Unit 5: Basic plotting

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1 Unit 5: Basic plotting

In this unit, we take a first look at plotting numerical data. Python itself does not have any built-in plotting capabilities, so we will be using *matplotlib (MPL)*, the most popular graphics library for Python.

- For details on a plotting function, have a look at the official documentation at https://matplotlib.org/
- There is an official introductory tutorial which you can use along-side this unit.

When using matplotlib in interactive Jupyter notebooks (such as this one), we can enable a more fancy plotting backend that allows us to dynamically adjust the zoom, etc. This is done by adding the line

```
%matplotlib widget
```

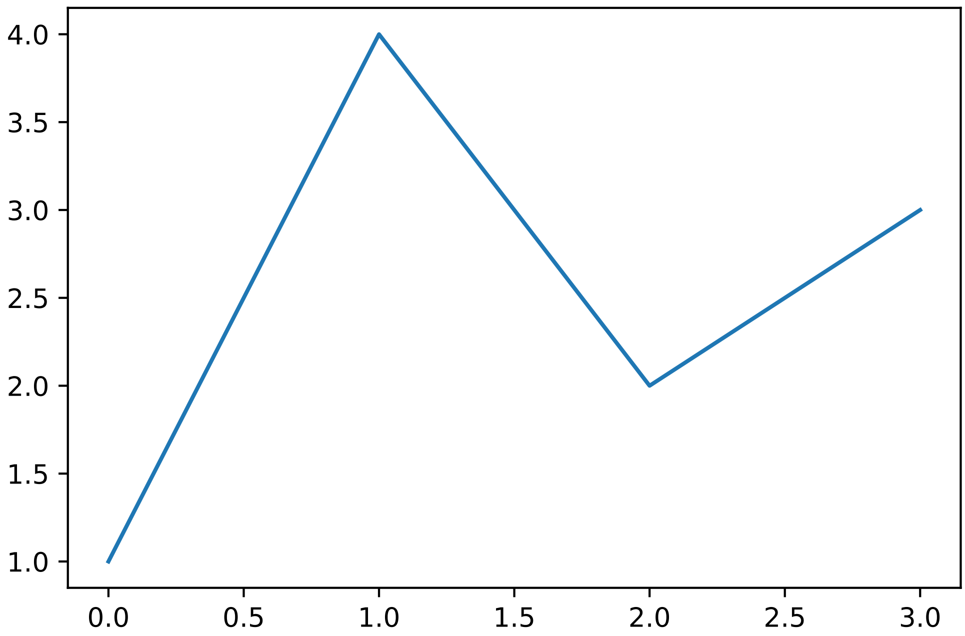
For this to work, the `ipympl` package needs to be installed, see here for details. Note that this is not supported or required (and in fact produces a syntax error) in regular `*.py` Python script files.

1.1 Line and scatter plots

One of the simplest plots we can generate is a line decribed by a list of points.

[1]:
```
# import matplotlib library
import matplotlib.pyplot as plt

# Plot list of integers
yvalues = [1, 4, 2, 3]
plt.plot(yvalues)
```

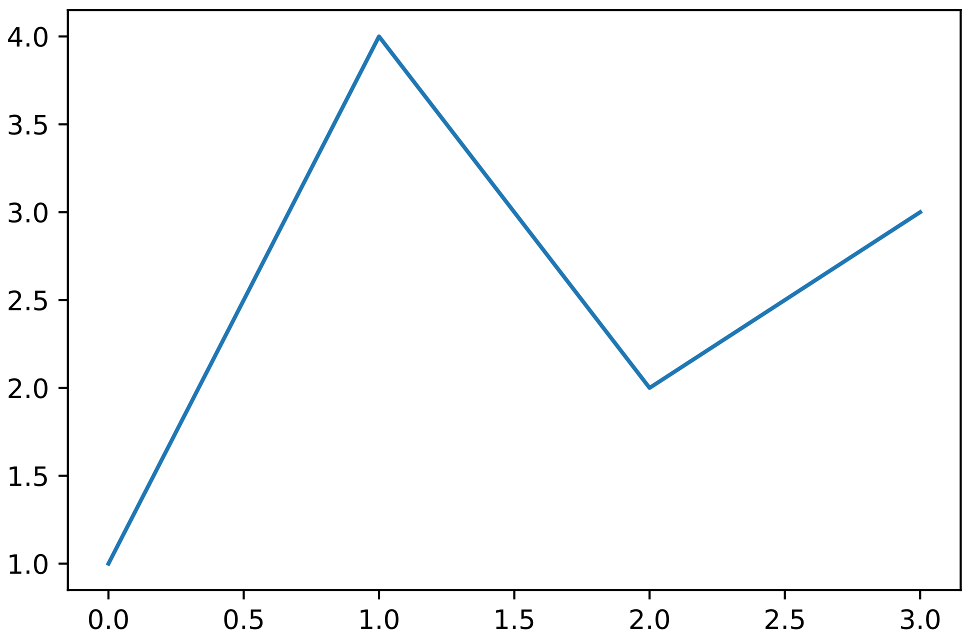
[1]:
```
[<matplotlib.lines.Line2D at 0x7f27613a0f10>]
```



We didn't even have to specify the corresponding x-values, as MPL automatically assumes them to be [0, 1, 2, . . .]

[2]:
```python
# explicitly specify x-values
xvalues = [0, 1, 2, 3]
plt.plot(xvalues, yvalues)
```

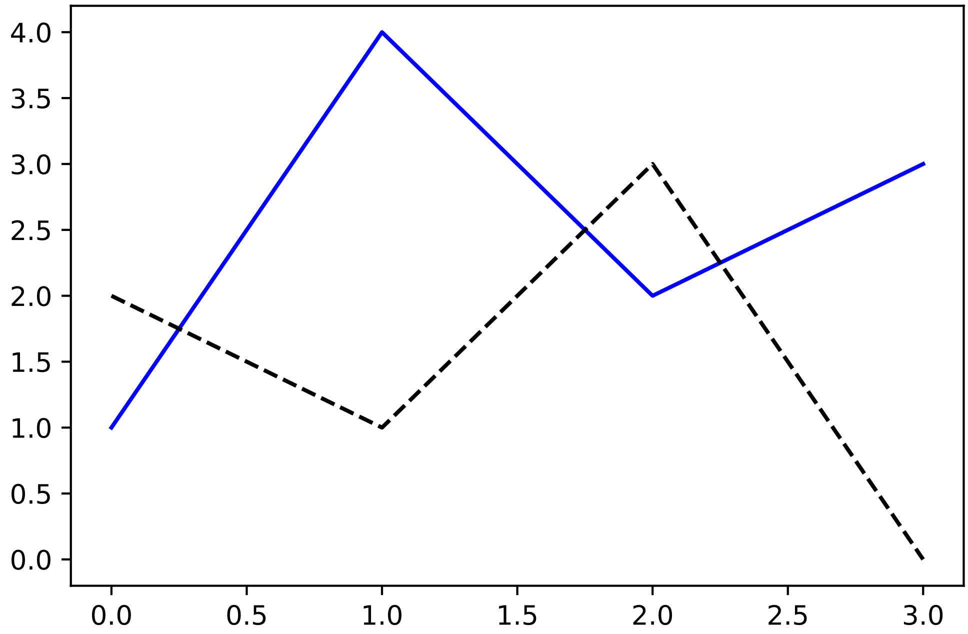
[2]:
```
[<matplotlib.lines.Line2D at 0x7f2734e8cbd0>]
```



Similar to Matlab, we can also specify multiple lines to be plotting in a single graph:

[3]:
```
yvalues2 = [2.0, 1.0, 3.0, 0.0]
plt.plot(xvalues, yvalues, 'b-', xvalues, yvalues2, 'k--')
```

[3]:
```
[<matplotlib.lines.Line2D at 0x7f2734e0c510>,
 <matplotlib.lines.Line2D at 0x7f2734e0c390>]
```



The characters following each set of y-values are style specifications that are very similar to the ones used in Matlab. More specifically, the letters are short-hand notations for colours: - `b`: blue - `g`: green - `r`: red - `c`: cyan - `m`: magenta - `y`: yellow - `k`: black - `w`: white

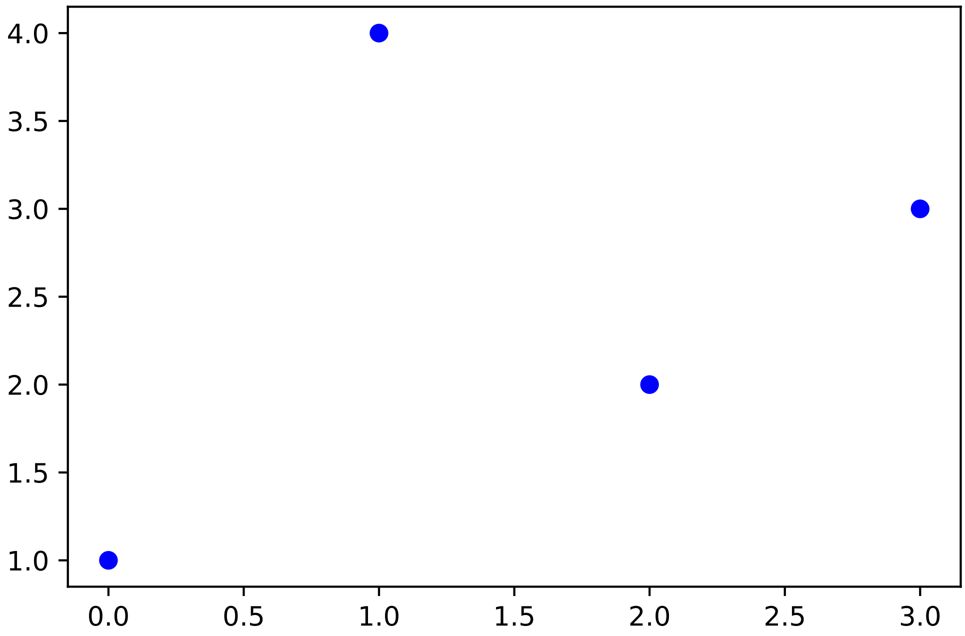
The remaining characters set the line styles. Valid values are `-`, `--`, `-.` and `:`, with the obvious interpretation.

It is possible to use any RGB colour or used one of the many predefined ones (see here for details), and to create your own line styles.

We use the `scatter()` routine to create scatter plots in a similar fashion:

[4]:
```
plt.scatter(xvalues, yvalues, color='blue')
```

[4]:
```
<matplotlib.collections.PathCollection at 0x7f2744809710>
```



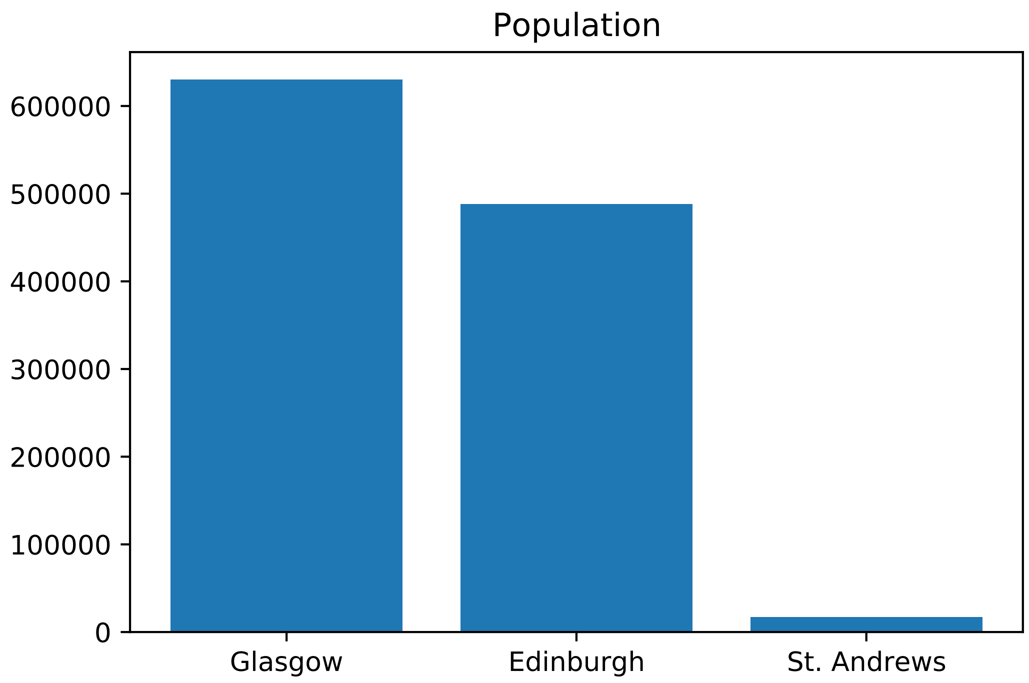
1.2 Plotting categorical data

Instead of numerical values on the x-axis, we can also plot categorical variables by passing them directly to the plotting function.

For example, assume we have three categorical “groups” and each has an associated numerical value:

[5]:
```python
import matplotlib.pyplot as plt

cities = ['Glasgow', 'Edinburgh', 'St. Andrews']
population = [630000, 488000,  16800]
plt.bar(cities, population)
plt.title('Population')
```

[5]:
```
Text(0.5, 1.0, 'Population')
```



1.3 Adding labels and annotations

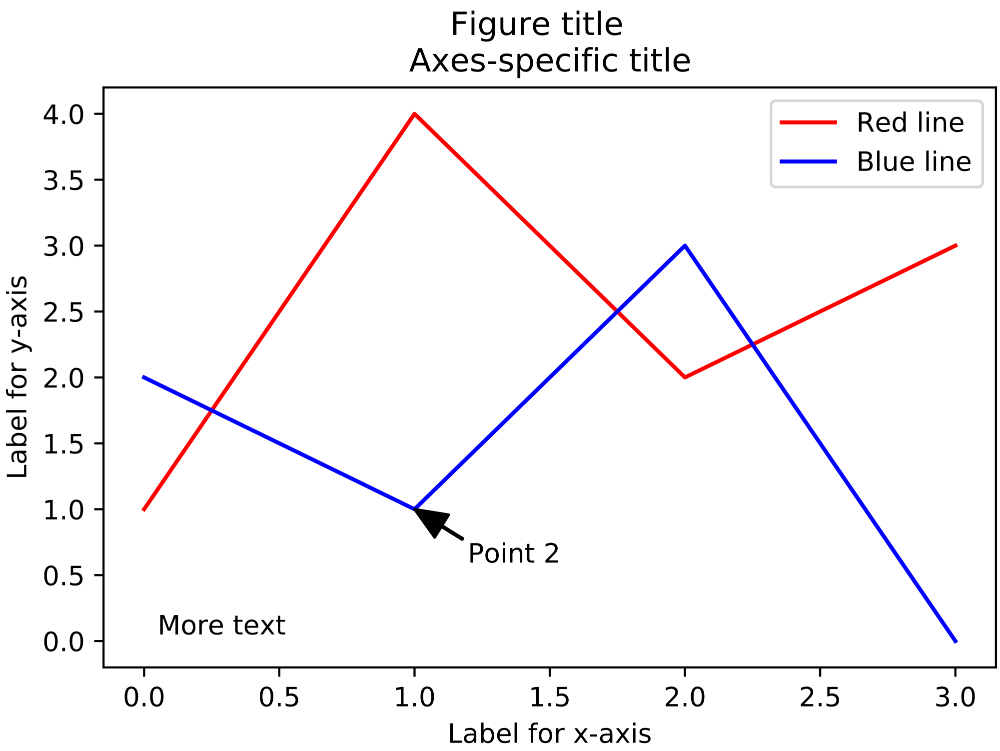
Matplotlib has numerous functions to add labels and annotations:

- Use `title()` and `suptitle()` to add titles to your graphs. The latter adds a title for the whole figure, which might span multiple plots (axes).
- We can add axis labels by calling `xlabel()` and `ylabel()`.
- To add a legend, call `legend()`, which in its most simple form takes a list of labels which are in the same order as the plotted data. [docs]
- Use `text()` to add additional text at arbitrary locations. [docs]
- Use `annotate()` to display text next to some data point; it's easier to position correctly than `text()` and you can add arrows! [docs]

[6]:
```
import matplotlib.pyplot as plt

xvalues = [0, 1, 2, 3]
yvalues = [1, 4, 2, 3]
yvalues2 = [2.0, 1.0, 3.0, 0.0]

plt.plot(xvalues, yvalues, 'r', xvalues, yvalues2, 'b')
plt.suptitle('Figure title')
plt.title('Axes-specific title')
plt.xlabel('Label for x-axis')
plt.ylabel('Label for y-axis')
plt.legend(['Red line', 'Blue line'])

# Adds text at data coordinates (0.05, 0.05)
plt.text(0.05, 0.05, 'More text')

# Annotate second point
plt.annotate('Point 2', (xvalues[1], yvalues2[1]), (20, -20),
             textcoords='offset points',
```

```
                 arrowprops={'facecolor': 'black', 'width': 0.5,
                             'headwidth': 10.0})
```

[6]: Text(20, -20, 'Point 2')



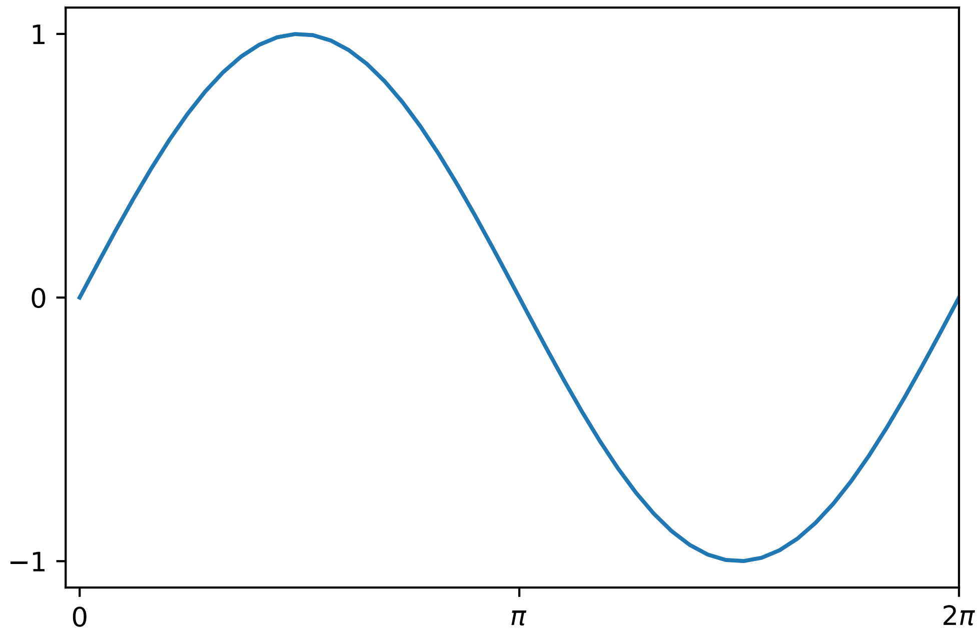
1.4 Plot limits, ticks and tick labels

We adjust the plot limits, ticks and tick labels as follows:

- Plotting limits are set using the `xlim()` and `ylim()` functions. Each accepts a tuple `(min,max)` to set the desired range.
- Ticks and tick labels can be set by calling `xticks()` or `yticks()`.

[7]:
```
import matplotlib.pyplot as plt
import numpy as np

xvalues = np.linspace(0.0, 2*np.pi, 50)
plt.plot(xvalues, np.sin(xvalues))

# Adjust plot limits in x and y direction
plt.xlim((-0.1, 1.1))
plt.ylim((-1.1, 1.1))

# Set major ticks for x and y axes, and xtick labels.
# We can use LaTeX code in labels!
plt.xticks([0.0, np.pi, 2*np.pi], ['0', r'$\pi$', r'$2\pi$'])
plt.yticks([-1.0, 0.0, 1.0])
```

```
[7]: ([<matplotlib.axis.YTick at 0x7f2734c22350>,
      <matplotlib.axis.YTick at 0x7f2734c1ce10>,
      <matplotlib.axis.YTick at 0x7f2734c1ac90>],
     [Text(0, 0, ''), Text(0, 0, ''), Text(0, 0, '')])
```



1.5 Object-oriented interface

So far, we have only used the so-called `pyplot` interface which involves calling *global* plotting functions from the `plt` module. This interface is intended to be similar to Matlab, but is also somewhat limited and less clean.

We can instead use the object-oriented interface (called this way because we call methods of the `Figure` and `Axes` objects instead). While there is not much point in using the object-oriented interface in a Jupyter notebook, it should be the preferred method when writing re-usable code in Python files.

To use the object-oriented interface, we need to get figure and axes objects. The easiest way to accomplish this is using the `subplots()` function, like this:

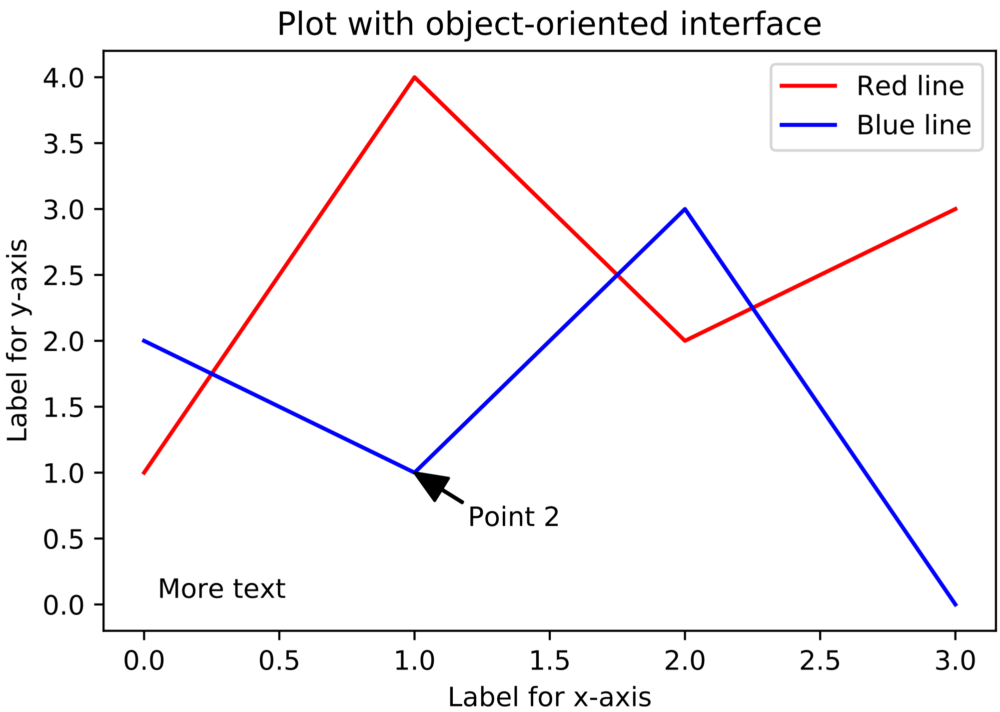
```
fig, ax = plt.subplots()
```

As an example, we recreate the graph from the section on labels and annotations using the object-oriented interface:

```
[8]: import matplotlib.pyplot as plt

xvalues = [0, 1, 2, 3]
yvalues = [1, 4, 2, 3]
yvalues2 = [2.0, 1.0, 3.0, 0.0]

fig, ax = plt.subplots()
ax.plot(xvalues, yvalues, color='red', label='Red line')
ax.plot(xvalues, yvalues2, color='blue', label='Blue line')
ax.set_xlabel('Label for x-axis')
ax.set_ylabel('Label for y-axis')
ax.legend()
```

```
ax.set_title('Plot with object-oriented interface')
ax.text(0.05, 0.05, 'More text')

# Annotate second point
plt.annotate('Point 2', (xvalues[1], yvalues2[1]), (20, -20),
             textcoords='offset points',
             arrowprops={'facecolor': 'black', 'width': 0.5,
                         'headwidth': 10.0})
```

[8]: Text(20, -20, 'Point 2')



The code is quite similar, except that attributes are set using the `set_xxx()` methods of the `ax` object. For example, instead of calling `xlim()`, we use `ax.set_xlim()`.

The above example also illustrates how we can specify plot properties such as styles and legend labels explicitly as keyword arguments when calling `plot()`:

```
ax.plot(xvalues, yvalues, property1=value1, property2=value2, ...)
```

1.6 Working with multiple plots (axes)

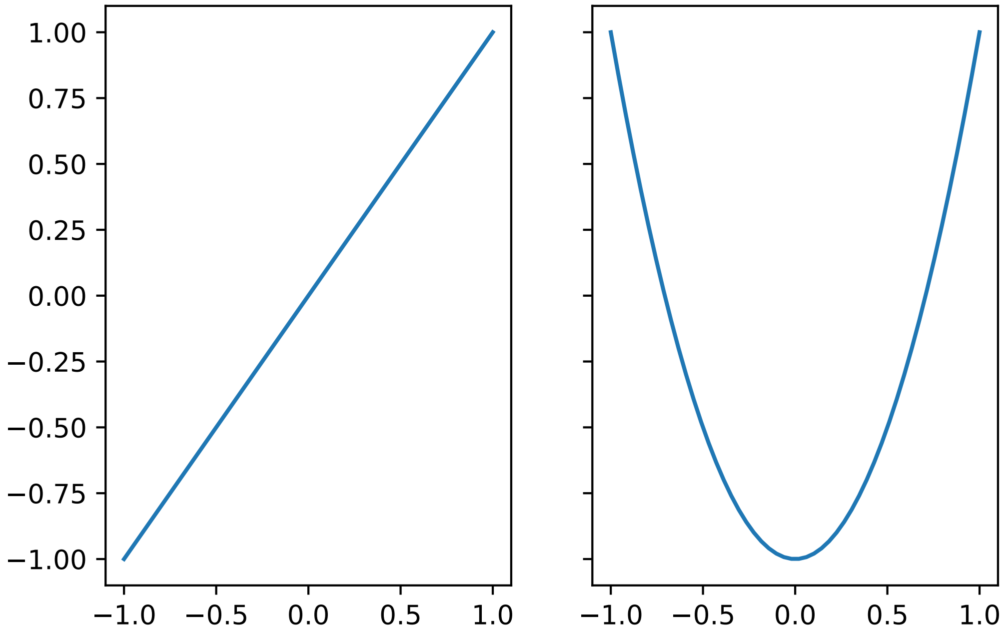
The object-oriented interface becomes particularly useful if we want to create multiple axes (or figures), which is possible with the `pyplot` programming model, but more obscure.

For example, to create a row with two plots, we use:

[9]:
```
import matplotlib.pyplot as plt
import numpy as np

fig, ax = plt.subplots(1, 2, sharex=True, sharey=True)
xvalues = np.linspace(-1.0, 1.0, 50)
ax[0].plot(xvalues, xvalues)
```

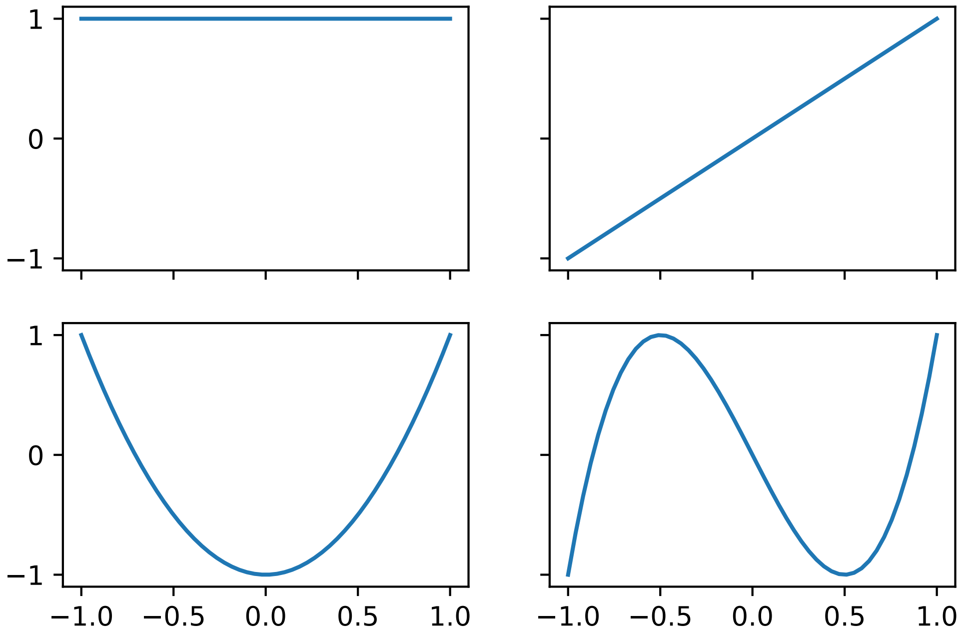
```
ax[1].plot(xvalues, 2*xvalues**2.0 - 1)
```

[9]:
```
[<matplotlib.lines.Line2D at 0x7f2734dbefd0>]
```



With multiple axes, the second object returned by `subplots()` is actually a NumPy array with a shape that corresponds to the number of plots. If we request a 2×2 plot, `ax[0,0]` will be the top-left axes object, `ax[0,1]` the top-right one, and so on.

[10]:
```
# Plot the first four Chebyshev polynomials on the interval [-1,1]
fig, ax = plt.subplots(2, 2, sharex=True, sharey=True)

xvalues = np.linspace(-1.0, 1.0, 50)
for i in range(2):
    for j in range(2):
        yvalues = np.cos((j + i*2) * np.arccos(xvalues))
        ax[i,j].plot(xvalues, yvalues)
```



Note the use of `sharex=True` and `sharey=True`. This tells matplotlib that all axes share the same plot limits, so the tick labels can be omitted in the figure's iterior to preserve space.

2 Exercises

2.1 Exercise 1: Trigonometric functions

Plot the functions $\sin(x)$ and $\cos(x)$ on the interval $[-\pi, \pi]$, each in a separate graph. Include a legend for each plot, and add pretty tick labels at $[-\pi, 0, \pi]$ which use the LaTeX symbol for π.

Hint: NumPy defines the functions `np.sin()` and `np.cos()` as well as the value `np.pi`.

2.2 Exercise 2: Logarithmic scaling

In economics and finance, we often plot using the $\log_{10}$ scale if the plotted data is of very different orders of magnitude.

Create a figure with two sub-plots, each plotting the function $f(x) = 10^x$ on a uniformly-spaced interval $[-5, 5]$ with 100 points. Use the (default) linear scale in the first plot, but apply the $\log_{10}$ scale in the second.

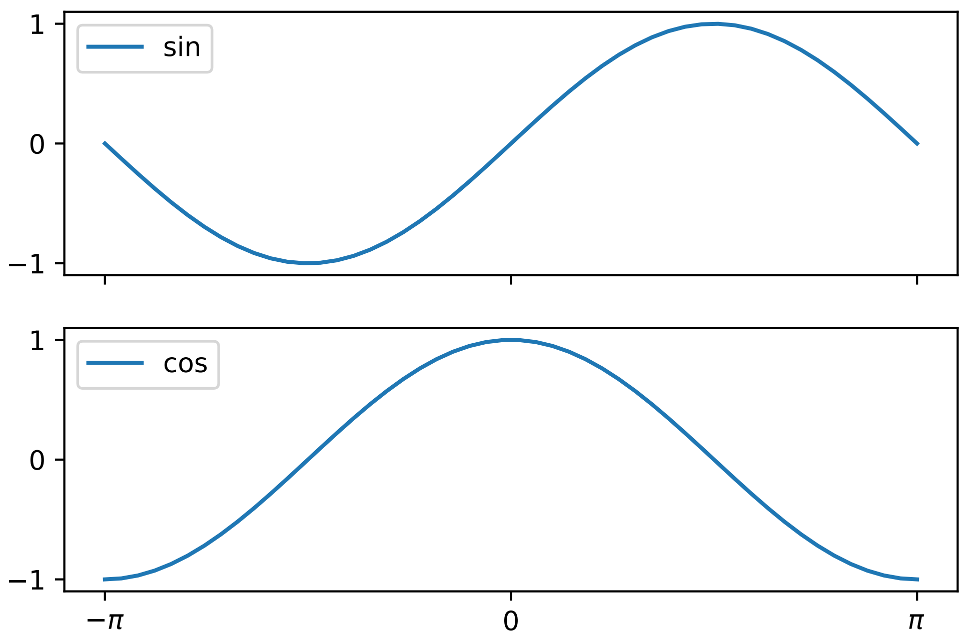
Hint: You can set the axis scale to log by calling `yscale('log')`, or `set_yscale('log')` when using the object-oriented interface.

3 Solutions

3.1 Solution for exercise 1

[11]:
```python
import matplotlib.pyplot as plt
import numpy as np

xvalues = np.linspace(-np.pi, np.pi, 50)
# Create figure with two rows, one column
fig, ax = plt.subplots(2, 1, sharey=True, sharex=True)

xticks = [-np.pi, 0.0, np.pi]
xticklabels = [r'$-\pi$', '0', r'$\pi$']
yticks = [-1.0, 0.0, 1.0]

# Create sin() plot using first axes object
ax[0].plot(xvalues, np.sin(xvalues), label='sin')
ax[0].set_xticks(xticks)
ax[0].set_xticklabels(xticklabels)
ax[0].set_yticks(yticks)
ax[0].legend(loc='upper left')

# Create cos() plot using second axes object
ax[1].plot(xvalues, np.cos(xvalues), label='cos')
ax[1].set_xticks(xticks)
ax[1].set_xticklabels(xticklabels)
ax[1].set_yticks(yticks)
ax[1].legend(loc='upper left')
```

[11]:
```
<matplotlib.legend.Legend at 0x7f2734a02b90>
```



3.2 Solution for exercise 2

[12]:
```
import matplotlib.pyplot as plt
import numpy as np

xvalues = np.linspace(-5.0, 5.0, 100)
fig, ax = plt.subplots(1, 2, sharex=True)
ax[0].plot(xvalues, 10.0**xvalues)
ax[0].set_title('Linear scale')

ax[1].plot(xvalues, 10.0**xvalues)
# Set y-axis to log scale (assumes base-10 log)
ax[1].set_yscale('log')
ax[1].set_title('Log scale')
```

[12]:
```
Text(0.5, 1.0, 'Log scale')
```