayed until explicitly asked to do so.

Getting ready

You need working installations of Python, NumPy, and Matplotlib packages.

Using the following commands, interactive mode can be set on or off, and also checked for current mode at any point in time:

- `matplotlib.pyplot.ion()` to set the interactive mode `ON`
- `matplotlib.pyplot.ioff()` to switch `OFF` the interactive mode
- `matplotlib.is_interactive()` to check whether the interactive mode is `ON` (`True`) or `OFF` (`False`)

How to do it...

Let's see how simple it is to work in interactive mode:

1. Set the screen output as the backend:

   ```
   %matplotlib inline
   ```

2. Import the `matplotlib` and `pyplot` libraries. It is common practice in Python to import libraries with crisp synonyms. Note `plt` is the synonym for the `matplotlib.pyplot` package:

   ```
   import matplotlib as mpl
   import matplotlib.pyplot as plt
   ```

3. Set the interactive mode to ON:

   ```
   plt.ion()
   ```

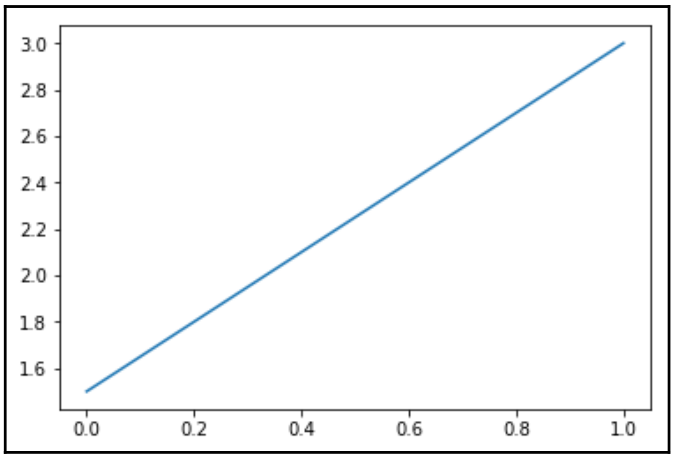
4. Check the status of interactive mode:

   ```
   mpl.is_interactive()
   ```

5. You should get the output as `True`.
6. Plot a line graph:

   ```
   plt.plot([1.5, 3.0])
   ```

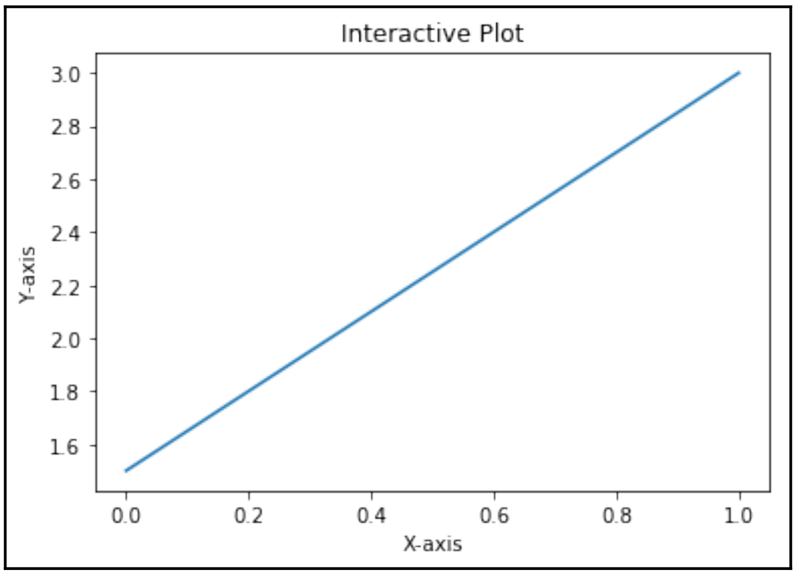
You should see the following graph as the output:



7. Now add the axis labels and a title to the graph with the help of the following code:

```
# Add labels and title
plt.title("Interactive Plot") #Prints the title on top of graph
plt.xlabel("X-axis")         # Prints X axis label as "X-axis"
plt.ylabel("Y-axis")         # Prints Y axis label as "Y-axis"
```

After executing the preceding three statements, your graph should look as follows:



How it works...

So, this is how the explanation goes:

- `plt.plot([1.5, 3.0])` plots a line graph connecting two points (0, 1.5) and (1.0, 3.0).
- The `plot` command expects two arguments (Python list, NumPy array or pandas DataFrame) for the *x* and *y* axis respectively.
- If only one argument is passed, it takes it as *y* axis co-ordinates and for *x* axis co-ordinates it takes the length of the argument provided.
- In this example, we are passing only one list of two points, which will be taken as *y* axis coordinates.

- For the *x* axis, it takes the default values in the range of 0 to 1, since the length of the list `[1.5, 3.0]` is 2.
- If we had three coordinates in the list for *y*, then for *x,* it would take the range of 0 to 2.
- You should see the graph like the one shown in *step 6.*
- `plt.title("Interactive Plot"),` prints the title on top of the graph as **Interactive Plot.**
- `plt.xlabel("X-axis"),` prints the *x* axis label as **X-axis.**
- `plt.ylabel("Y-axis"),` prints the *y* axis label as **Y-axis.**
- After executing preceding three statements, you should see the graph as shown in *step 7.*

If you are using Python shell, after executing each of the code statements, you should see the graph getting updated with title first, then the *x* axis label, and finally the *y* axis label.

If you are using Jupyter Notebook, you can see the output only after all the statements in a given cell are executed, so you have to put each of these three statements in separate cells and execute one after the other, to see the graph getting updated after each code statement.

In older versions of Matplotlib or certain backends (such as `macosx`), the graph may not be updated immediately. In such cases, you need to call `plt.draw()` explicitly at the end, so that the graph gets displayed.

There's more...

You can add one more line graph to the same plot and go on until you complete your interactive session:

1. Plot a line graph:

```
plt.plot([1.5, 3.0])
```

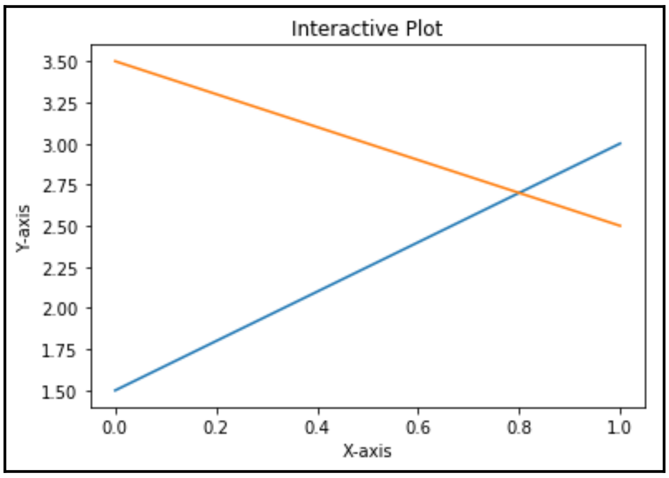
2. Add labels and title:

```
plt.title("Interactive Plot")
plt.xlabel("X-axis")
plt.ylabel("Y-axis")
```

3. Add one more line graph:

```
plt.plot([3.5, 2.5])
```

The following graph is the output obtained after executing the code:



Hence, we have now worked in interactive mode.

Working in non-interactive mode

In the interactive mode, we have seen the graph getting built step by step with each instruction. In non-interactive mode, you give all instructions to build the graph and then display the graph with a command explicitly.

How to do it...

Working on non-interactive mode won't be difficult either:

1. Start the kernel afresh, and import the `matplotlib` and `pyplot` libraries:

```
import matplotlib
import matplotlib.pyplot as plt
```

2. Set the interactive mode to OFF:

```
plt.ioff()
```

3. Check the status of interactive mode:

```
matplotlib.is_interactive()
```

4. You should get the output `False`.
5. Execute the following code; you will not see the plot on your screen:

```
# Plot a line graph
plt.plot([1.5, 3.0])

# Plot the title, X and Y axis labels
plt.title("Non Interactive Mode")
plt.xlabel("X-axis")
plt.ylabel("Y-axis")
```

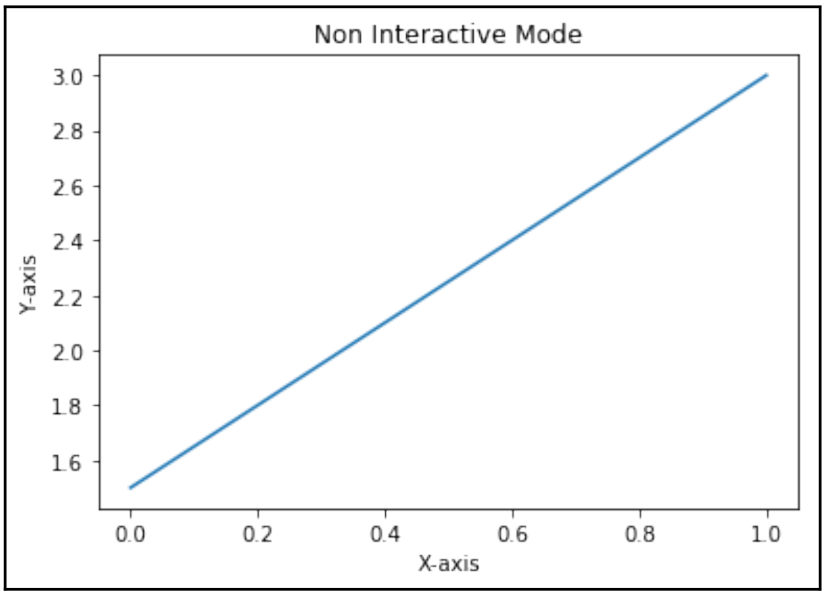
6. Execute the following statement, and then you will see the plot on your screen:

```
# Display the graph on the screen
plt.show()
```

How it works...

Each of the preceding code statements is self-explanatory. The important thing to note is in non-interactive mode, you write complete code for the graph you want to display, and call `plt.show()` explicitly to display the graph on the screen.

The following is the output obtained:



The latest versions of Jupyter Notebook seem to display the figure without calling `plt.show()` command explicitly. However, in Python shell or embedded applications, `plt.show()` or `plt.draw()` is required to display the figure on the screen.

Reading from external files and plotting

By default, Matplotlib accepts input data as a Python list, NumPy array, or pandas DataFrame. So all external data needs to be read and converted to one of these formats before feeding it to Matplotlib for plotting the graph. From a performance perspective, NumPy format is more efficient, but for default labels, pandas format is convenient.

If the data is a `.txt` file, you can use NumPy function to read the data and put it in NumPy arrays. If the data is in `.csv` or `.xlsx` formats, you can use pandas to read the data. Here we will demonstrate how to read `.txt`, `.csv`, and `.xlsx` formats and then plot the graph.

Getting ready

Import the `matplotlib.pyplot`, `numpy` , and `pandas` packages that are required to read the input files:

1. Import the `pyplot` library with the `plt` synonym:

   ```
   import matplotlib.pyplot as plt
   ```

2. Import the `numpy` library with the `np` synonym. The `numpy` library can manage n-dimensional arrays, supporting all mathematical operations on these arrays:

   ```
   import numpy as np
   ```

3. Import the `pandas` package with `pd` as a synonym:

   ```
   import pandas as pd
   ```

How to do it...

We will follow the order of `.txt`, `.csv`, and `.xlsx` files, in three separate sections.

Reading from a .txt file

Here are some steps to follow:

1. Read the text file into the `txt` variable:

   ```
   txt = np.loadtxt('test.txt', delimiter = ',')
   txt
   ```

Here is the explanation for the preceding code block:

- The `test.txt` text file has 10 numbers separated by a comma, representing the *x* and *y* coordinates of five points (1, 1), (2, 4), (3, 9), (4, 16), and (5, 25) in a two-dimensional space.
- The `loadtxt()` function loads text data into a NumPy array.

You should get the following output:

```
array([ 1., 1., 2., 4., 3., 9., 4., 16., 5., 25.])
```

2. Convert the flat array into five points in 2D space:

   ```
   txt = txt.reshape(5,2)
   txt
   ```

After executing preceding code, you should see the following output:

```
array([[ 1., 1.], [ 2., 4.], [ 3., 9.], [ 4., 16.], [ 5., 25.]])
```

3. Split the `.txt` variable into `x` and `y` axis co-ordinates:

   ```
   x = txt[:,0]
   y = txt[:,1]
   print(x, y)
   ```

Here is the explanation for the preceding code block:

- Separate the `x` and `y` axis points from the `txt` variable.
- `x` is the first column in `txt` and `y` is the second column.
- The Python indexing starts from 0.

After executing the preceding code, you should see the following output:

```
[ 1. 2. 3. 4. 5.] [ 1. 4. 9. 16. 25.]
```

Reading from a .csv file

The `.csv` file has a relational database structure of rows and columns, and the `test.csv` file has *x*, *y* co-ordinates for five points in 2D space. Each point is a row in the file, with two columns: `x` and `y`. The same NumPy `loadtxt()` function is used to load data:

```
x, y = np.loadtxt ('test.csv', unpack = True, usecols = (0,1), delimiter =
',')
print(x)
print(y)
```

On execution of the preceding code, you should see the following output:

```
[ 1. 2. 3. 4. 5.] [ 1. 4. 9. 16. 25.]
```

Reading from an .xlsx file

Now let's read the same data from an `.xlsx` file and create the `x` and `y` NumPy arrays. The `.xlsx` file format is not supported by the NumPy `loadtxt()` function. A Python data processing package, `pandas` can be used:

1. Read the `.xlsx` file into pandas DataFrame. This file has the same five points in 2D space, each in a separate row with `x`, `y` columns:

   ```
   df = pd.read_excel('test.xlsx', 'sheet', header=None)
   ```

2. Convert the pandas DataFrame to a NumPy array:

   ```
   data_array = np.array(df)
   print(data_array)
   ```

   You should see the following output:

   ```
   [[ 1 1] [ 2 4] [ 3 9] [ 4 16] [ 5 25]]
   ```

3. Now extract the `x` and `y` coordinates from the NumPy array:

   ```
   x , y = data_array[:,0], data_array[:,1]
   print(x,y)
   ```

   You should see the following output:

   ```
   [1 2 3 4 5] [ 1 4 9 16 25]
   ```

Plotting the graph

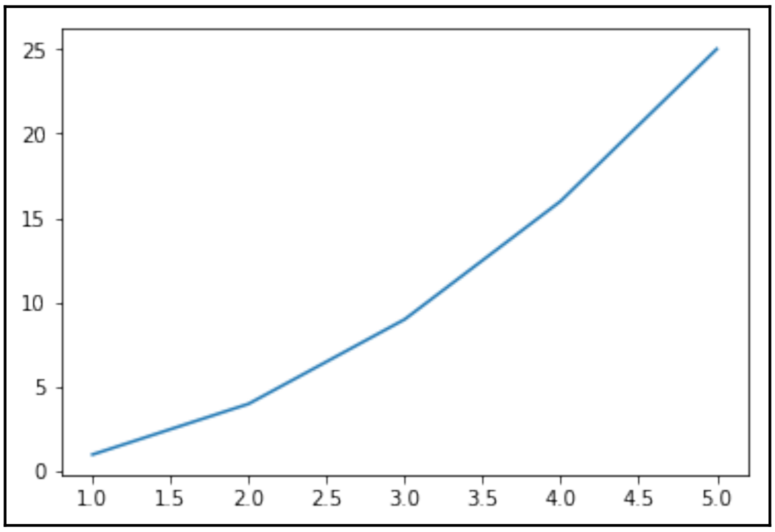
After reading the data from any of the three formats (`.txt`, `.csv`, `.xlsx`) and format it to `x` and `y` variables, then we plot the graph using these variables as follows:

```
plt.plot(x, y)
```

Display the graph on the screen:

```
plt.show()
```

The following is the output obtained:



How it works...

Depending on the format and the structure of the data, we will have to use the Python, NumPy, or pandas functions to read the data and reformat it into an appropriate structure that can be fed into the `matplotlib.pyplot` function. After that, follow the usual plotting instructions to plot the graph that you want.

Changing and resetting default environment variables

Matplotlib uses the `matplotlibrc` file to store default values for various environment and figure parameters used across matplotlib functionality. Hence, this file is very long. These default values are customizable to apply for all the plots within a session.

You can use the `print(matplotlib.rcParams)` command to get all the default parameter settings from this file.

The `matplotlib.rcParams` command is used to change these default values to any other supported values, one parameter at a time. The `matplotlib.rc` command is used to set default values for multiple parameters within a specific group, for example, lines, font, text, and so on. Finally, the `matplotlib.rcdefaults()` command is used to restore default parameters.

The `matplotlib.rcsetup()` command is used internally by Matplotlib to validate that the parameters being changed are acceptable values.

Getting ready

The following code block provides the path to the file containing all configuration the parameters:

```
# Get the location of matplotlibrc file
import matplotlib
matplotlib.matplotlib_fname()
```

You should see the directory path like the one that follows. The exact directory path depends on your installation:

```
'C:\\Anaconda3\\envs\\keras35\\lib\\site-packages\\matplotlib\\mpl-
    data\\matplotlibrc'
```

How to do it...

The following block of code along with comments helps you to understand the process of changing and resetting default environment variables:

1. Import the `matplotlib.pyplot` package with the `plt` synonym:

   ```
   import matplotlib.pyplot as plt
   ```

2. Load `x` and `y` variables from same `test.csv` file that we used in the preceding recipe:

   ```
   x, y = np.loadtxt ('test.csv', unpack = True, usecols = (0,1),
                      delimiter = ',')
   ```

3. Change the default values for multiple parameters within the group `'lines'`:

   ```
   matplotlib.rc('lines', linewidth=4, linestyle='-', marker='*')
   ```

4. Change the default values for parameters individually:

   ```
   matplotlib.rcParams['lines.markersize'] = 20
   matplotlib.rcParams['font.size'] = '15.0'
   ```

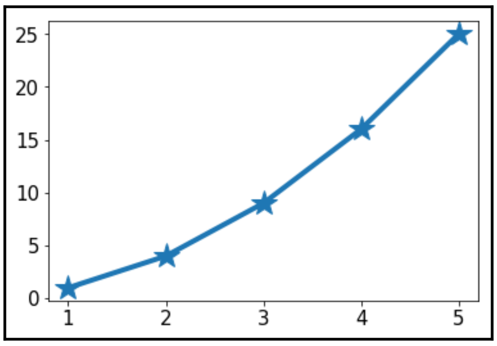
5. Plot the graph:

   ```
   plt.plot(x,y)
   ```

6. Display the graph:

   ```
   plt.show()
   ```

The following is the output that will be obtained:



How it works...

The `matplotlib.rc` and `matplotlib.rcParams` commands overwrite the default values for specified parameters as arguments in these commands. These new values will be used by the `pyplot` tool while plotting the graph.

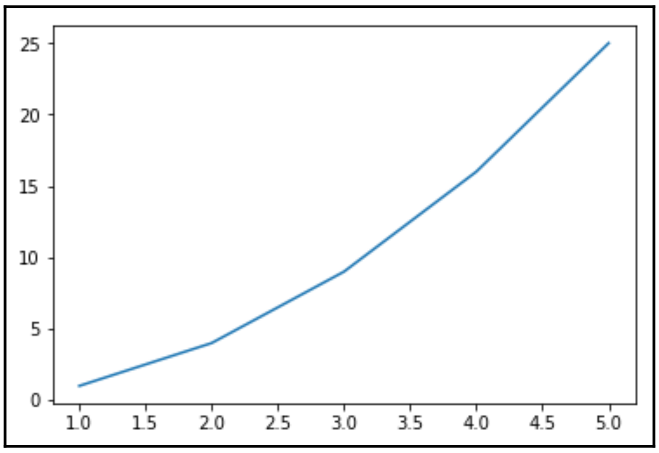
It should be noted that these values will be active for all plots in the session. If you want different settings for each plot in the same session, then you should use the attributes available with the `plot` command.

There's more...

You can reset all the parameters to their default values, using the `rsdefaults()` command, as shown in the following block:

```
# To restore all default parameters
matplotlib.rcdefaults()
plt.plot(x,y)
plt.show()
```

The graph will look as follows:



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