Plotting and Visualisation in Python using `matplotlib` Package

Plotting and Visualisation in Python

- In almost all fields, visualisation of data is an universal tool to communicatie the results to wide-array of users.
- Graphical representation of data provides more knowledge and insights in intrepreting the compuational results.
- In the scientific computing environment of Python, there are a number of high-quality visualisation libraries.
- The most population general-purpose visulisation library is `matplotlib`, which maninly focuses on generating static publication-quality 2D and 3D graphs.
- Many other libraries focus on specific areas of visualisation.
  - `bokeh` and `plotly` – primarily focus on interactivity and web connectivity.
  - `seaborn` – a high-level plotting libarry which focuses on statistical data analysis (this library is based on `matplotlib`).
  - Few others are `mayavi`, `vispy` for 3D visualisation and `paraview`, a scritable with Python.

Matplotlib Library

- Matplotlib is a Python library for publicaiton-quality 2D and 3D graphis, with support for a variety of different output formats.
- The latest version (at the time of preparing this notes) is 3.8.0
- Matplotlib is available at the project's website www.matplotlib.org
- One can visit this site for detailed documentation and extensive gallery showcasing the various types of graphs that can be generated using the matplotlib library.
- This gallery is a great source of insipiration for visualisation idea, and I highly recommend you to exploring this gallery.

Importing the Libraries

- Matplotlib actually provides multiple entry points into the library, with the different application programming interfaces (APIs)
  - a stateful API
  - an object-oriented API
- Both these APIs are provided by the module `matplotlib.pyplot`
- To use the object-orienented Matplotlib API, we first need to import its Python modules
- The Matplotlib is imported using the following standard conventions:

```
%matplotlib inline
import matplotlib as mpl
```

```
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d.axes3d import Axes3D
```

- The first line assumes that we are working in an IPython environment (Jupyter Notebook) and the `inline` specifies that figures need to be placed inline in the notebook.
  - The other options include 'qt5agg' for viewing the figures in a separate window supported with Qt5 backend.

Preamble for the codes presented in this notebook

[2]:
```
%matplotlib inline
import matplotlib as mpl
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d.axes3d import Axes3D
import numpy as np
```

Figure Object

- A graph in matplotlib is structured in terms of a `Figure` instance and one or more `Axes` instances within the figure.
- The various components of a Matplotlib Figure are shown in the following:
- The main components of a Figure object are:
  - Figure (The whole Figure, which contains Axes)
  - Axes (The region of Figure that contains the plotting data, which include two/three Axis objects)
  - Axis (The object that sets the limits and scales the plotting data)
  - Artist (Basically everthing that is present in the Figure)
- The plotting functions expect `NumPy Array` objects as inputs. Every other object has to be converted to NumPy array.

Creating Figure Object

```
fig = plt.figure()  # an empty figure with no Axes
fig, ax = plt.subplots()  # a figure with a single Axes
fig, axs = plt.subplots(2, 2)  # a figure with a 2x2 grid of Axes
```

Coding styles

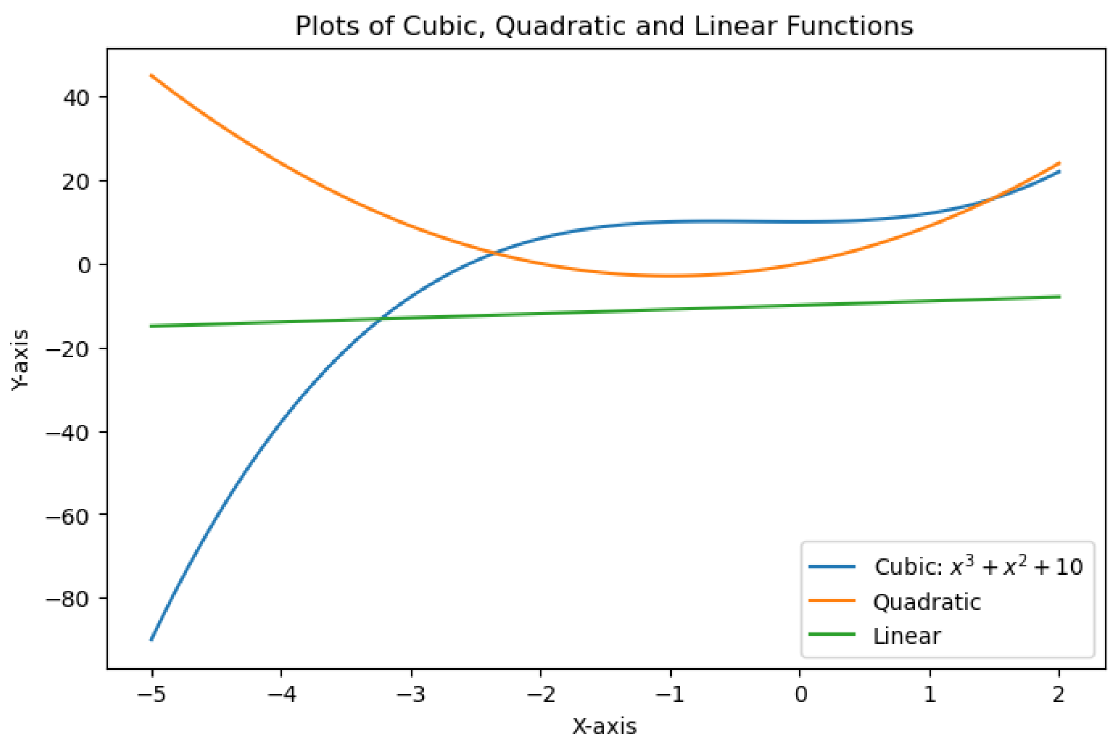
The explicit and the implicit interfaces

There are essentially two ways to use Matplotlib:

- Explicitly create Figures and Axes, and call methods on them (the "object-oriented (OO) style").
- Rely on pyplot to implicitly create and manage the Figures and Axes, and use pyplot functions for plotting.

The explicit "Axes" interface (OO-style)

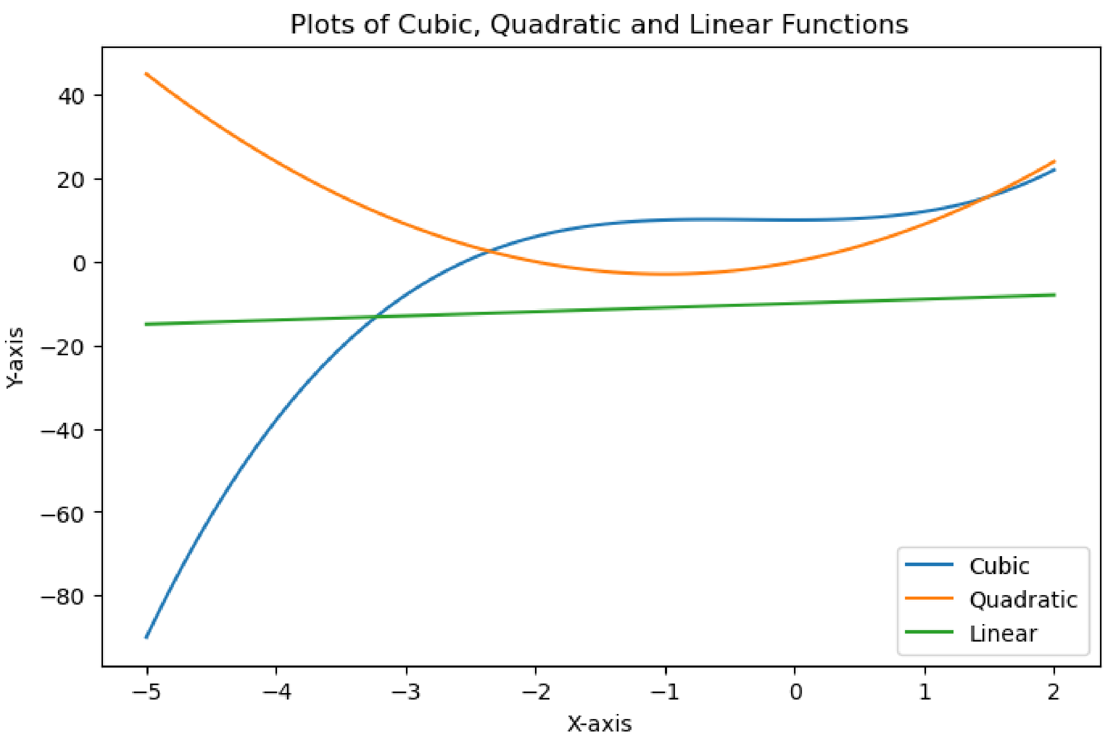
[2]:
```
x = np.linspace(-5,2,100)
y1 = x**3 + x**2 + 10
y2 = 3*x**2 + 6*x
y3 = x - 10

fig, ax = plt.subplots(figsize=(8,5))
ax.plot(x,y1,label='Cubic: $x^3 + x^2 + 10$')
ax.plot(x,y2,label='Quadratic')
ax.plot(x,y3,label='Linear')
ax.set_xlabel('X-axis')
ax.set_ylabel('Y-axis')
ax.set_title('Plots of Cubic, Quadratic and Linear Functions')
ax.legend()
plt.show()
```



The implicit "PyPlot" interface (PP-style)

[3]:
```
x = np.linspace(-5,2,100)
y1 = x**3 + x**2 + 10
y2 = 3*x**2 + 6*x
y3 = x - 10
```

```
fig = plt.figure(figsize=(8,5))
plt.plot(x,y1,label='Cubic')
plt.plot(x,y2,label='Quadratic')
plt.plot(x,y3,label='Linear')
plt.xlabel('X-axis')
plt.ylabel('Y-axis')
plt.title('Plots of Cubic, Quadratic and Linear Functions')
plt.legend()
plt.show()
```

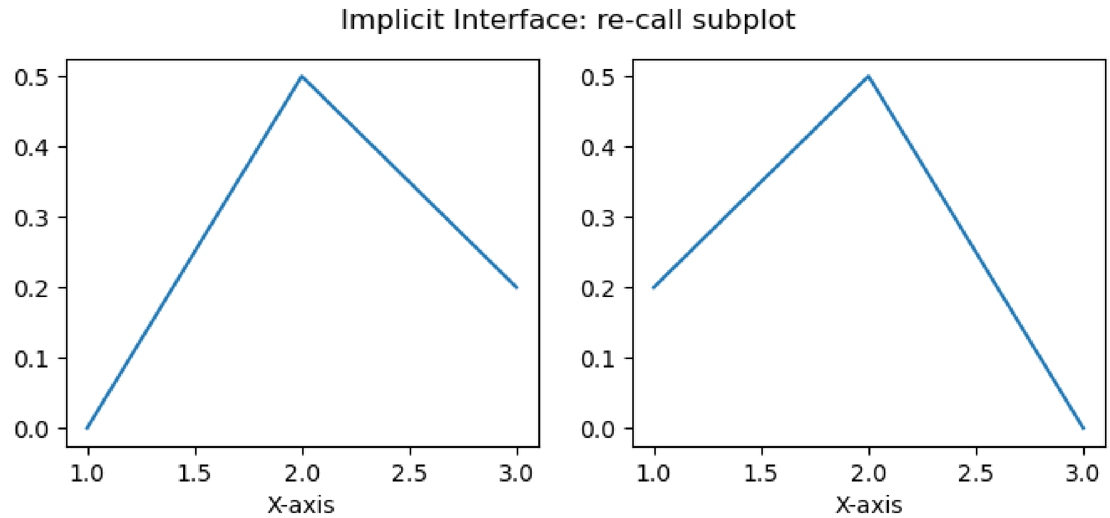


Comparison of above two approaches

Plotting using implicit style - Approach #1

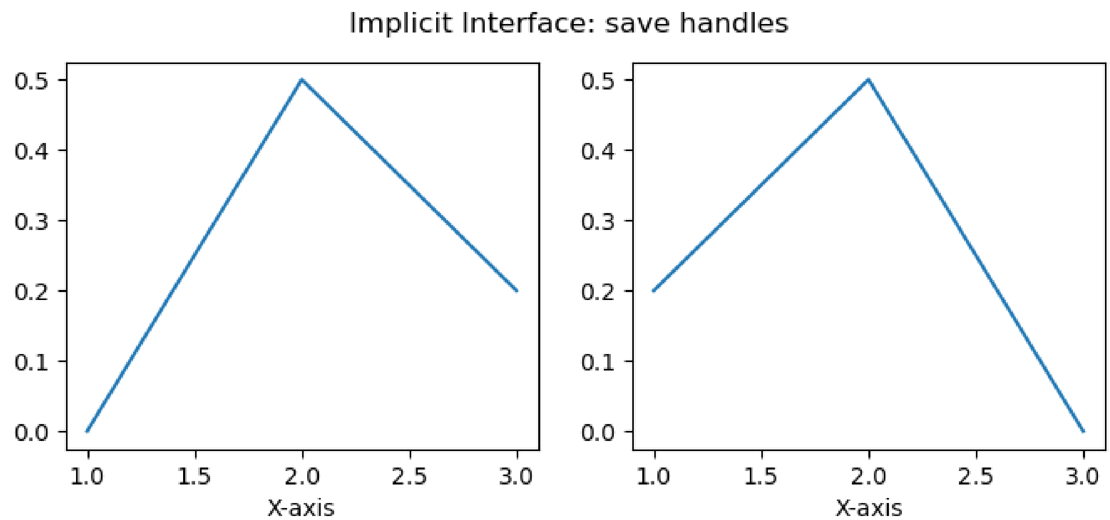
[4]:
```
plt.figure(figsize=(8,3))
plt.subplot(1, 2, 1)
plt.plot([1, 2, 3], [0, 0.5, 0.2])

plt.subplot(1, 2, 2)
plt.plot([3, 2, 1], [0, 0.5, 0.2])

plt.suptitle('Implicit Interface: re-call subplot')
```

```
for i in range(1, 3):
    plt.subplot(1, 2, i)
    plt.xlabel('X-axis')
```



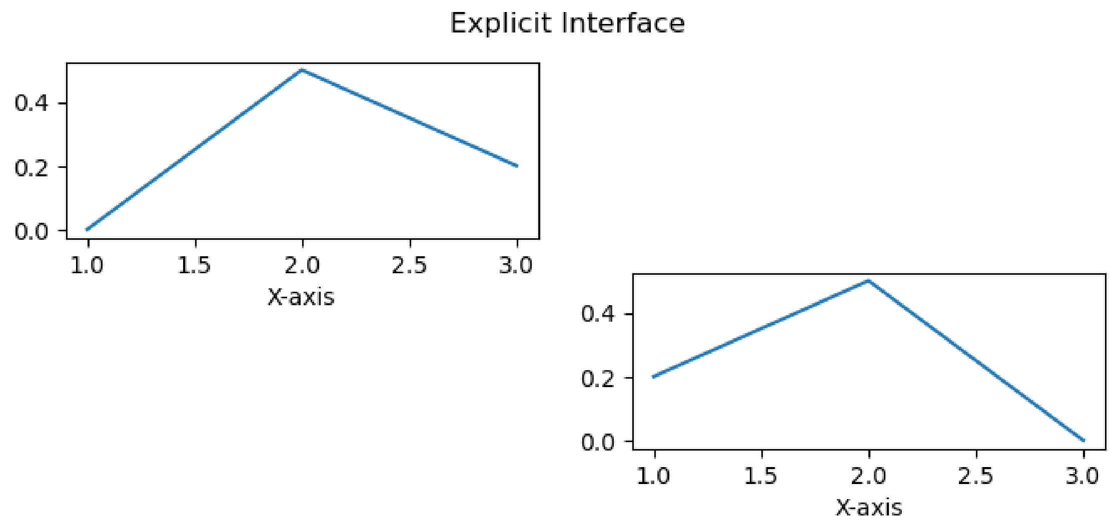
Plotting using implicit style - Approach #2 (Saving the handles)

[5]:
```
plt.figure(figsize=(8,3))
axs = []
ax = plt.subplot(1, 2, 1)
axs += [ax]
plt.plot([1, 2, 3], [0, 0.5, 0.2])

ax = plt.subplot(1, 2, 2)
axs += [ax]
plt.plot([3, 2, 1], [0, 0.5, 0.2])

plt.suptitle('Implicit Interface: save handles')

#plt.xlabel('X-axis')
for i in range(2):
    plt.sca(axs[i])
    plt.xlabel('X-axis')
```

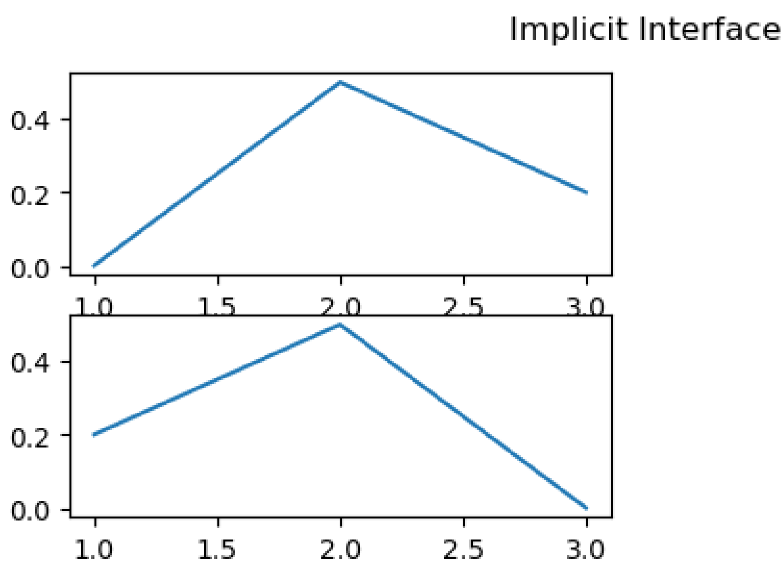


Recommend way - Explicit approach

[6]:
```
fig, axs = plt.subplots(2, 2, figsize=(8,3))
axs[0,0].plot([1, 2, 3], [0, 0.5, 0.2])
axs[1,1].plot([3, 2, 1], [0, 0.5, 0.2])
axs[0,1].remove() # Remove the axis object at (0,1)
axs[1,0].remove() # Remove the axis object at (1,0)

for i in range(2):
    for j in range(2):
        axs[i,j].set_xlabel('X-axis')

fig.suptitle('Explicit Interface')
plt.show()
```

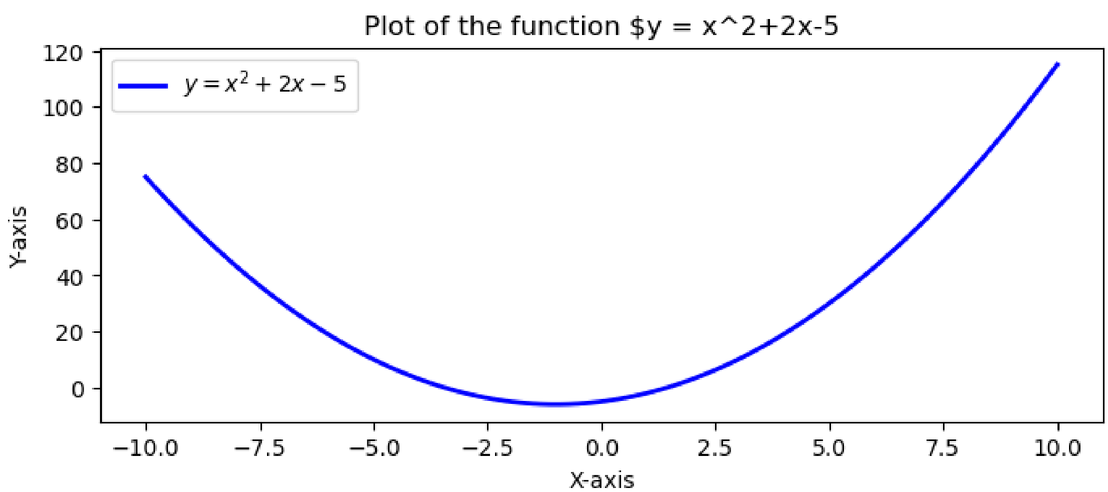


[7]:
```
fig = plt.figure(figsize=(8,3))
plt.subplot(221)
plt.plot([1, 2, 3], [0, 0.5, 0.2])
plt.subplot(223)
plt.plot([3, 2, 1], [0, 0.5, 0.2])
fig.suptitle('Implicit Interface')
plt.show()
```



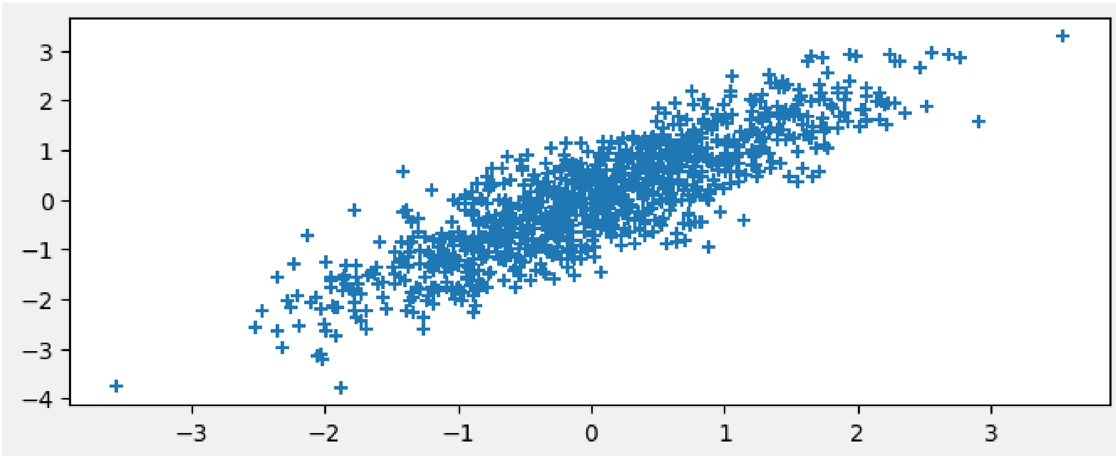
Line Plot

[8]:
```
x = np.linspace(-10,10,100)
y = x**2 + 2*x - 5

fig, ax = plt.subplots(figsize=(8,3))
ax.plot(x,y,'-b',lw=2,label='$y=x^2+2x-5$')
ax.legend()
ax.set_xlabel('X-axis')
ax.set_ylabel('Y-axis')
ax.set_title('Plot of the function $y = x^2+2x-5')
plt.show()
```



Scatter Plot

[9]:
```
x = np.random.randn(1,1000)
y = np.random.randn(1,1000)

fig,ax = plt.subplots(figsize=(8,3),facecolor='#f1f1f1')
ax.scatter(x,x+0.6*y,marker='+')
plt.show()
```



Barcharts

[25]:
```
help(ax.bar)
```

```
Help on method bar in module matplotlib.axes._axes:

bar(x, height, width=0.8, bottom=None, *, align='center', data=None, **kwargs)
method of matplotlib.axes._axes.Axes instance
    Make a bar plot.

    The bars are positioned at *x* with the given *align*\ment. Their
    dimensions are given by *height* and *width*. The vertical baseline
    is *bottom* (default 0).

    Many parameters can take either a single value applying to all bars
    or a sequence of values, one for each bar.

    Parameters
    ----------
    x : float or array-like
        The x coordinates of the bars. See also *align* for the
        alignment of the bars to the coordinates.

    height : float or array-like
        The height(s) of the bars.

    width : float or array-like, default: 0.8
        The width(s) of the bars.

    bottom : float or array-like, default: 0
        The y coordinate(s) of the bottom side(s) of the bars.
```

```
align : {'center', 'edge'}, default: 'center'
    Alignment of the bars to the *x* coordinates:

    - 'center': Center the base on the *x* positions.
    - 'edge': Align the left edges of the bars with the *x* positions.

    To align the bars on the right edge pass a negative *width* and
    ``align='edge'``.

Returns
-------
`.BarContainer`
    Container with all the bars and optionally errorbars.

Other Parameters
----------------
color : color or list of color, optional
    The colors of the bar faces.

edgecolor : color or list of color, optional
    The colors of the bar edges.

linewidth : float or array-like, optional
    Width of the bar edge(s). If 0, don't draw edges.

tick_label : str or list of str, optional
    The tick labels of the bars.
    Default: None (Use default numeric labels.)

label : str or list of str, optional
    A single label is attached to the resulting `.BarContainer` as a
    label for the whole dataset.
    If a list is provided, it must be the same length as *x* and
    labels the individual bars. Repeated labels are not de-duplicated
    and will cause repeated label entries, so this is best used when
    bars also differ in style (e.g., by passing a list to *color*.)

xerr, yerr : float or array-like of shape(N,) or shape(2, N), optional
    If not *None*, add horizontal / vertical errorbars to the bar tips.
    The values are +/- sizes relative to the data:

    - scalar: symmetric +/- values for all bars
    - shape(N,): symmetric +/- values for each bar
    - shape(2, N): Separate - and + values for each bar. First row
      contains the lower errors, the second row contains the upper
      errors.
    - *None*: No errorbar. (Default)
```

```
        See :doc:`/gallery/statistics/errorbar_features` for an example on
        the usage of *xerr* and *yerr*.

    ecolor : color or list of color, default: 'black'
        The line color of the errorbars.

    capsize : float, default: :rc:`errorbar.capsize`
       The length of the error bar caps in points.

    error_kw : dict, optional
        Dictionary of keyword arguments to be passed to the
        `~.Axes.errorbar` method. Values of *ecolor* or *capsize* defined
        here take precedence over the independent keyword arguments.

    log : bool, default: False
        If *True*, set the y-axis to be log scale.

    data : indexable object, optional
        If given, all parameters also accept a string ``s``, which is
        interpreted as ``data[s]`` (unless this raises an exception).

    **kwargs : `.Rectangle` properties

    Properties:
        agg_filter: a filter function, which takes a (m, n, 3) float array and a
dpi value, and returns a (m, n, 3) array and two offsets from the bottom left
corner of the image
        alpha: scalar or None
        angle: unknown
        animated: bool
        antialiased or aa: bool or None
        bounds: (left, bottom, width, height)
        capstyle: `.CapStyle` or {'butt', 'projecting', 'round'}
        clip_box: `.Bbox`
        clip_on: bool
        clip_path: Patch or (Path, Transform) or None
        color: color
        edgecolor or ec: color or None
        facecolor or fc: color or None
        figure: `.Figure`
        fill: bool
        gid: str
        hatch: {'/', '\\', '|', '-', '+', 'x', 'o', 'O', '.', '*'}
        height: unknown
        in_layout: bool
        joinstyle: `.JoinStyle` or {'miter', 'round', 'bevel'}
        label: object
        linestyle or ls: {'-', '--', '-.', ':', '', (offset, on-off-seq), ...}
```

```
        linewidth or lw: float or None
        mouseover: bool
        path_effects: `.AbstractPathEffect`
        picker: None or bool or float or callable
        rasterized: bool
        sketch_params: (scale: float, length: float, randomness: float)
        snap: bool or None
        transform: `.Transform`
        url: str
        visible: bool
        width: unknown
        x: unknown
        xy: (float, float)
        y: unknown
        zorder: float

    See Also
    --------
    barh : Plot a horizontal bar plot.

    Notes
    -----
    Stacked bars can be achieved by passing individual *bottom* values per
    bar. See :doc:`/gallery/lines_bars_and_markers/bar_stacked`.
```

[26]:
```
help(ax.barh)
```

```
Help on method barh in module matplotlib.axes._axes:

barh(y, width, height=0.8, left=None, *, align='center', data=None, **kwargs)
method of matplotlib.axes._axes.Axes instance
    Make a horizontal bar plot.

    The bars are positioned at *y* with the given *align*\ment. Their
    dimensions are given by *width* and *height*. The horizontal baseline
    is *left* (default 0).

    Many parameters can take either a single value applying to all bars
    or a sequence of values, one for each bar.

    Parameters
    ----------
    y : float or array-like
        The y coordinates of the bars. See also *align* for the
        alignment of the bars to the coordinates.

    width : float or array-like
```

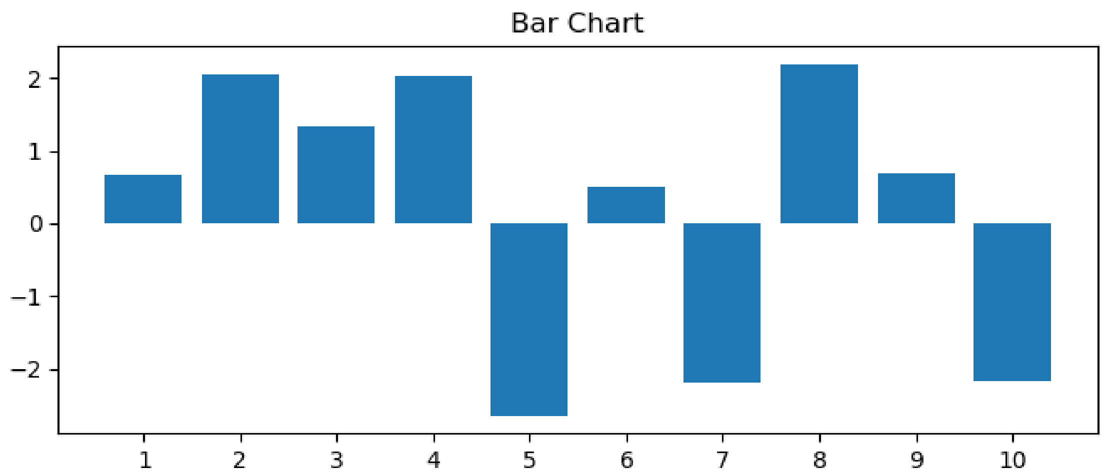
```
        The width(s) of the bars.

    height : float or array-like, default: 0.8
        The heights of the bars.

    left : float or array-like, default: 0
        The x coordinates of the left side(s) of the bars.

    align : {'center', 'edge'}, default: 'center'
        Alignment of the base to the *y* coordinates*:

        - 'center': Center the bars on the *y* positions.
        - 'edge': Align the bottom edges of the bars with the *y*
          positions.

        To align the bars on the top edge pass a negative *height* and
        ``align='edge'``.

    Returns
    -------
    `.BarContainer`
        Container with all the bars and optionally errorbars.

    Other Parameters
    ----------------
    color : color or list of color, optional
        The colors of the bar faces.

    edgecolor : color or list of color, optional
        The colors of the bar edges.

    linewidth : float or array-like, optional
        Width of the bar edge(s). If 0, don't draw edges.

    tick_label : str or list of str, optional
        The tick labels of the bars.
        Default: None (Use default numeric labels.)

    label : str or list of str, optional
        A single label is attached to the resulting `.BarContainer` as a
        label for the whole dataset.
        If a list is provided, it must be the same length as *y* and
        labels the individual bars. Repeated labels are not de-duplicated
        and will cause repeated label entries, so this is best used when
        bars also differ in style (e.g., by passing a list to *color*.)

    xerr, yerr : float or array-like of shape(N,) or shape(2, N), optional
        If not *None*, add horizontal / vertical errorbars to the bar tips.
```

```
        The values are +/- sizes relative to the data:

        - scalar: symmetric +/- values for all bars
        - shape(N,): symmetric +/- values for each bar
        - shape(2, N): Separate - and + values for each bar. First row
          contains the lower errors, the second row contains the upper
          errors.
        - *None*: No errorbar. (default)

        See :doc:`/gallery/statistics/errorbar_features` for an example on
        the usage of *xerr* and *yerr*.

    ecolor : color or list of color, default: 'black'
        The line color of the errorbars.

    capsize : float, default: :rc:`errorbar.capsize`
       The length of the error bar caps in points.

    error_kw : dict, optional
        Dictionary of keyword arguments to be passed to the
        `~.Axes.errorbar` method. Values of *ecolor* or *capsize* defined
        here take precedence over the independent keyword arguments.

    log : bool, default: False
        If ``True``, set the x-axis to be log scale.

    data : indexable object, optional
        If given, all parameters also accept a string ``s``, which is
        interpreted as ``data[s]`` (unless this raises an exception).

    **kwargs : `.Rectangle` properties

    Properties:
        agg_filter: a filter function, which takes a (m, n, 3) float array and a
dpi value, and returns a (m, n, 3) array and two offsets from the bottom left
corner of the image
        alpha: scalar or None
        angle: unknown
        animated: bool
        antialiased or aa: bool or None
        bounds: (left, bottom, width, height)
        capstyle: `.CapStyle` or {'butt', 'projecting', 'round'}
        clip_box: `.Bbox`
        clip_on: bool
        clip_path: Patch or (Path, Transform) or None
        color: color
        edgecolor or ec: color or None
        facecolor or fc: color or None
```

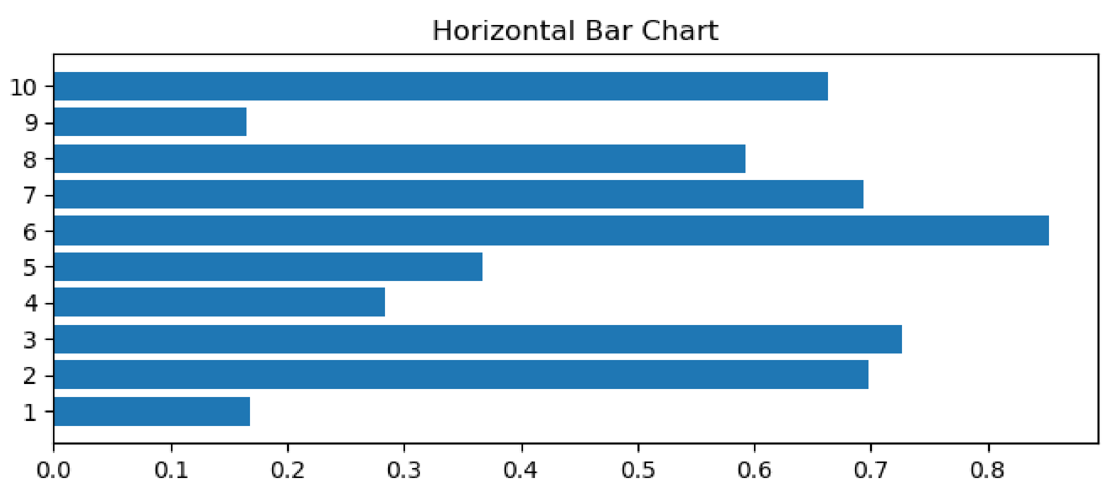
```
        figure: `.Figure`
        fill: bool
        gid: str
        hatch: {'/', '\\', '|', '-', '+', 'x', 'o', 'O', '.', '*'}
        height: unknown
        in_layout: bool
        joinstyle: `.JoinStyle` or {'miter', 'round', 'bevel'}
        label: object
        linestyle or ls: {'-', '--', '-.', ':', '', (offset, on-off-seq), ...}
        linewidth or lw: float or None
        mouseover: bool
        path_effects: `.AbstractPathEffect`
        picker: None or bool or float or callable
        rasterized: bool
        sketch_params: (scale: float, length: float, randomness: float)
        snap: bool or None
        transform: `.Transform`
        url: str
        visible: bool
        width: unknown
        x: unknown
        xy: (float, float)
        y: unknown
        zorder: float

    See Also
    --------
    bar : Plot a vertical bar plot.

    Notes
    -----
    Stacked bars can be achieved by passing individual *left* values per
    bar. See
    :doc:`/gallery/lines_bars_and_markers/horizontal_barchart_distribution`.
```

[10]:

```
x = np.random.randn(10).flatten()
fig,ax = plt.subplots(figsize=(8,3))
xaxisdata= np.arange(x.size)
ax.bar(xaxisdata,x)
ax.set_xticks(xaxisdata,xaxisdata+1)
ax.set_title('Bar Chart')
plt.show()
```

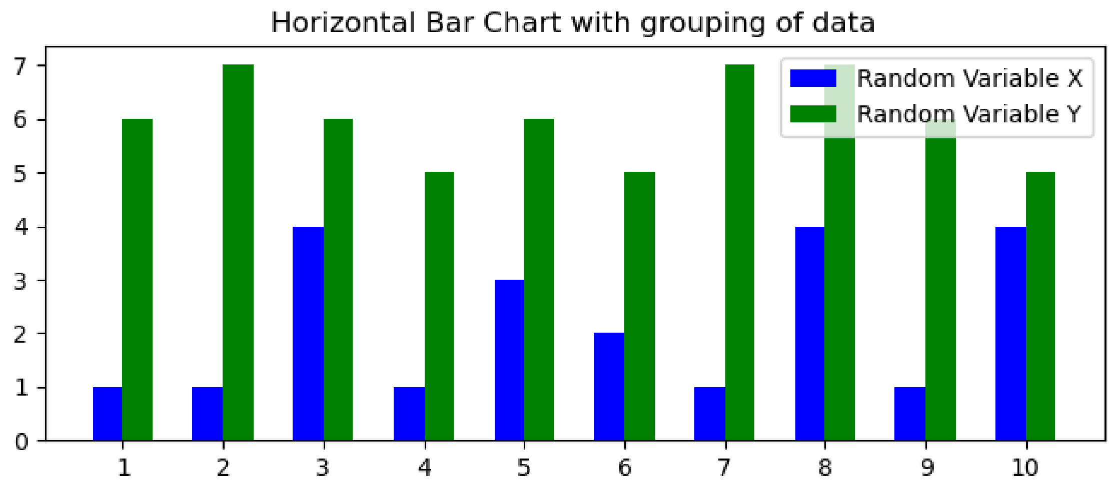


[11]:
```
x = np.random.rand(10)
fig,ax = plt.subplots(figsize=(8,3))
xaxisdata= np.arange(x.size)
ax.barh(xaxisdata,x)
ax.set_yticks(xaxisdata,xaxisdata+1)
ax.set_title('Horizontal Bar Chart')
plt.show()
```

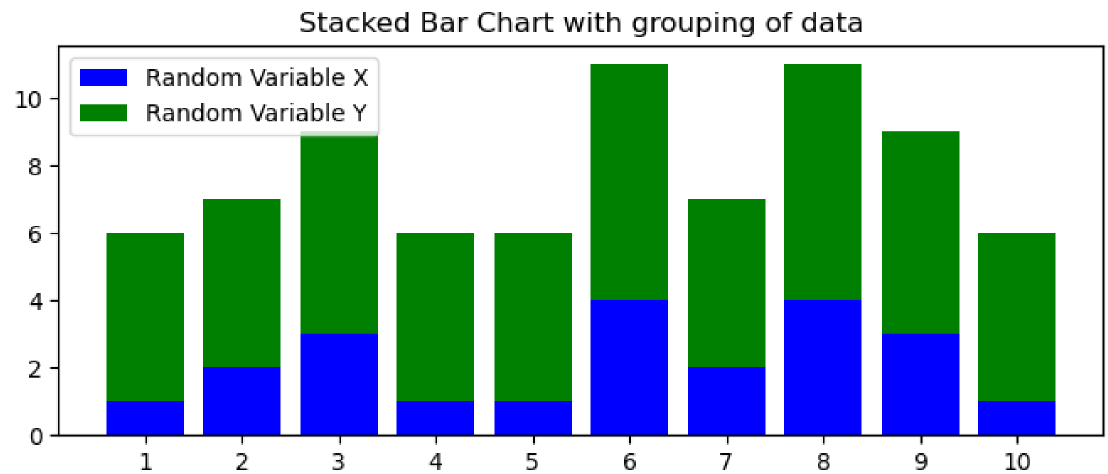


[12]:
```
x = np.random.randint(1,5,size=(10))
y = np.random.randint(5,8,size=(10))
fig,ax = plt.subplots(figsize=(8,3))
xaxisdata = np.arange(len(x))
ax.bar(xaxisdata-0.15,x,width=0.3,color='b',label='Random Variable X')
```

```
ax.bar(xaxisdata+0.15,y,width=0.3,color='g',label='Random Variable Y')
ax.set_xticks(xaxisdata,xaxisdata+1)
ax.set_title('Horizontal Bar Chart with grouping of data')
ax.legend()
plt.show()
```



[13]:
```
x = np.random.randint(1,5,size=(10))
y = np.random.randint(5,8,size=(10))
fig,ax = plt.subplots(figsize=(8,3))
xaxisdata = np.arange(len(x))
ax.bar(xaxisdata,x,color='b',label='Random Variable X')
ax.bar(xaxisdata,y,bottom=x,color='g',label='Random Variable Y')
ax.set_xticks(xaxisdata,xaxisdata+1)
ax.set_title('Stacked Bar Chart with grouping of data')
ax.legend()
plt.show()
```



Pie chart

[15]:
```
help(ax.pie)
```

```
Help on method pie in module matplotlib.axes._axes:

pie(x, explode=None, labels=None, colors=None, autopct=None, pctdistance=0.6,
shadow=False, labeldistance=1.1, startangle=0, radius=1, counterclock=True,
wedgeprops=None, textprops=None, center=(0, 0), frame=False, rotatelabels=False,
*, normalize=True, hatch=None, data=None) method of matplotlib.axes._axes.Axes
instance
    Plot a pie chart.

    Make a pie chart of array *x*.  The fractional area of each wedge is
    given by ``x/sum(x)``.

    The wedges are plotted counterclockwise, by default starting from the
    x-axis.

    Parameters
    ----------
    x : 1D array-like
        The wedge sizes.

    explode : array-like, default: None
        If not *None*, is a ``len(x)`` array which specifies the fraction
        of the radius with which to offset each wedge.

    labels : list, default: None
        A sequence of strings providing the labels for each wedge
```

```
colors : array-like, default: None
    A sequence of colors through which the pie chart will cycle.  If
    *None*, will use the colors in the currently active cycle.

hatch : str or list, default: None
    Hatching pattern applied to all pie wedges or sequence of patterns
    through which the chart will cycle. For a list of valid patterns,
    see :doc:`/gallery/shapes_and_collections/hatch_style_reference`.

    .. versionadded:: 3.7

autopct : None or str or callable, default: None
    If not *None*, *autopct* is a string or function used to label the
    wedges with their numeric value. The label will be placed inside
    the wedge. If *autopct* is a format string, the label will be
    ``fmt % pct``. If *autopct* is a function, then it will be called.

pctdistance : float, default: 0.6
    The relative distance along the radius at which the text
    generated by *autopct* is drawn. To draw the text outside the pie,
    set *pctdistance* > 1. This parameter is ignored if *autopct* is
    ``None``.

labeldistance : float or None, default: 1.1
    The relative distance along the radius at which the labels are
    drawn. To draw the labels inside the pie, set  *labeldistance* < 1.
    If set to ``None``, labels are not drawn but are still stored for
    use in `.legend`.

shadow : bool, default: False
    Draw a shadow beneath the pie.

startangle : float, default: 0 degrees
    The angle by which the start of the pie is rotated,
    counterclockwise from the x-axis.

radius : float, default: 1
    The radius of the pie.

counterclock : bool, default: True
    Specify fractions direction, clockwise or counterclockwise.

wedgeprops : dict, default: None
    Dict of arguments passed to each `.patches.Wedge` of the pie.
    For example, ``wedgeprops = {'linewidth': 3}`` sets the width of
    the wedge border lines equal to 3. By default, ``clip_on=False``.
    When there is a conflict between these properties and other
    keywords, properties passed to *wedgeprops* take precedence.
```

```
textprops : dict, default: None
    Dict of arguments to pass to the text objects.

center : (float, float), default: (0, 0)
    The coordinates of the center of the chart.

frame : bool, default: False
    Plot Axes frame with the chart if true.

rotatelabels : bool, default: False
    Rotate each label to the angle of the corresponding slice if true.

normalize : bool, default: True
    When *True*, always make a full pie by normalizing x so that
    ``sum(x) == 1``. *False* makes a partial pie if ``sum(x) <= 1``
    and raises a `ValueError` for ``sum(x) > 1``.

data : indexable object, optional
    If given, the following parameters also accept a string ``s``, which is
    interpreted as ``data[s]`` (unless this raises an exception):

    *x*, *explode*, *labels*, *colors*

Returns
-------
patches : list
    A sequence of `matplotlib.patches.Wedge` instances

texts : list
    A list of the label `.Text` instances.

autotexts : list
    A list of `.Text` instances for the numeric labels. This will only
    be returned if the parameter *autopct* is not *None*.

Notes
-----
The pie chart will probably look best if the figure and Axes are
square, or the Axes aspect is equal.
This method sets the aspect ratio of the axis to "equal".
The Axes aspect ratio can be controlled with `.Axes.set_aspect`.
```

[24]:
```
x = np.random.randint(1,5,size=(10))
labels = ["Data "+str(i+1) for i in range(x.size)]
fig,ax = plt.subplots(figsize=(8,3))
```

```
ax.pie(x,labels=labels,labeldistance=1.15,rotatelabels=True)
plt.show()
```

Plot Styles

- `Axes.step` for step plot
- `Axes.hist` for histogram
- `Axes.errorbar` for plotting error bars
- `Axes.fill_between` for filling the regions between two curves
- `Axes.quiver` for plotting quiver (directional fields)

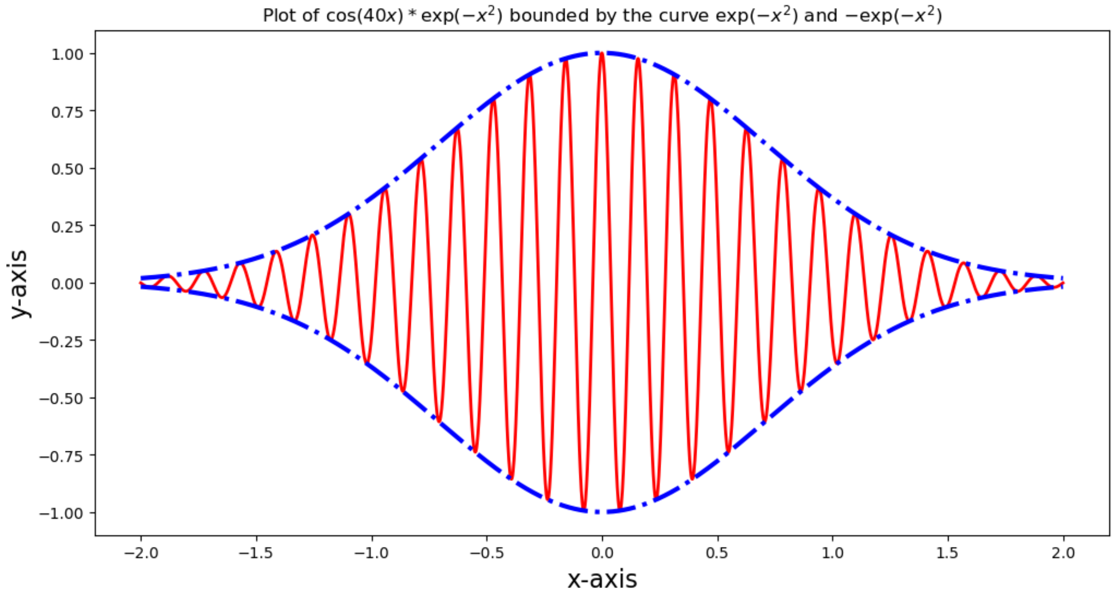
One can refer the `matplotlib` documentation for examples. We will workout these examples in the upcoming

Line and Maker Properties

Examples

[15]:
```
x = np.linspace(-2,2,2000)
y1 = np.cos(40*x)
y2 = np.exp(-x**2)

fig,ax = plt.subplots(figsize=(12,6))
ax.plot(x,y1*y2,ls='-',color='red',lw=2)
ax.plot(x,y2,ls='-.',color='blue',lw=3)
ax.plot(x,-y2,ls='-.',color='blue',lw=3)
ax.set_xlabel('x-axis',fontsize=16)
ax.set_ylabel('y-axis',fontsize=16)
```

```
ax.set_title('Plot of $\cos(40x)*\exp(-x^2)$ bounded by the curve $\exp(-x^2)$␣
↪and $-\exp(-x^2)$')
plt.show()
```



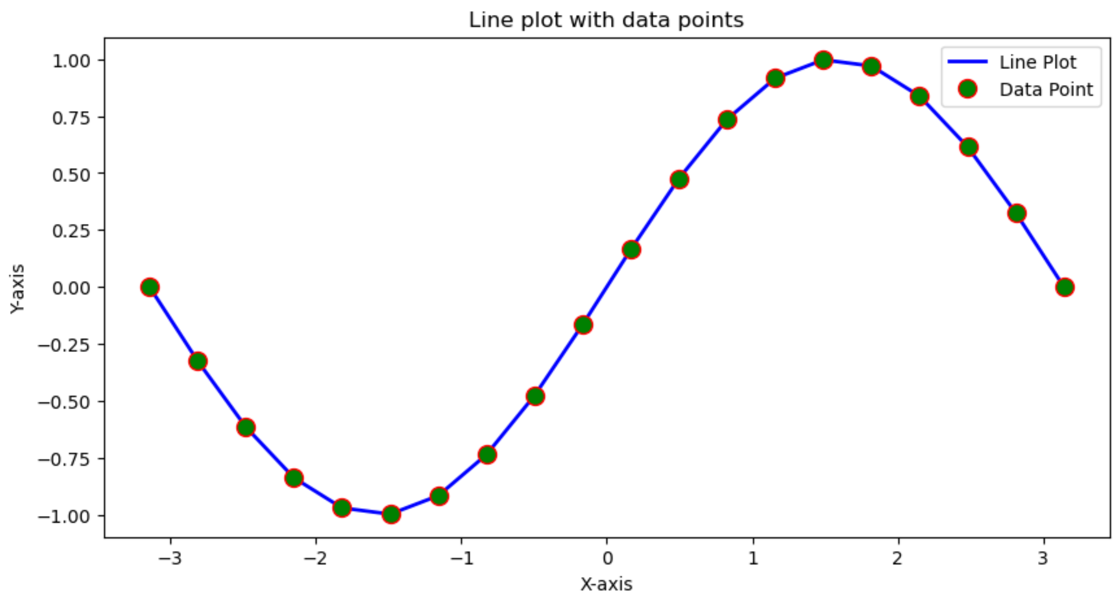
Legends

- A graph with multiple lines may often benefit from a legend, which dispalys a label along each line type (at some place) within the figure.
- A legend may be added to an `Axes` instance in a Matplotlib figure using the `legend` method.
- Only lines with assigned labels are cincluded in the legend and to assign a label to a line, use the `label` argument of `Axes.plot`.
- The legend method accepts a large number of optional arugments — see `help(plt.legend)` for more details.
- Here, we emphasise on few useful arguments.
  - `loc` – allows us to specify where in the `Axes` area the legend is to be added.
    - `loc = 1` for upper-right corner
    - `loc = 2` for upper-left corner
    - `loc = 3` for lower-left corner
    - `loc = 4` for lower-right corner
    - If `loc` is omitted then the Matplotlib automatically evaluates the placement such that legend is minimally interacts with the figure data.
  - `bbox_to_anchor` help us to place the legend at an arbitrary location within the figure.
    - The `bbox_to_anchor` argument takes the value of a tuple on the form (x, y), where x and y are the *canvas coordinates* within the `Axes` object.
      - Point $(0, 0)$ corresponds to lower-left corner
      - Point $(0, 1)$ corresponds to lower-right corner
      - Point $(1, 0)$ corresponds to upper-left corner

- · Point $(1,1)$ corresponds to upper-right corner
- ∗ Using the `ncol` argument, we can split the legend labels into multiple columns

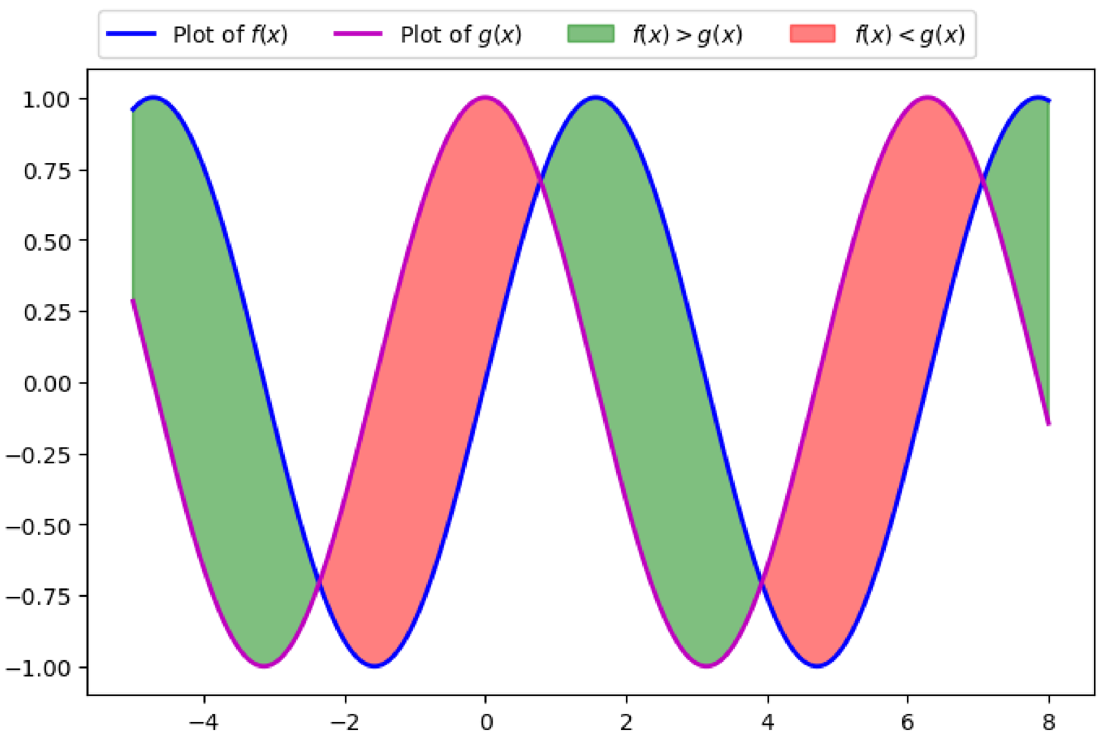
Basic Line Plot Example with Data Points

[16]:
```
%matplotlib inline
import numpy as np
import matplotlib.pyplot as plt

fig = plt.figure(figsize=(10,5))
x = np.linspace(-np.pi, np.pi, 20)
y = np.sin(x)

plt.plot(x,y,color='blue',lw=2)
plt.plot(x,y,'o',markeredgecolor='r',markerfacecolor='green',ms=10)
plt.title('Line plot with data points')
plt.xlabel('X-axis')
plt.ylabel('Y-axis')
plt.legend(['Line Plot','Data Point'])
plt.show()
```



Example illustrating the `fill_between` and the use of `bbox_to_anchor` in `plt.legend` to place the legend ourside of the figure

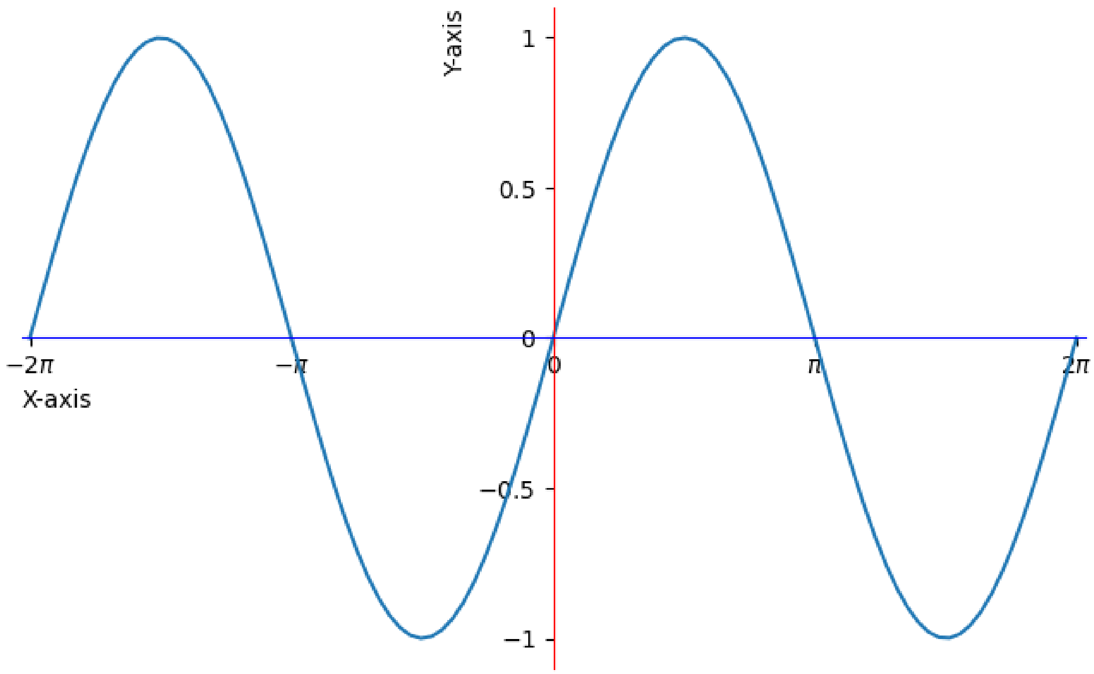
[17]:
```
x = np.linspace(-5,8,1000)
f = np.sin(2*np.pi+x)
g = np.cos(2*np.pi-x)

fig, ax = plt.subplots(figsize=(8,5))
ax.plot(x,f,c='b',lw=2,label='Plot of $f(x)$')
ax.plot(x,g,c='m',lw=2,label='Plot of $g(x)$')
ax.fill_between(x,f,g,where=(f > g),color='green',alpha=0.5,label='$f(x) >␣
↪g(x)$')
ax.fill_between(x,f,g,where=(f < g),color='red',alpha=0.5,label='$f(x) < g(x)$')
ax.legend(ncol=4, loc=3, bbox_to_anchor=(0,1))

plt.show()
```



Axes Ticks, Tick Labels, Spines and Grids

[9]:
```
x = np.linspace(-2*np.pi,2*np.pi,100)
y = np.sin(x)

fig,ax = plt.subplots(figsize=(8,5))
```

```
ax.plot(x,y)

# set x-axis and y-axis limits
ax.set_xlim([-2*np.pi-0.1, 2*np.pi+0.1])
ax.set_ylim([-1.1, 1.1])

# set x-axis and y-axis labels
ax.set_xlabel('X-axis',loc='left') #loc = 'left', 'center', 'right' -- default␣
↪is 'center'
ax.set_ylabel('Y-axis',loc='top') #loc = 'top', 'center', 'bottom' -- default is␣
↪'center'

# set x-axis and y-axis ticks
ax.set_xticks([-2*np.pi, -np.pi, 0, np.pi, 2*np.pi])
ax.set_yticks([-1, -0.5, 0, 0.5, 1])

# set x-axis and y-axis tick labels
ax.set_xticklabels(['$-2\pi$', '$-\pi$', '$0$', '$\pi$', '$2\pi$'])
ax.set_yticklabels(['$-1$', '$-0.5$', '$0$', '$0.5$', '$1$'])

# remove top and right spines (axis)
ax.spines['right'].set_color('none')
ax.spines['top'].set_color('none')
ax.spines['left'].set_color('red')
ax.spines['bottom'].set_color('blue')

# remove top and right spines (axis) ticks
ax.xaxis.set_ticks_position('bottom')
ax.yaxis.set_ticks_position('left')

# move bottom and left spine (axis) to $x = 0$ and $y=0$
ax.spines['bottom'].set_position(('data', 0))
ax.spines['left'].set_position(('data', 0))

plt.show()
```

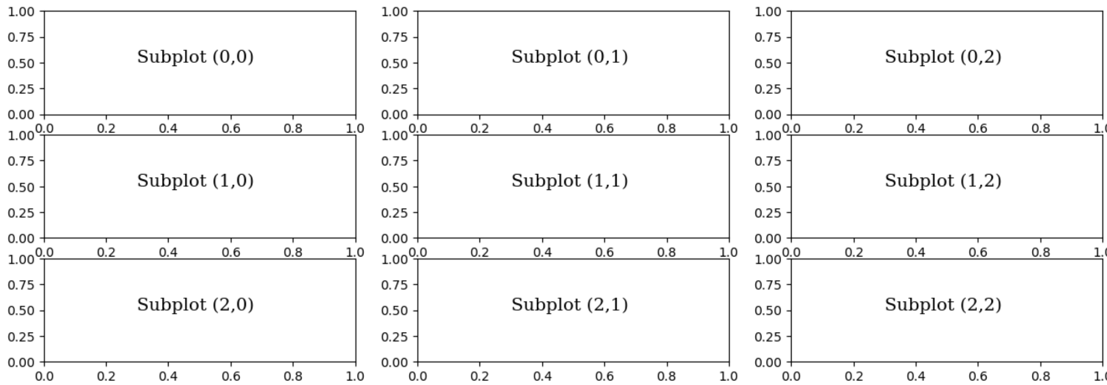


Subplots

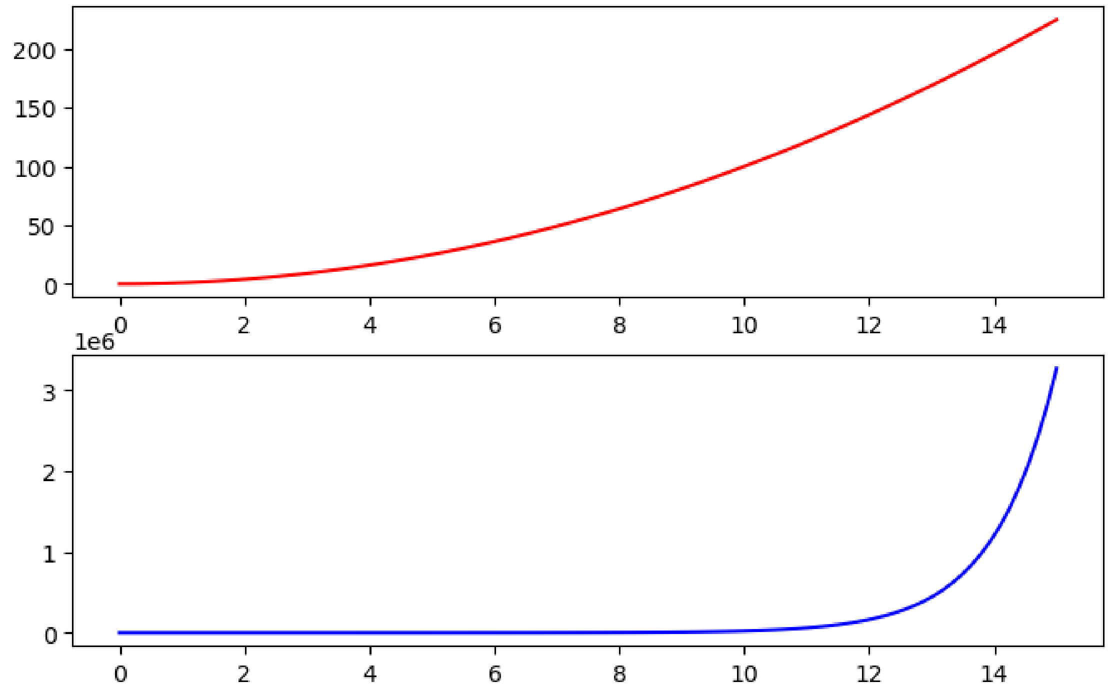
- The matplotlib command `plt.subplots` returns a tuple with a `Figure` instance and a NumPy array with the `Axes` objects for each row and colum that was requested in the functiona call.
- If the either $x-$axis or $y-$axis or both of the suplots shares the same value, then one can use `sharex=Ture` and `sharey=True` arguments of `plt.subplots` to aovid the same axis labels to be repeated across multiple axes.
- One should remember that the dimension of the NumPy array with `Axes` instances that is returned by `plt.subplots` is "squeezed" by default: that is, the dimensions with length 1 are removed from the array.
  - If both requested number of column and row are greater than one, then a two-dimensional array is returned, but if either (or both) the number of columns or rows is one, then a one-dimensional (or scalar, i.e., the only `Axes` object itself) is returned.
  - We can turn off the squeezing of the dimensions of the NumPy array by passing the arugment `squeeze=False` to the `plt.subplots` function. In this case the `ax` variable in `fig, ax = plt.subplots(nrows,ncols)` is always a two-dimentional array.
- Another important function, which is of useful many times while using subplots is `plt.subplot_adjust` function.
  - This function allows to explicity set the left, right, bottom and top coordinates of the overall `Axes` grid, as well as the width (`wspace`) and height spacing (`hspace`) between `Axes` instances in the grid.

Basic Example of Subplots without any axes plots

[19]:
```
fig, ax = plt.subplots(3,3,figsize=(15,5))
for i in range(len(ax)):
    for j in range(len(ax[0])):
        ax[i,j].text(0.3,0.5,'Subplot ('+str(i)+','+str(j)+')', fontsize=14,␣
↪family='serif')
```



[20]:
```
x = np.linspace(0,15,100)
y1 = x**2
y2 = np.exp(x)

fig, ax = plt.subplots(2,1,figsize=(8,5))
ax[0].plot(x,y1,'r')
ax[1].plot(x,y2,'b')
plt.show()
```

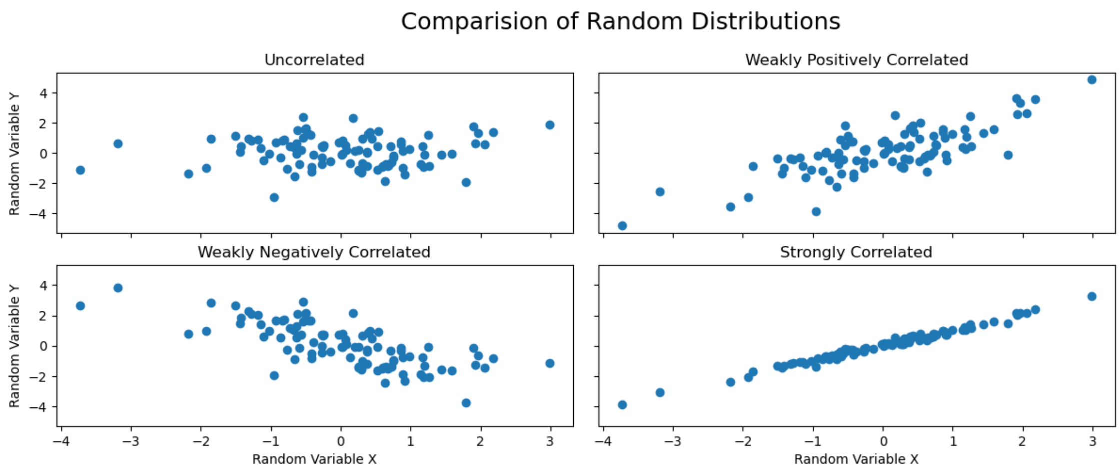


Some advanced examples

Example with subplot_adjust

[21]:
```
x1 = np.random.randn(100)
x2 = np.random.randn(100)

fig,ax = plt.subplots(2,2,figsize=(15,5),sharex = True, sharey=True)
ax[0,0].scatter(x1,x2)
ax[0,0].set_title('Uncorrelated')
ax[0,0].set_ylabel('Random Variable Y')

ax[0,1].scatter(x1,x1+x2)
ax[0,1].set_title('Weakly Positively Correlated')

ax[1,0].scatter(x1,-x1+x2)
ax[1,0].set_title('Weakly Negatively Correlated')
ax[1,0].set_xlabel('Random Variable X')
ax[1,0].set_ylabel('Random Variable Y')

ax[1,1].scatter(x1,x1+ 0.15*x2)
ax[1,1].set_title('Strongly Correlated')
ax[1,1].set_xlabel('Random Variable X')
```

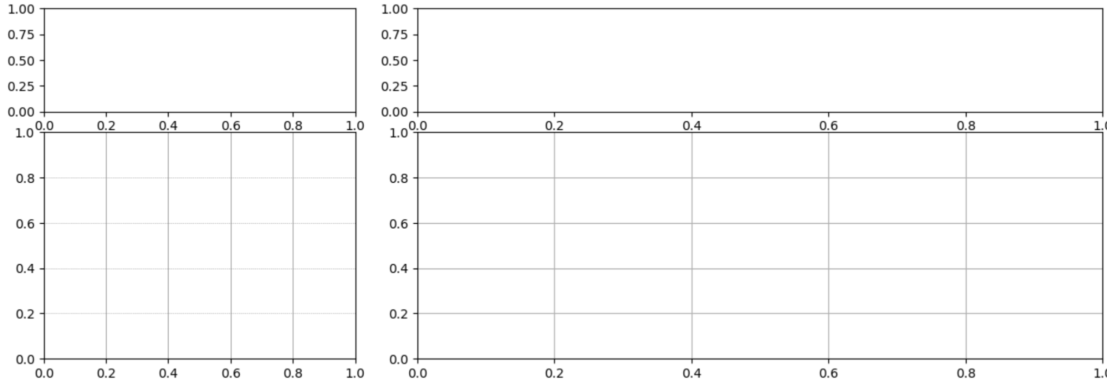
```
plt.suptitle('Comparision of Random Distributions',fontsize=18)

plt.subplots_adjust(left=0.1,right=0.85,bottom=0.1, top=0.85, wspace=0.05,␣
↪hspace=0.2)
plt.show()
```



Deleting a subplot using `Axes.remove()` and then merging the subplots with GridSpec

[22]:
```
fig, axs = plt.subplots(3,3,figsize=(15,5))

# Let us remove subplts at (0,1) and (0,2) and add a subplot spanned to these␣
↪two places
# We first need to obtain the Grid Specifiactions using ax.get_gridspec()
gs = axs[0,0].get_gridspec()
axs[0,1].remove()
axs[0,2].remove()
axs_012 = fig.add_subplot(gs[0, 1:])

# Let us combine the subplots at (1,0) and (2,0)
axs[1,0].remove()
axs[2,0].remove()
axs_120 = fig.add_subplot(gs[1:,0])
axs_120.grid(color='grey',which='major',axis='x',linestyle='-',linewidth=0.5)
axs_120.grid(color='grey',which='major',axis='y',linestyle=':',linewidth=0.5)

# Let us combine the subplots at (1,1),(1,2),(2,1) and (2,2)
for ax in axs[1:,1]:
    ax.remove()
for ax in axs[1:,2]:
    ax.remove()
```

```
ax_1122 = fig.add_subplot(gs[1:,1:])
ax_1122.grid()
```



3D-Plotting

Plotting 3D functions on 2D space: `contour`, `confourf`, `pcolor`, `imshow`

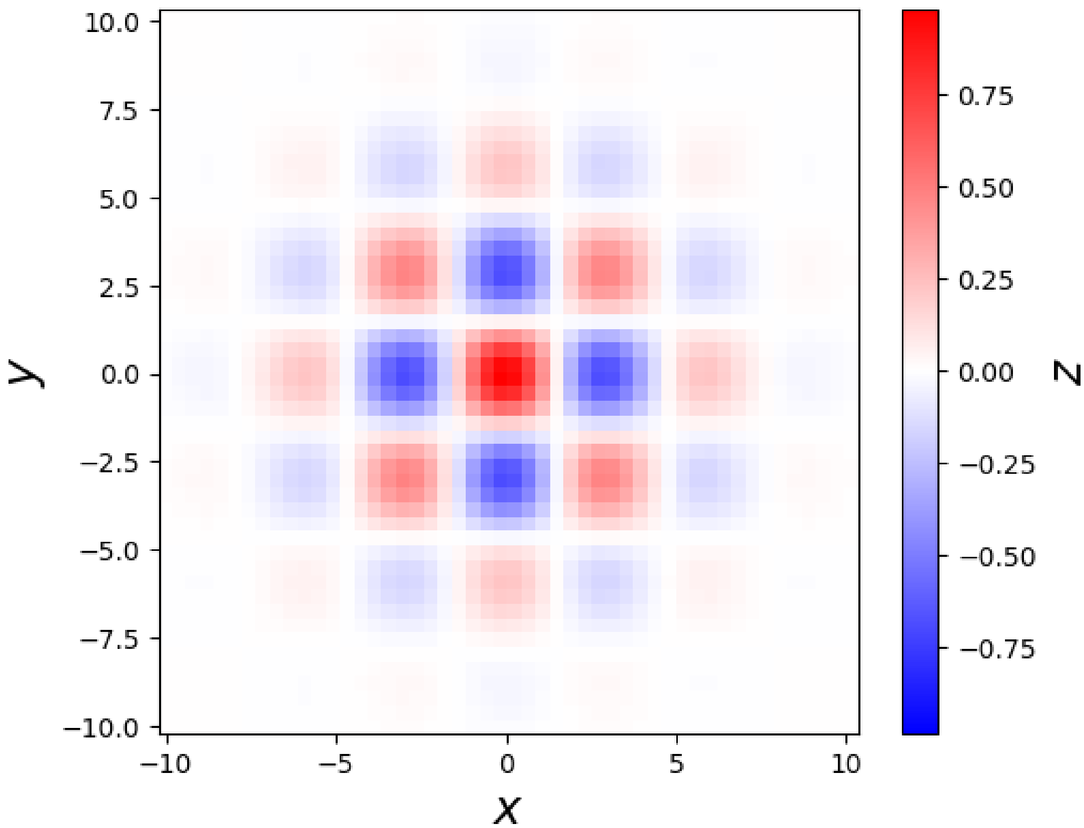
To illustrate this let us consider plotting of the function

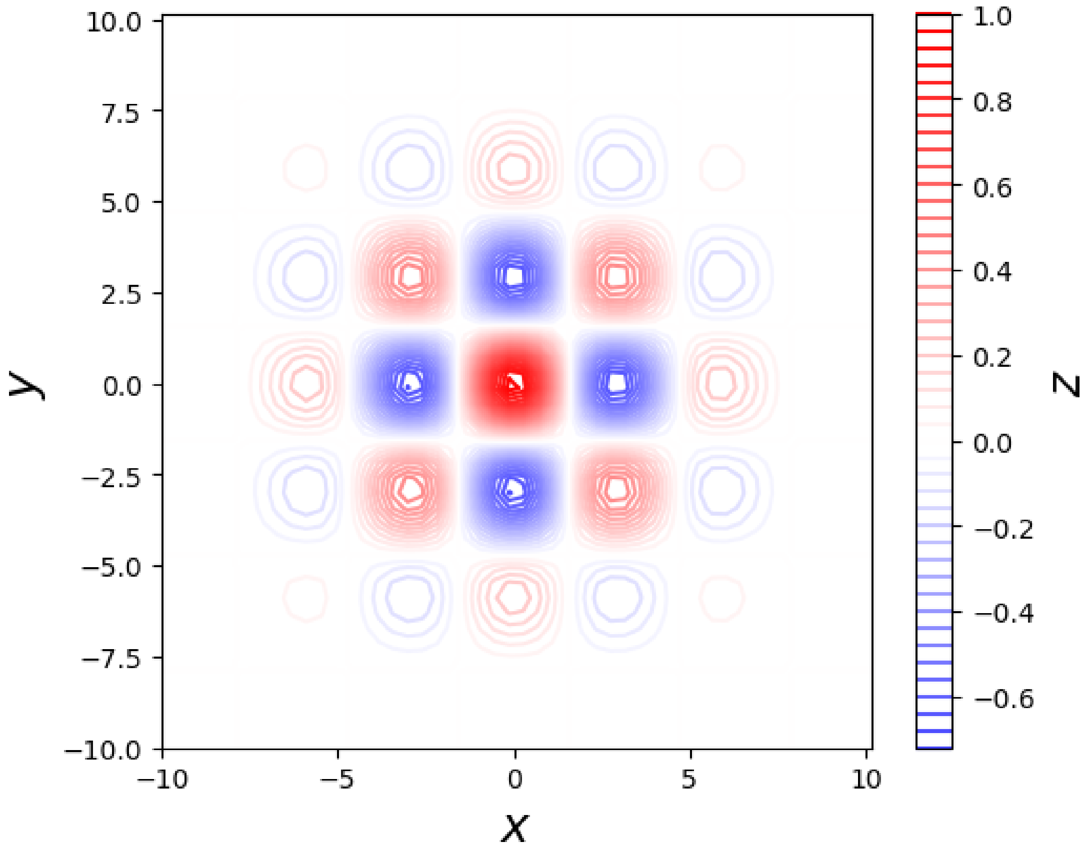
$$z = f(x,y) = \cos(x)\cos(y)e^{-\left(\frac{x}{5}\right)^2-\left(\frac{y}{5}\right)^2}$$

over the $xy-$grid $[-10,10]\times[-10,10]$

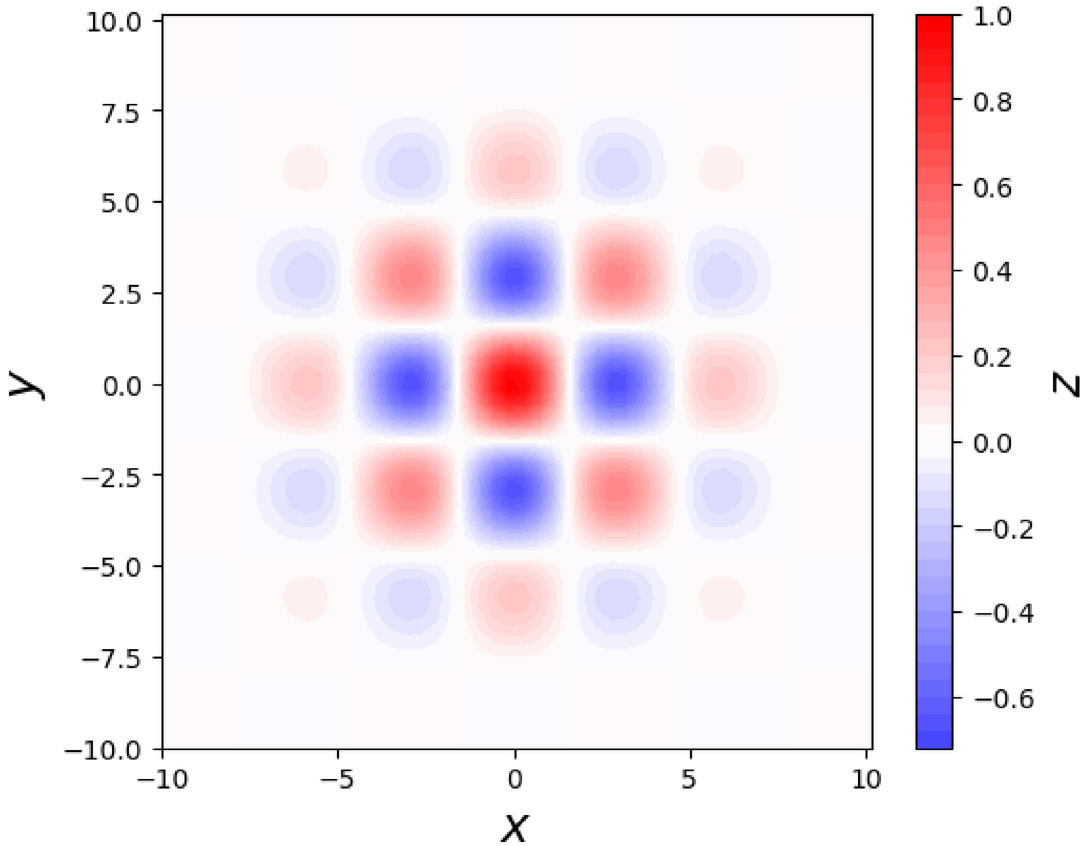
[23]:
```
# first generated the x,y values over which the function to be evaluated.
x = y = np.linspace(-10,10,150)

# now generate the $XY-$ grid using numpy.meshgrid
X,Y = np.meshgrid(x,y)

# now evaluate the function values on the above grid
Z = np.cos(X)*np.cos(Y)*np.exp(-(X/5)**2-(Y/5)**2)

# Patch Color Plot

fig,ax = plt.subplots(figsize=(6,5))

norm = mpl.colors.Normalize(-abs(Z).max(), abs(Z).max()) #for normang the colors␣
↪in the plotting
p = ax.pcolor(X,Y,Z, norm=norm, cmap=mpl.cm.bwr)

ax.axis('tight')
ax.set_xlabel('$x$',fontsize=18)
ax.set_ylabel('$y$',fontsize=18)
```

```
cb = fig.colorbar(p,ax=ax)
cb.set_label('$z$', fontsize=18)

# Contour Plot

fig,ax = plt.subplots(figsize=(6,5))

norm = mpl.colors.Normalize(-abs(Z).max(), abs(Z).max()) #for normang the colors␣
↪in the plotting
p = ax.contour(X,Y,Z, 50, norm=norm, cmap=mpl.cm.bwr)

ax.axis('tight')
ax.set_xlabel('$x$',fontsize=18)
ax.set_ylabel('$y$',fontsize=18)

cb = fig.colorbar(p,ax=ax)
cb.set_label('$z$', fontsize=18)

# Filled Contour Plot

fig,ax = plt.subplots(figsize=(6,5))

norm = mpl.colors.Normalize(-abs(Z).max(), abs(Z).max()) #for normang the colors␣
↪in the plotting
p = ax.contourf(X,Y,Z, 50, norm=norm, cmap=mpl.cm.bwr)

ax.axis('tight')
ax.set_xlabel('$x$',fontsize=18)
ax.set_ylabel('$y$',fontsize=18)

cb = fig.colorbar(p,ax=ax)
cb.set_label('$z$', fontsize=18)
```


10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
y
−10
−5
0
5
10
x
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
z



10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
y
−10
−5
0
5
10
x
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
z



3D Surfaces: `contour3D`, `plot_wireframe`, `plot_surface`

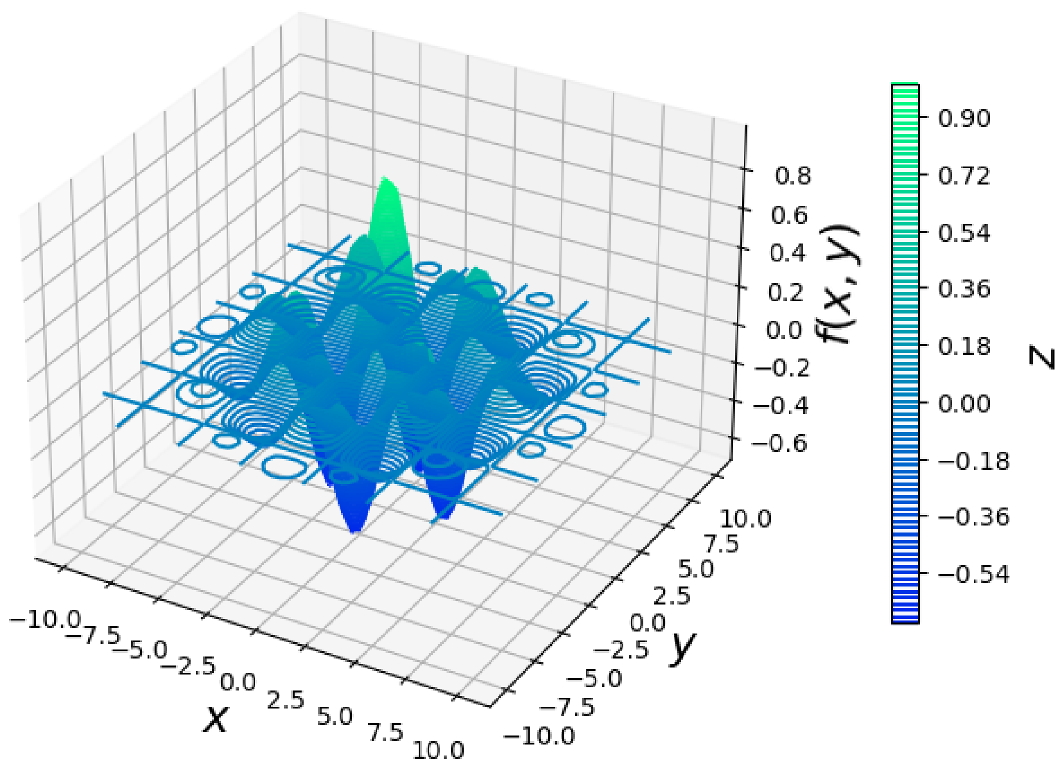
- For visualising the 3D graphs, we need to introuced a $z-$axis to the existing `Axes` object of Matplotlib.
- This requires a different axes object, namely, the `Axes3D` which is avaialble in `mpl_toolkits.mplot3d` module.
- We can create a 3D-aware `Axes` instance explicitly using the constructor of the `Axes3D` class, by passing a `Figure` instance as an argument: `ax = Axes3D(fig)`.
- Alternatively, we can use the `add_subplot` function with the `projection = '3d'` argument: `ax = fig.add_subplot(1,1,1,projection='3d')` or use `plt.subplots` with the `subplot_kw={'projection':'3d'}` argument: `fig, ax = plt.subplots(1,1, figsize=(8,6), subplot_kw={'projection':'3d'})`

[11]:
```
import numpy as np
x = np.array([1,2,3])
y = np.array([2,3,4])

X,Y = np.meshgrid(x,y)
print(X)
print(Y)
```

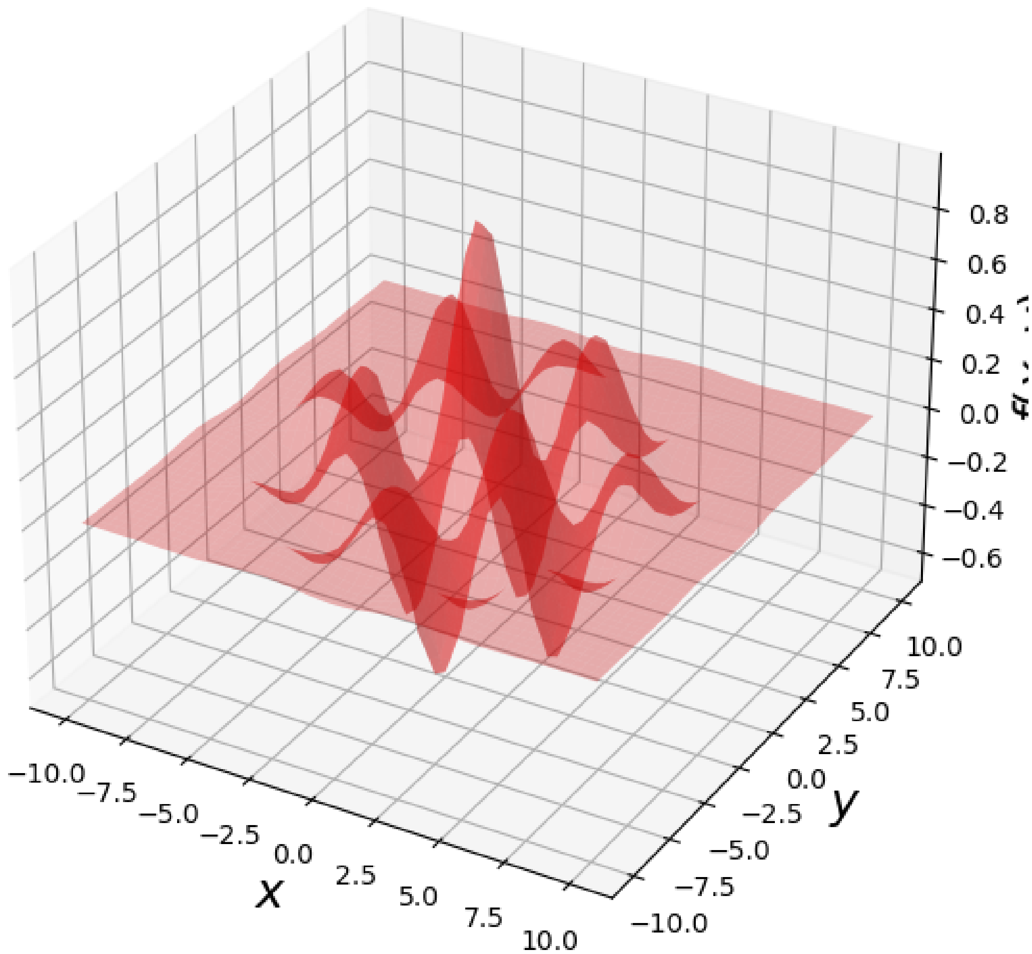
```
[[1 2 3]
 [1 2 3]
 [1 2 3]]
[[2 2 2]
 [3 3 3]
 [4 4 4]]
```

[6]:

```
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
import matplotlib as mpl
import numpy as np

# first generated the x,y values over which the function to be evaluated.
x = y = np.linspace(-10,10.150)

# now generate the $XY-$ grid using numpy.meshgrid
X,Y = np.meshgrid(x,y)

# now evaluate the function values on the above grid
Z = np.cos(X)*np.cos(Y)*np.exp(-(X/5)**2-(Y/5)**2)

# 3D Contour Plot

fig, ax = plt.subplots(figsize=(6,5))
ax.remove()
ax = Axes3D(fig,auto_add_to_figure=False)
fig.add_axes(ax)

norm = mpl.colors.Normalize(-abs(Z).max(), abs(Z).max()) #for normalising the␣
↪colors in the plotting
p = ax.contour3D(X,Y,Z, 100, norm=norm, cmap=mpl.cm.winter)

ax.axis('tight')
ax.set_xlabel('$x$',fontsize=18)
ax.set_ylabel('$y$',fontsize=18)
ax.set_zlabel('$f(x,y)$',fontsize=18)
cb = fig.colorbar(p,ax=ax, shrink=0.6, pad=0.1)
cb.set_label('$z$', fontsize=18)

plt.show()
```



[11]:
```
# 3D Wireframe Plot
%matplotlib inline
fig, ax = plt.subplots(figsize=(7,7),subplot_kw={'projection':'3d'})

#norm = mpl.colors.Normalize(-abs(Z).max(), abs(Z).max()) #for normalising the␣
↪colors in the plotting
p = ax.plot_surface(X,Y,Z, color='red', alpha=0.3)
ax.axis('tight')
ax.set_xlabel('$x$',fontsize=18)
ax.set_ylabel('$y$',fontsize=18)
ax.set_zlabel('$f(x,y)$',fontsize=18)
plt.show()
```



[27]:
```
import matplotlib as mpl
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d.axes3d import Axes3D
import numpy as np

# 3D Surface Plot
%matplotlib qt5

# first generated the x,y values over which the function to be evaluated.
x = y = np.linspace(-10,10.150)

# now generate the $XY-$ grid using numpy.meshgrid
X,Y = np.meshgrid(x,y)
```

```
# now evaluate the function values on the above grid
Z = np.cos(X)*np.cos(Y)*np.exp(-(X/5)**2-(Y/5)**2)

fig, ax = plt.subplots(1,1,figsize=(8,8),subplot_kw={'projection':'3d'})

p = ax.plot_surface(X,Y,Z, cmap = mpl.cm.spring, alpha=0.8)
ax.axis('tight')
ax.set_xlabel('$x$',fontsize=12)
ax.set_ylabel('$y$',fontsize=12)
ax.set_zlabel('$f(x,y)$',fontsize=12,labelpad=10)
cb = fig.colorbar(p,ax=ax, shrink=0.5, pad=0.15)
cb.set_label('$z$', fontsize=12)

ax.set_xlim([X.min(), X.max()])
ax.set_ylim([Y.min(), Y.max()])
ax.set_zlim([Z.min(), Z.max()])
ax.set_xticks(np.linspace(-10,10,5))
ax.set_xticklabels([])
ax.set_yticks(np.linspace(-10,10,5))
ax.set_zticks(np.linspace(Z.min(),Z.max(),6))

cset1 = ax.contour(X,Y,Z, zdir='z', offset=Z.min(), cmap=mpl.cm.winter)
cset2 = ax.contour(X,Y,Z, zdir='y', offset=Y.max(), cmap=mpl.cm.jet)
cset3 = ax.contour(X,Y,Z, zdir='x', offset=X.min(), cmap=mpl.cm.spring)

plt.show()
```

[ ]:

```

```