Bokeh

tutorialspoint

SIMPLY EASY LEARNING

About the Tutorial

This tutorial will help you in understanding about Bokeh which is a data visualization library for Python. Here, you will learn about how to use Bokeh to create data applications, interactive plots and dashboards.

Audience

This tutorial is designed for software programmers who want to learn the basics of Bokeh and its programming concepts in simple and easy way. This tutorial will give you enough understanding on various functionalities of Bokeh with illustrative examples.

Prerequisites

Before proceeding, we assume that the reader has basic understanding in programming language Python and interactive data visualization.

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1. Bokeh — Introduction

Bokeh is a data visualization library for Python. Unlike Matplotlib and Seaborn, they are also Python packages for data visualization, Bokeh renders its plots using HTML and JavaScript. Hence, it proves to be extremely useful for developing web based dashboards.

The Bokeh project is sponsored by NumFocus (https://numfocus.org/). NumFocus also supports PyData, an educational program, involved in development of other important tools such as NumPy, Pandas and more. Bokeh can easily connect with these tools and produce interactive plots, dashboards and data applications.

Features

Bokeh primarily converts the data source into a JSON file which is used as input for BokehJS, a JavaScript library, which in turn is written in TypeScript and renders the visualizations in modern browsers.

Some of the **important features of Bokeh** are as follows:

Flexibility

Bokeh is useful for common plotting requirements as well as custom and complex use-cases.

Productivity

Bokeh can easily interact with other popular Pydata tools such as Pandas and Jupyter notebook.

Interactivity

This is an important advantage of Bokeh over Matplotlib and Seaborn, both produce static plots. Bokeh creates interactive plots that change when the user interacts with them. You can give your audience a wide range of options and tools for inferring and looking at data from various angles so that user can perform "what if" analysis.

Powerful

By adding custom JavaScript, it is possible to generate visualizations for specialised use-cases.

Sharable

Plots can be embedded in output of **Flask** or **Django** enabled web applications. They can also be rendered in **Jupyter** notebooks.

Open source

Bokeh is an open source project. It is distributed under Berkeley Source Distribution (BSD) license. Its source code is available on https://github.com/bokeh/bokeh.

2. Bokeh — Environment Setup

Bokeh can be installed on **CPython** versions **2.7** and **3.5+** only both with Standard distribution and Anaconda distribution. Current version of Bokeh at the time of writing this tutorial is ver. 1.3.4. Bokeh package has the following dependencies:

- jinja2 >=2.7
- numpy >=1.7.1
- packaging >=16.8
- pillow >=4.0
- python-dateutil >=2.1
- pyyaml >=3.10
- six >=1.5.2
- tornado >=4.3

Generally, above packages are installed automatically when Bokeh is installed using Python's built-in Package manager PIP as shown below:

```
pip3 install bokeh
```

If you are using Anaconda distribution, use conda package manager as follows:

```
conda install bokeh
```

In addition to the above dependencies, you may require additional packages such as pandas, psutil, etc., for specific purposes.

To verify if Bokeh has been successfully installed, import bokeh package in Python terminal and check its version:

```
>>> import bokeh

>>> bokeh.__version__

'1.3.4'
```

3. Bokeh — Getting Started

Creating a simple line plot between two numpy arrays is very simple. To begin with, import following functions from **bokeh.plotting** modules:

```
from bokeh.plotting import figure, output_file, show
```

The **figure()** function creates a new figure for plotting.

The **output_file()** function is used to specify a HTML file to store output.

The **show()** function displays the Bokeh figure in browser on in notebook.

Next, set up two numpy arrays where second array is sine value of first.

```
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
y=np.sin(x)
```

To obtain a Bokeh Figure object, specify the title and x and y axis labels as below:

```
p = figure(title="sine wave example", x_axis_label='x', y_axis_label='y')
```

The Figure object contains a line() method that adds a line glyph to the figure. It needs data series for x and y axes.

```
p.line(x, y, legend="sine", line_width=2)
```

Finally, set the output file and call show() function.

```
output_file("sine.html")
show(p)
```

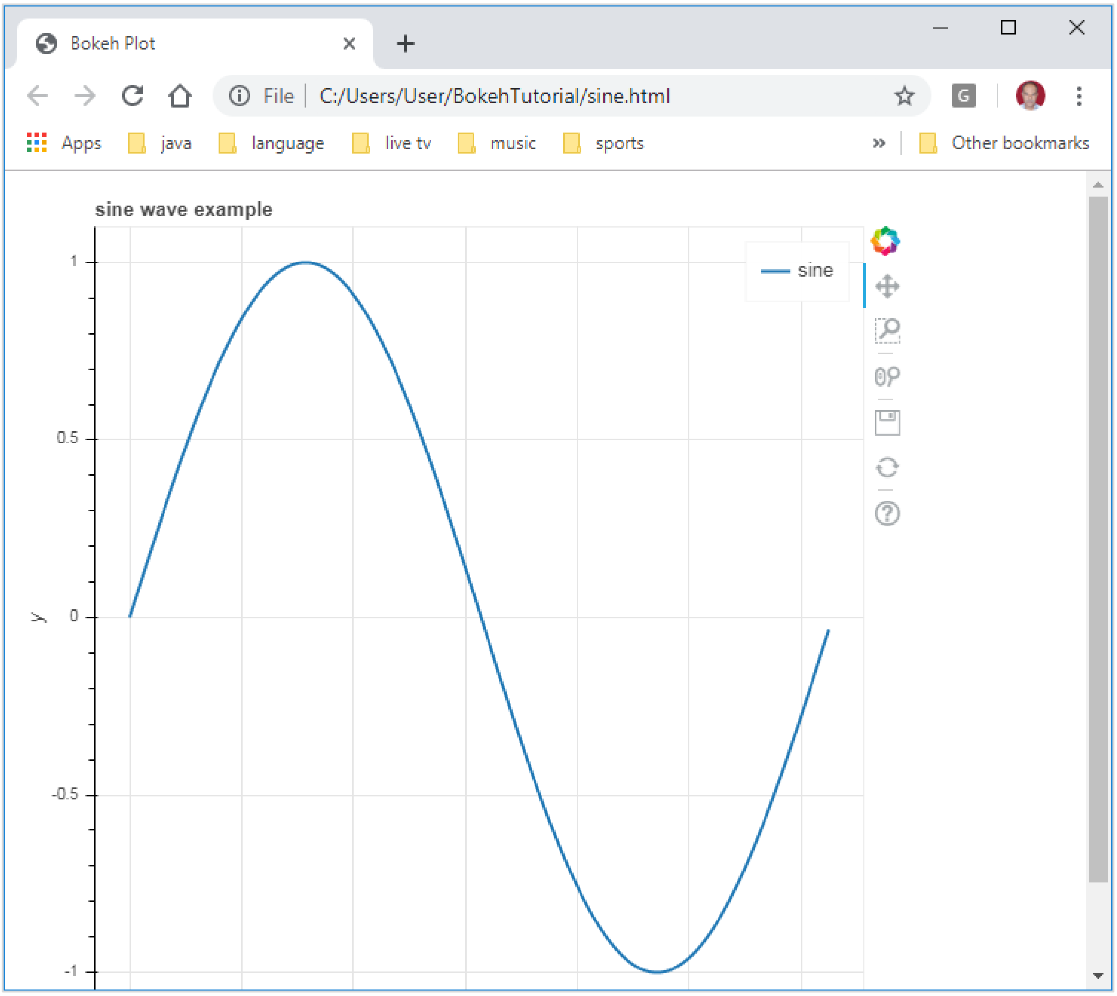
This will render the line plot in 'sine.html' and will be displayed in browser.

Complete code and its output is as follows:

```
from bokeh.plotting import figure, output_file, show
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
y=np.sin(x)
output_file("sine.html")
p = figure(title="sine wave example", x_axis_label='x', y_axis_label='y')
```

```
p.line(x, y, legend="sine", line_width=2)
show(p)
```

Output on browser



4. Bokeh — Jupyter Notebook

Displaying Bokeh figure in Jupyter notebook is very similar to the above. The only change you need to make is to import output_notebook instead of output_file from bokeh.plotting module.

```
from bokeh.plotting import figure, output_notebook, show
```

Call to **output_notebook()** function sets Jupyter notebook's output cell as the destination for show() function as shown below:

```
output_notebook()

show(p)
```

Enter the code in a notebook cell and run it. The sine wave will be displayed inside the notebook.

5. Bokeh — Basic Concepts

Bokeh package offers two interfaces using which various plotting operations can be performed.

bokeh.models

This module is a low level interface. It provides great deal of flexibility to the application developer in developing visualizations. A Bokeh plot results in an object containing visual and data aspects of a scene which is used by BokehJS library. The low-level objects that comprise a Bokeh scene graph are called Models.

bokeh.plotting

This is a higher level interface that has functionality for composing visual glyphs. This module contains definition of Figure class. It actually is a subclass of plot class defined in bokeh.models module.

Figure class simplifies plot creation. It contains various methods to draw different vectorized graphical glyphs. Glyphs are the building blocks of Bokeh plot such as lines, circles, rectangles, and other shapes.

bokeh.application

Bokeh package Application class which is a lightweight factory for creating Bokeh Documents. A Document is a container for Bokeh Models to be reflected to the client side BokehJS library.

bokeh.server

It provides customizable Bokeh Server Tornadocore application. Server is used to share and publish interactive plots and apps to an audience of your choice.

6. Bokeh — Plots with Glyphs

Any plot is usually made up of one or many geometrical shapes such as **line, circle, rectangle,** etc. These shapes have visual information about the corresponding set of data. In Bokeh terminology, these geometrical shapes are called **gylphs**. Bokeh plots constructed using **bokeh.plotting interface** use a default set of tools and styles. However, it is possible to customize the styles using available plotting tools.

Types of Plots

Different types of plots created using glyphs are as given below:

Line plot

This type of plot is useful for visualizing the movements of points along the x-and y-axes in the form of a line. It is used to perform time series analytics.

Bar plot

This is typically useful for indicating the count of each category of a particular column or field in your dataset.

Patch plot

This plot indicates a region of points in a particular shade of color. This type of plot is used to distinguish different groups within the same dataset.

Scatter plot

This type of plot is used to visualize relationship between two variables and to indicate the strength of correlation between them.

Different glyph plots are formed by calling appropriate method of Figure class. The Figure object is obtained by following constructor:

```
from bokeh.plotting import figure
figure(**kwargs)
```

The Figure object can be customised by various keyword arguments.

Title	**Set the title for the plot**
x_axis_label	Set title of x axis
y_axis_label	Set title for y axis
plot_width	Set width of figure
plot_height	Set height of figure

Line plot

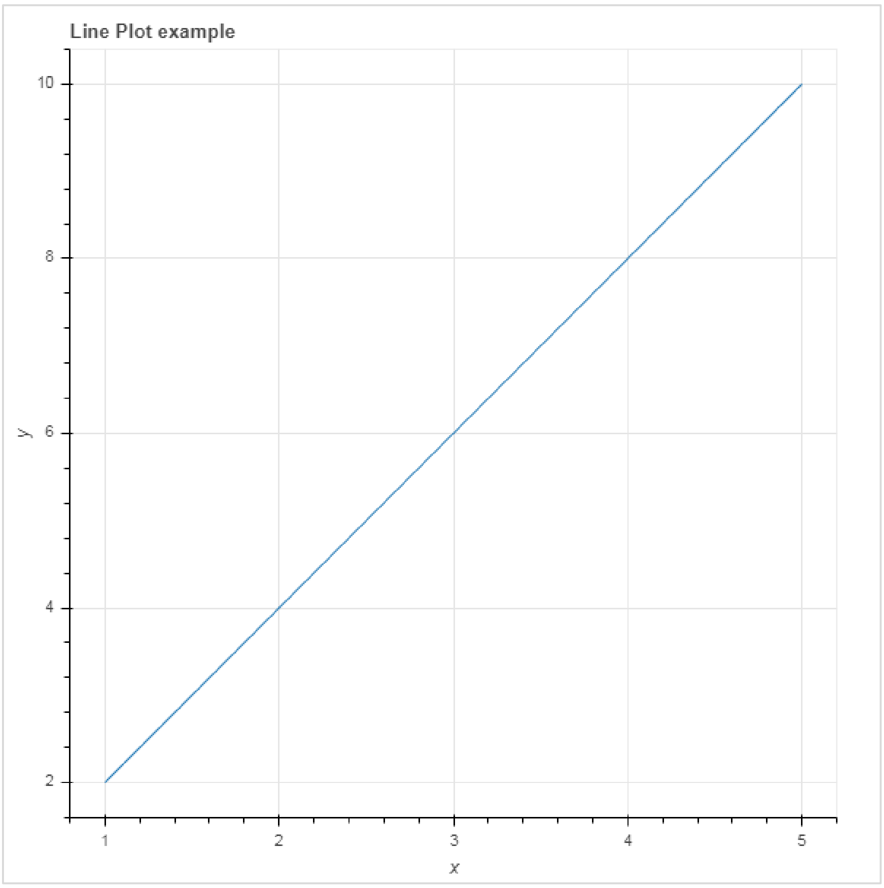
The **line() method** of Figure object adds a line glyph to the Bokeh figure. It needs **x** and **y** parameters as data arrays for showing their linear relationship.

```
from bokeh.plotting import figure, show
fig=figure()
fig.line(x,y)
show(fig)
```

Following code renders a simple line plot between two sets of values in the form Python list objects:

```
from bokeh.plotting import figure, output_file, show
x=[1,2,3,4,5]
y=[2,4,6,8,10]
output_file('line.html')
fig=figure(title='Line Plot example', x_axis_label='x', y_axis_label='y')
fig.line(x,y)
show(fig)
```

Output



Bar plot

The figure object has two different methods for constructing bar plot

hbar()

The bars are shown horizontally across plot width. The **hbar() method** has the following parameters:

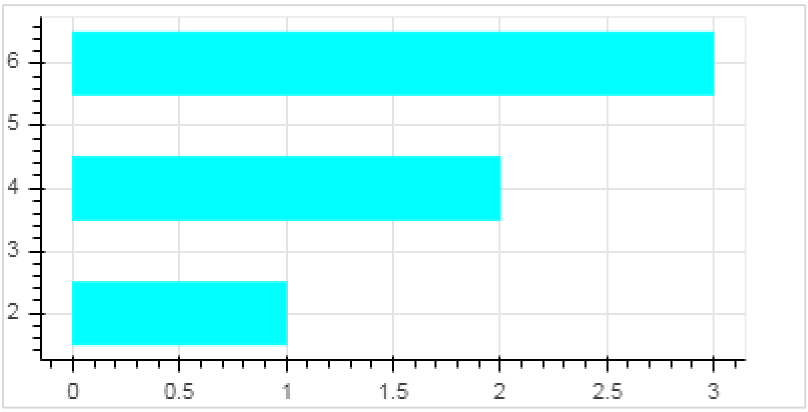
y	**The y coordinates of the centers of the horizontal bars.**
height	The heights of the vertical bars.
right	The x coordinates of the right edges.
left	The x coordinates of the left edges.

Following code is an example of **horizontal bar** using Bokeh.

```
from bokeh.plotting import figure, output_file, show


fig = figure(plot_width=400, plot_height=200)
```

```
fig.hbar(y=[2,4,6], height=1, left=0, right=[1,2,3], color="Cyan")
output_file('bar.html')
show(fig)
```

Output



vbar()

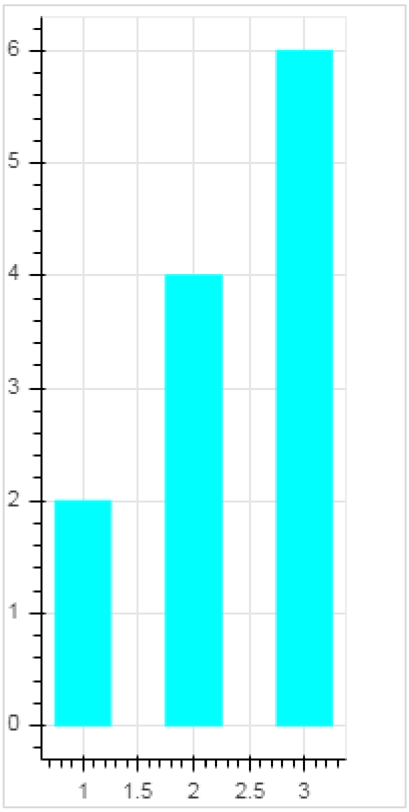
The bars are shown vertically across plot height. The **vbar() method** has following parameters:

x	**The x-coordinates of the centers of the vertical bars.**
width	The widths of the vertical bars.
top	The y-coordinates of the top edges.
bottom	The y-coordinates of the bottom edges.

Following code displays **vertical bar plot**:

```
from bokeh.plotting import figure, output_file, show

fig = figure(plot_width=200, plot_height=400)
fig.vbar(x=[1,2,3], width=0.5, bottom=0, top=[2,4,6], color="Cyan")
output_file('bar.html')
show(fig)
```

Output



Patch plot

A plot which shades a region of space in a specific color to show a region or a group having similar properties is termed as a patch plot in Bokeh. Figure object has patch() and patches() methods for this purpose.

patch()

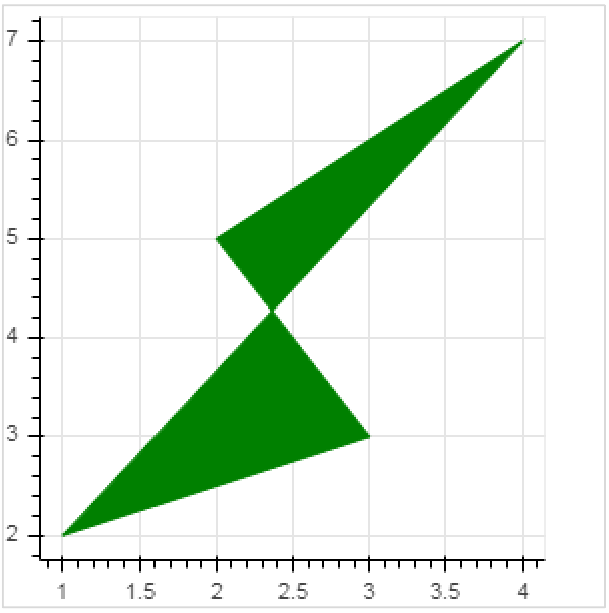
This method adds patch glyph to given figure. The method has the following arguments:

x	The x-coordinates for the points of the patch.
y	The y-coordinates for the points of the patch.

A simple **patch plot** is obtained by the following Python code:

```
from bokeh.plotting import figure, output_file, show


p = figure(plot_width=300, plot_height=300)
p.patch(x=[1, 3,2,4], y=[2,3,5,7], color="green")
output_file('patch.html')
show(p)
```

Output



patches()

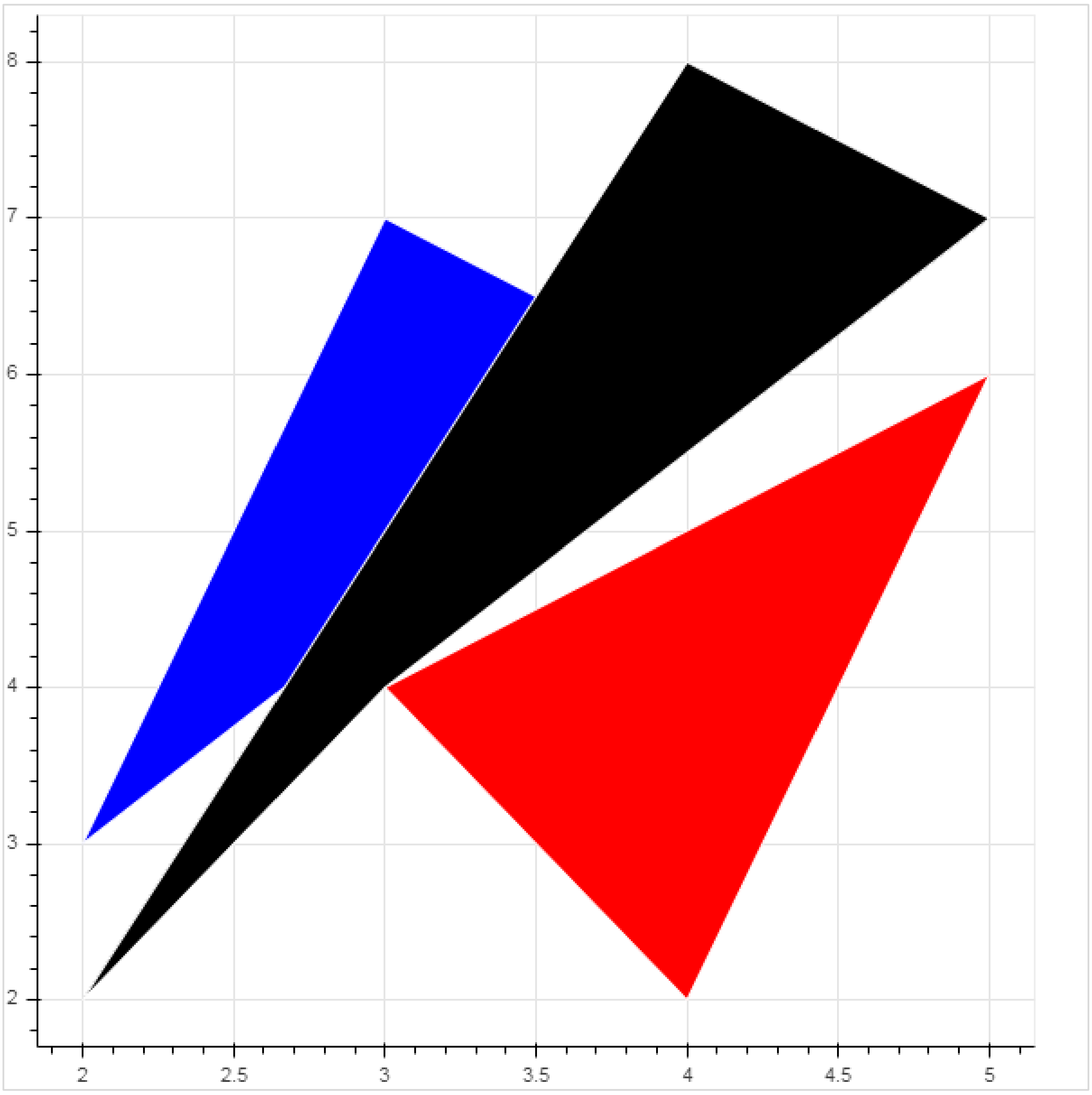
This method is used to draw multiple polygonal patches. It needs following arguments:

xs	The x-coordinates for all the patches, given as a "list of lists".
ys	The y-coordinates for all the patches, given as a "list of lists".

As an example of patches() method, run the following code:

```
from bokeh.plotting import figure, output_file, show

xs = [[5,3,4], [2,4,3], [2,3,5,4]]

ys = [[6,4,2], [3,6,7], [2,4,7,8]]

fig = figure()

fig.patches(xs, ys, fill_color = ['red', 'blue', 'black'], line_color = 
'white')

output_file('patch_plot.html')

show(fig)
```

Output



Scatter Markers

Scatter plots are very commonly used to determine the bi-variate relationship between two variables. The enhanced interactivity is added to them using Bokeh. Scatter plot is obtained by calling scatter() method of Figure object. It uses the following parameters:

x	values or field names of center x coordinates
y	values or field names of center y coordinates
size	values or field names of sizes in screen units
marker	values or field names of marker types
color	set fill and line color

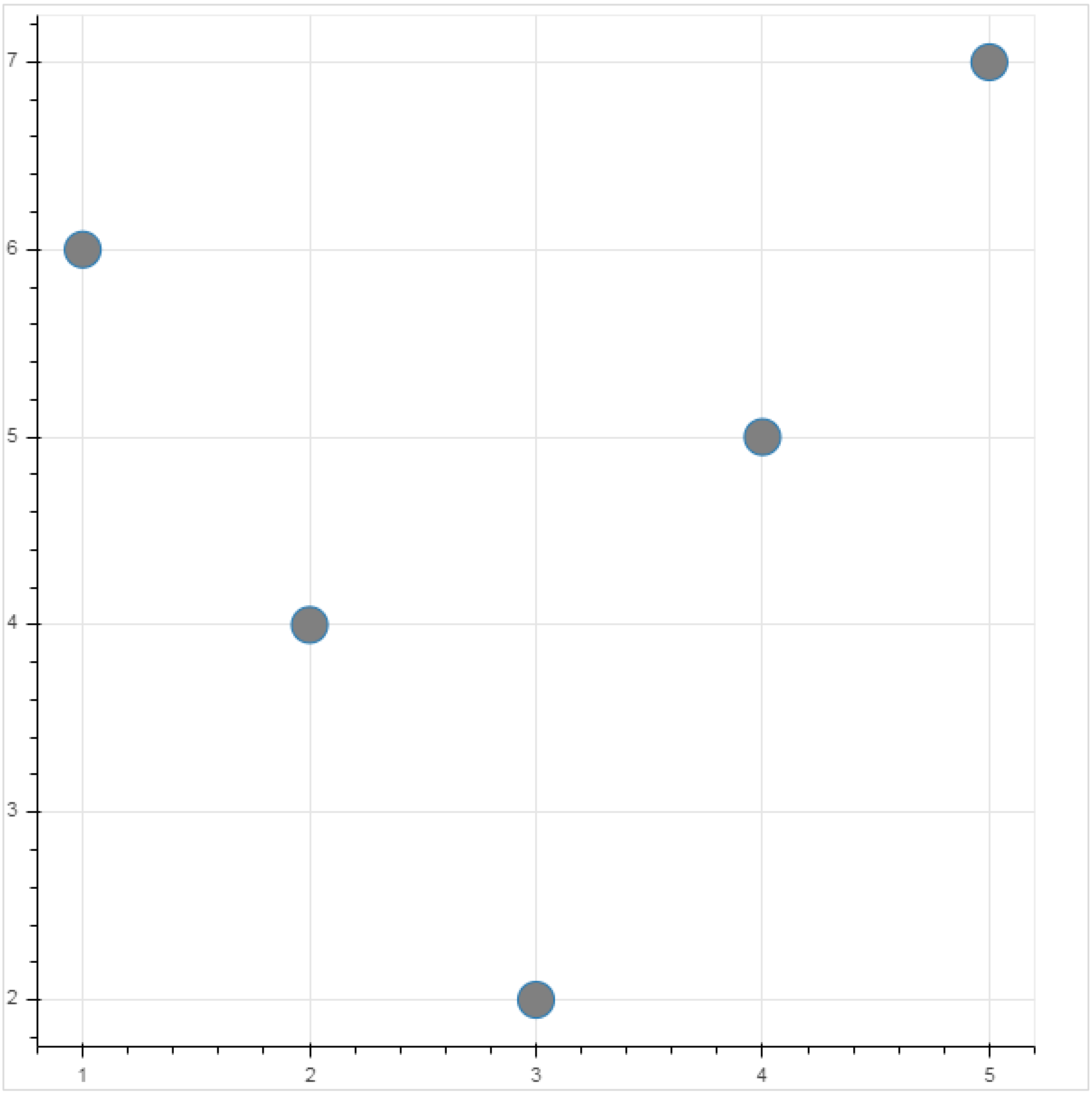
Following marker type constants are defined in Bokeh:

- Asterisk
- Circle
- CircleCross
- CircleX
- Cross
- Dash
- Diamond
- DiamondCross
- Hex
- InvertedTriangle
- Square
- SquareCross
- SquareX
- Triangle
- X

Following Python code generates scatter plot with circle marks.

```
from bokeh.plotting import figure, output_file, show
fig = figure()
fig.scatter([1, 4, 3, 2, 5], [6, 5, 2, 4, 7], marker="circle", size=20,
fill_color="grey")
output_file('scatter.html')
show(fig)
```

Output


7
6
5
4
3
2
1
2
3
4
5

7. Bokeh — Area Plots

Area plots are filled regions between two series that share a common index. Bokeh's Figure class has two methods as follows:

varea()

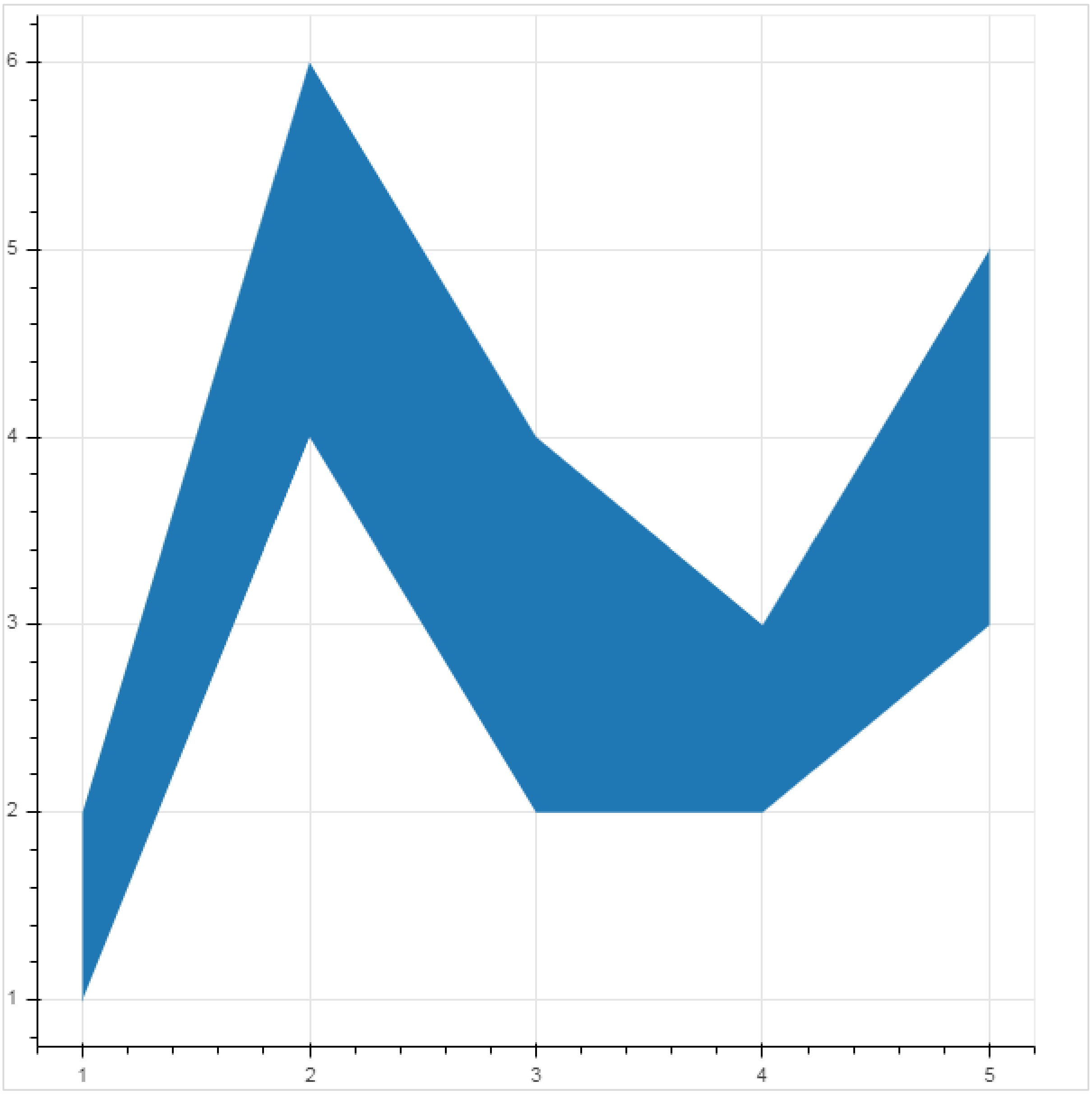
Output of the varea() method is a vertical directed area that has one x coordinate array, and two y coordinate arrays, y1 and y2, which will be filled between.

x	The x-coordinates for the points of the area.
y1	The y-coordinates for the points of one side of the area.
y2	The y-coordinates for the points of the other side of the area.

Example

```
from bokeh.plotting import figure, output_file, show
fig = figure()
x=[1, 2, 3, 4, 5]
y1=[2, 6, 4, 3, 5]
y2=[1, 4, 2, 2, 3]
fig.varea(x=x,y1=y1,y2=y2)
output_file('area.html')
show(fig)
```

Output



harea()

The harea() method on the other hand needs x1, x2 and y parameters.

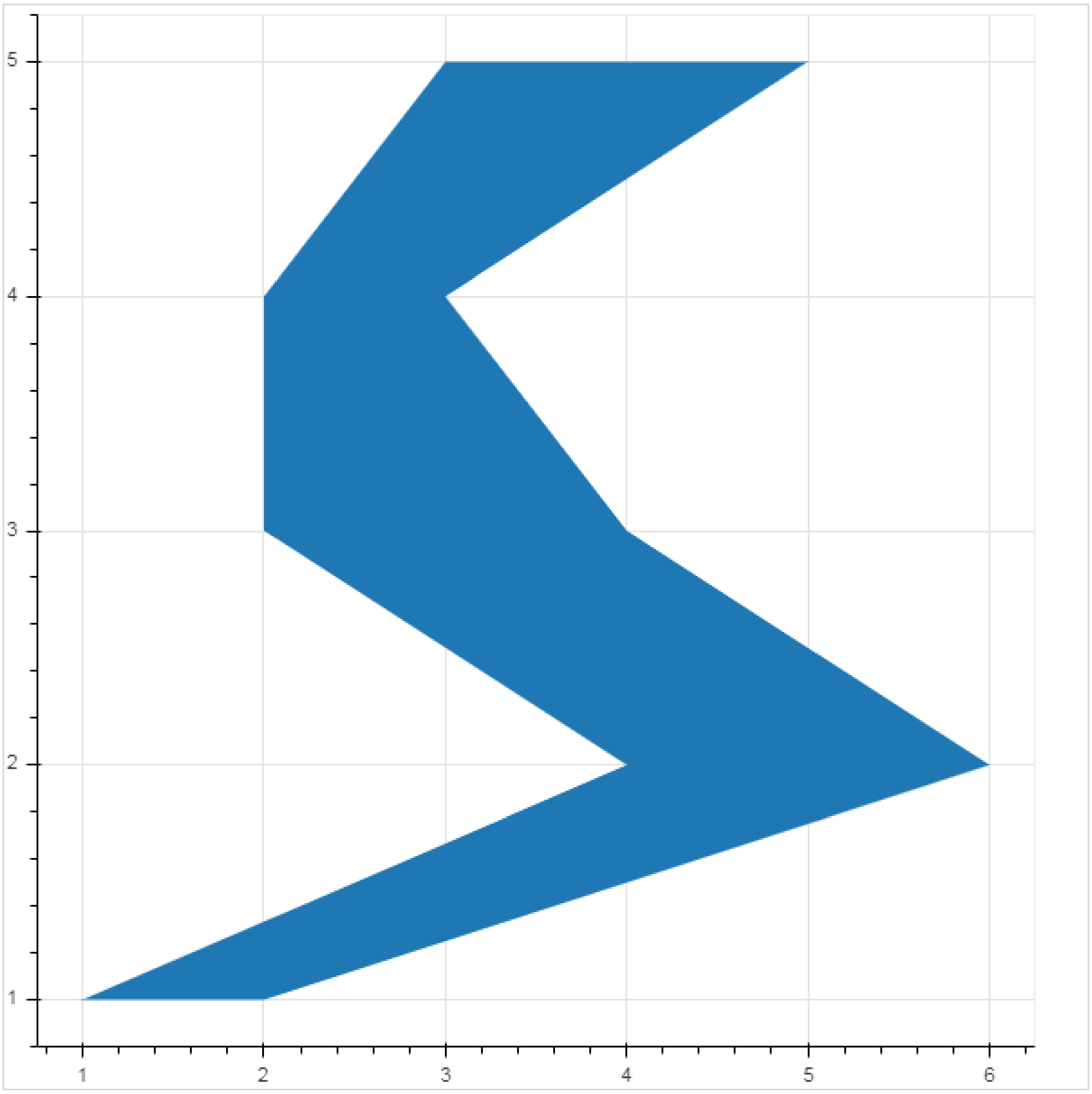
x1	The x-coordinates for the points of one side of the area.
x2	The x-coordinates for the points of the other side of the area.
y	The y-coordinates for the points of the area.

Example

```
from bokeh.plotting import figure, output_file, show
fig = figure()
y=[1, 2, 3, 4, 5]
```

```
x1=[2, 6, 4, 3, 5]
x2=[1, 4, 2, 2, 3]
fig.harea(x1=x1,x2=x2,y=y)
output_file('area.html')
show(fig)
```

Output



8. Bokeh — Circle Glyphs

The figure object has many methods using which vectorised glyphs of different shapes such as **circle, rectangle, polygon,** etc. can, be drawn.

Following methods are available for drawing **circle glyphs**:

circle()

The **circle()** method adds a circle glyph to the figure and needs **x** and **y** coordinates of its center. Additionally, it can be configured with the help of parameters such as **fill_color**, **line-color**, **line_width** etc.

circle_cross()

The circle_cross() method adds circle glyph with a **'+'** cross through the center.

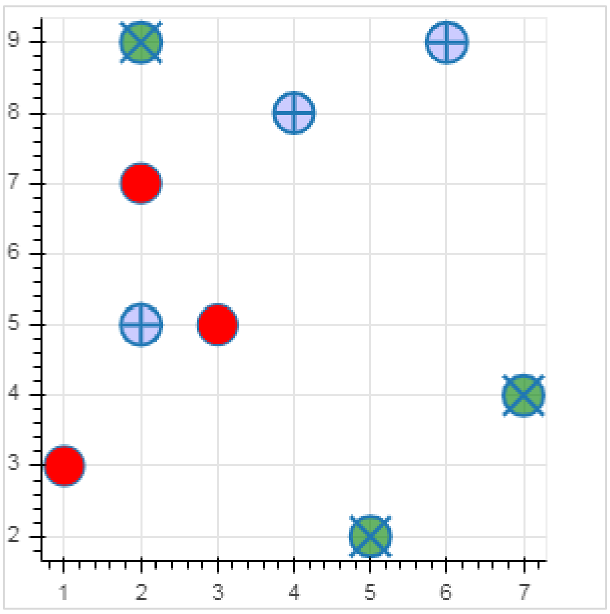
circle_x()

The circle_x() method adds circle with an 'X' cross through the center.

Following example shows use of various circle glyphs added to Bokeh figure:

```
from bokeh.plotting import figure, output_file, show


plot = figure(plot_width=300, plot_height=300)
plot.circle(x=[1, 2, 3], y=[3,7,5], size=20, fill_color='red')
plot.circle_cross(x=[2,4,6], y=[5,8,9], size=20,
fill_color='blue',fill_alpha=0.2, line_width=2)
plot.circle_x(x=[5,7,2], y=[2,4,9], size=20, fill_color='green',fill_alpha=0.6,
line_width=2)
show(plot)
```

Output


9
8
7
6
5
4
3
2
1
2
3
4
5
6
7

9. Bokeh — Rectangle, Oval and Polygon

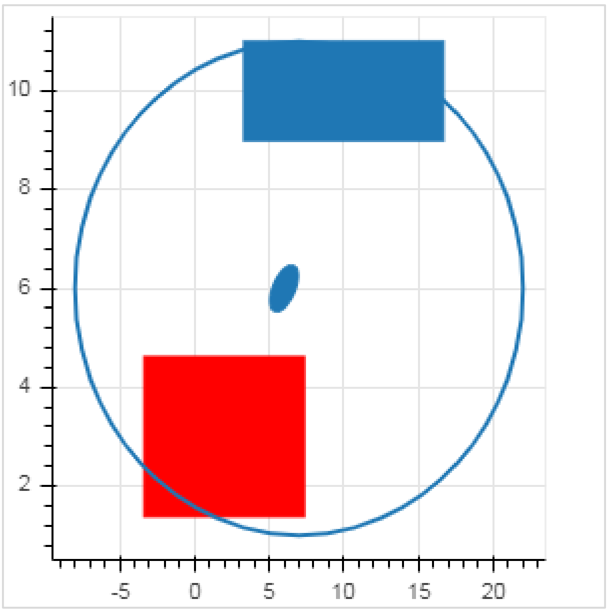
It is possible to render **rectangle, ellipse and polygons** in a Bokeh figure. The **rect() method** of Figure class adds a rectangle glyph based on x and y coordinates of center, width and height. The square() method on the other hand has size parameter to decide dimensions.

The ellipse() and oval() methods adds an ellipse and oval glyph. They use similar signature to that of rect() having x, y,w and h parameters. Additionally, angle parameter determines rotation from horizontal.

Following code shows use of different **shape glyph methods**:

```
from bokeh.plotting import figure, output_file, show


fig = figure(plot_width=300, plot_height=300)
fig.rect(x=10,y=10,width=100, height=50, width_units='screen',
height_units='screen')
fig.square(x=2,y=3,size=80, color='red')
fig.ellipse(x=7,y=6, width=30, height=10, fill_color=None, line_width=2)
fig.oval(x=6,y=6,width=2, height=1, angle=-0.4)
show(fig)
```

Output



10. Bokeh — Wedges and Arcs

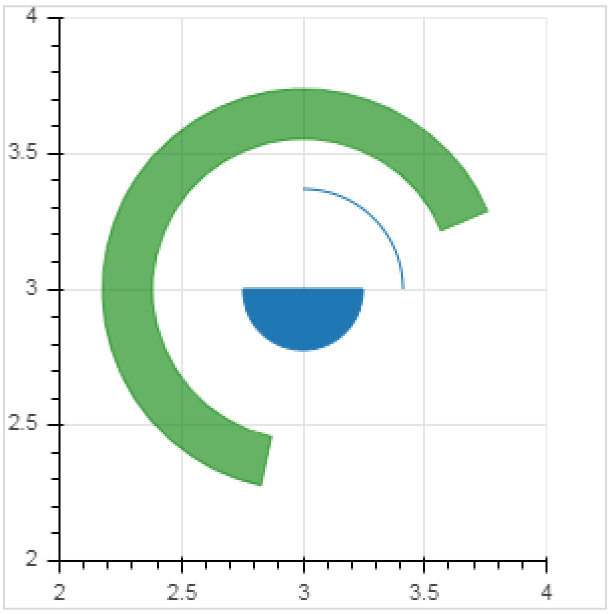
The **arc() method** draws a simple line arc based on x and y coordinates, start and end angles and radius. Angles are given in radians whereas radius may be in screen units or data units. The wedge is a filled arc.

The **wedge() method** has same properties as arc() method. Both methods have provision of optional direction property which may be clock or anticlock that determines the direction of arc/wedge rendering. The annular_wedge() function renders a filled area between to arcs of inner and outer radius.

Here is an example of **arc** and **wedge glyphs** added to Bokeh figure:

```
from bokeh.plotting import figure, output_file, show

import math

fig = figure(plot_width=300, plot_height=300)

fig.arc(x=3, y=3, radius=50, radius_units='screen', start_angle=0.0,
end_angle=math.pi/2)

fig.wedge(x=3, y=3, radius=30, radius_units='screen',

          start_angle=0, end_angle=math.pi, direction='clock')

fig.annular_wedge(x=3,y=3, inner_radius=100,
outer_radius=75,outer_radius_units='screen',

                  inner_radius_units='screen',start_angle=0.4,
end_angle=4.5,color="green", alpha=0.6)

show(fig)
```

Output


4
3.5
3
2.5
2
2
2.5
3
3.5
4

11. Bokeh — Specialized Curves

The **bokeh.plotting** API supports methods for rendering following specialised curves:

beizer()

This method adds a Bézier curve to the figure object. A Bézier curve is a parametric curve used in computer graphics. Other uses include the design of computer fonts and animation, user interface design and for smoothing cursor trajectory.

In vector graphics, Bézier curves are used to model smooth curves that can be scaled indefinitely. A "Path" is combination of linked Bézier curves.

The beizer() method has following parameters which are defined:

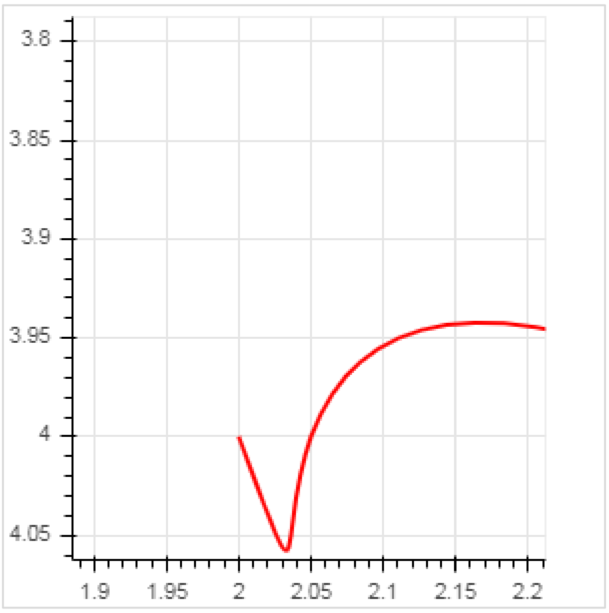
x0	The x-coordinates of the starting points.
y0	The y-coordinates of the starting points.
x1	The x-coordinates of the ending points.
y1	The y-coordinates of the ending points.
cx0	The x-coordinates of first control points.
cy0	The y-coordinates of first control points.
cx1	The x-coordinates of second control points.
cy1	The y-coordinates of second control points.

Default value for all parameters is None.

Following code generates a HTML page showing a Bézier curve and parabola in Bokeh plot:

```
x=2
y=4
xp02=x+0.4
xp01=x+0.1
xm01=x-0.1
yp01=y+0.2
ym01=y-0.2
fig=figure(plot_width=300, plot_height=300)
fig.bezier(x0=x, y0=y, x1=xp02, y1=y, cx0=xp01, cy0=yp01,
           cx1=xm01, cy1=ym01, line_color="red", line_width=2)
```

Output



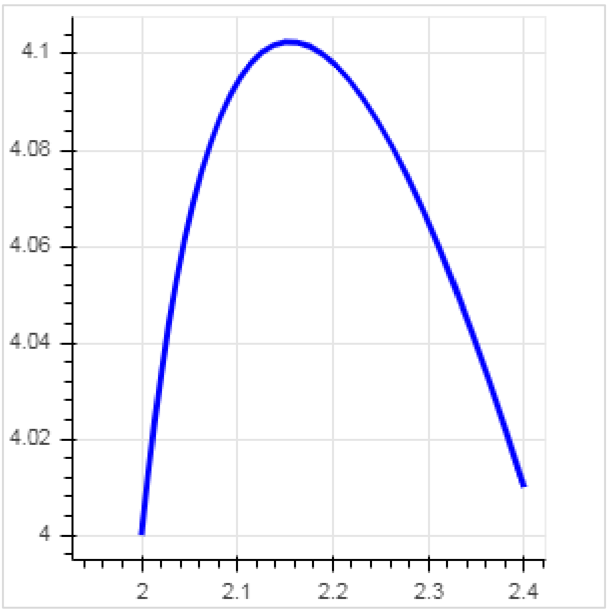
quadratic()

This method adds a **parabola glyph** to bokeh figure. The function has same parameters as beizer(), except **cx0** and **cx1**.

The code given below generates a quadratic curve.

```
x=2

y=4

xp02=x+0.3

xp01=x+0.2

xm01=x-0.4

yp01=y+0.1

ym01=y-0.2

        x=x,

        y=y,

        xp02=x+0.4,

        xp01=x+0.1,

        yp01=y+0.2,

fig.quadratic(x0=x, y0=y, x1=x+0.4, y1=y+0.01, cx=x+0.1,

           cy=y+0.2, line_color="blue", line_width=3)
```

Output


4.1
4.08
4.06
4.04
4.02
4
2
2.1
2.2
2.3
2.4

12. Bokeh — Setting Ranges

Numeric ranges of data axes of a plot are automatically set by Bokeh taking into consideration the dataset under process. However, sometimes you may want to define the range of values on x and y axis explicitly. This is done by assigning x_range and y_range properties to a figure() function.

These ranges are defined with the help of range1d() function.

Example

```
xrange=range1d(0,10)
```

To use this range object as x_range property, use the below code:

```
fig=figure(x,y,x_range=xrange)
```

13. Bokeh — Axes

In this chapter, we shall discuss about various types of axes.

Axes	**Description**
Categorical Axes	The bokeh plots show numerical data along both x and y axes. In order to use categorical data along either of axes, we need to specify a FactorRange to specify categorical dimensions for one of them.
Log Scale Axes	If there exists a power law relationship between x and y data series, it is desirable to use log scales on both axes.
Twin Axes	It may be needed to show multiple axes representing varying ranges on a single plot figure. The figure object can be so configured by defining **extra_x_range** and **extra_y_range** properties

Categorical Axes

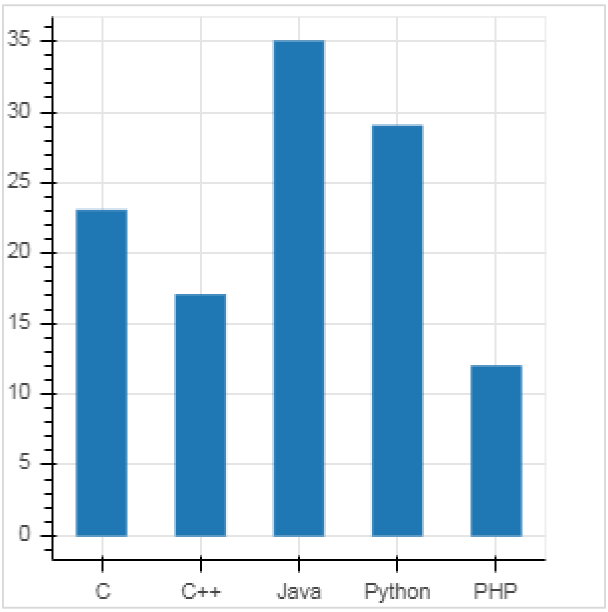
In the examples so far, the Bokeh plots show numerical data along both x and y axes. In order to use categorical data along either of axes, we need to specify a FactorRange to specify categorical dimensions for one of them. For example, to use strings in the given list for x axis:

```
langs=['C', 'C++', 'Java', 'Python', 'PHP']
fig=figure(x_range=langs, plot_width=300, plot_height=300)
```

With following example, a simple bar plot is displayed showing number of students enrolled for various courses offered.

```
from bokeh.plotting import figure, output_file, show
langs=['C', 'C++', 'Java', 'Python', 'PHP']
students=[23,17,35,29,12]
fig=figure(x_range=langs, plot_width=300, plot_height=300)
fig.vbar(x=langs, top=students, width=0.5)
show(fig)
```

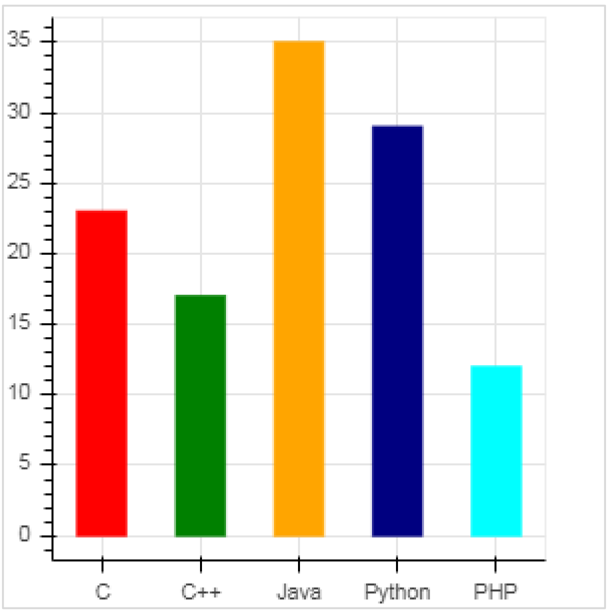
Output



To show each bar in different colour, set color property of vbar() function to list of color values.

```
cols=['red','green','orange','navy', 'cyan']
fig.vbar(x=langs, top=students, color=cols,width=0.5)
```

Output

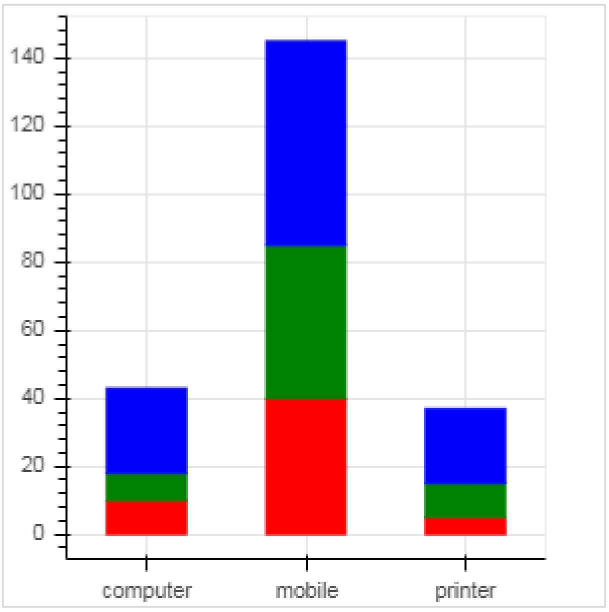


To render a vertical (or horizontal) stacked bar using vbar_stack() or hbar_stack() function, set stackers property to list of fields to stack successively and source property to a dict object containing values corresponding to each field.

In following example, sales is a dictionary showing sales figures of three products in three months.

```
from bokeh.plotting import figure, output_file, show
products=['computer','mobile','printer']
months=['Jan','Feb','Mar']
sales={'products':products,
       'Jan':[10,40,5],
       'Feb':[8,45,10],
       'Mar':[25,60,22]}
cols=['red','green','blue']#,'navy', 'cyan']
fig=figure(x_range=products, plot_width=300, plot_height=300)
fig.vbar_stack(months, x='products', source=sales, color=cols,width=0.5)
show(fig)
```

Output



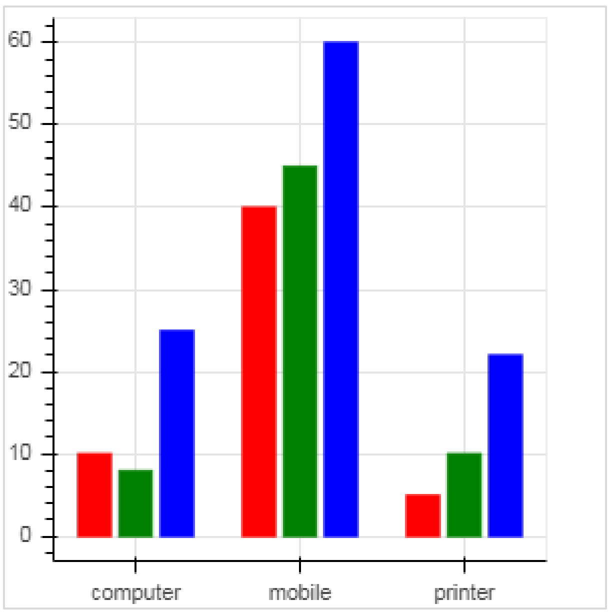
A grouped bar plot is obtained by specifying a visual displacement for the bars with the help of dodge() function in **bokeh.transform** module.

The **dodge() function** introduces a relative offset for each bar plot thereby achieving a visual impression of group. In following example, **vbar() glyph** is separated by an offset of 0.25 for each group of bars for a particular month.

```
from bokeh.plotting import figure, output_file, show
from bokeh.transform import dodge


products=['computer','mobile','printer']
```

```
months=['Jan','Feb','Mar']
sales={'products':products,
       'Jan':[10,40,5],
       'Feb':[8,45,10],
       'Mar':[25,60,22]}
fig=figure(x_range=products, plot_width=300, plot_height=300)
fig.vbar(x=dodge('products', -0.25, range=fig.x_range), top='Jan',
         width=0.2,source=sales, color="red")

fig.vbar(x=dodge('products',  0.0,  range=fig.x_range), top='Feb',
         width=0.2, source=sales,color="green")

fig.vbar(x=dodge('products',  0.25, range=fig.x_range), top='Mar',
         width=0.2,source=sales,color="blue")

show(fig)
```

Output



Log Scale Axes

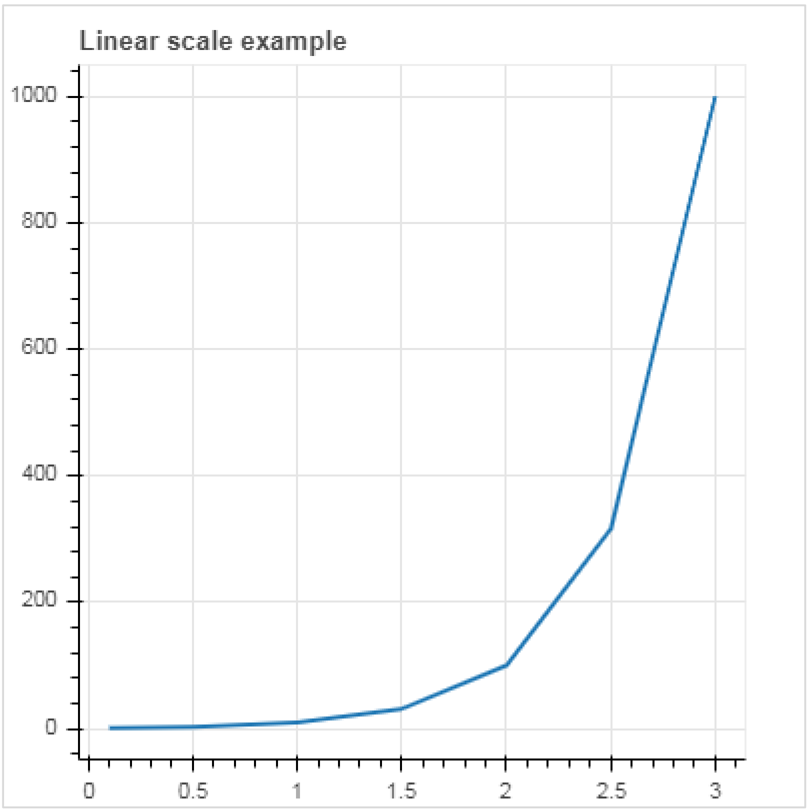
When values on one of the axes of a plot grow exponentially with linearly increasing values of another, it is often necessary to have the data on former axis be displayed on a log scale. For example, if there exists a power law relationship between x and y data series, it is desirable to use log scales on both axes.

Bokeh.plotting API's figure() function accepts x_axis_type and y_axis_type as arguments which may be specified as log axis by passing "log" for the value of either of these parameters.

First figure shows plot between x and 10^x on a linear scale. In second figure y_axis_type is set to 'log'

```
from bokeh.plotting import figure, output_file, show
x = [0.1, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0]
y = [10**i for i in x]
fig = figure(title='Linear scale example',plot_width=400, plot_height=400)
fig.line(x, y, line_width=2)
show(fig)
```

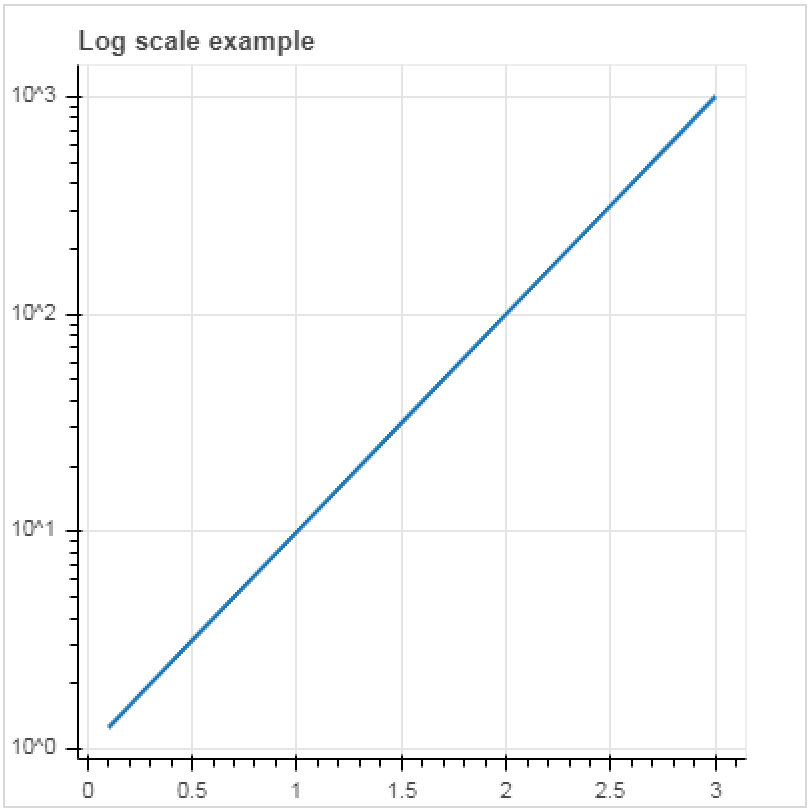
Output



Now change figure() function to configure y_axis_type='log'

```
fig=figure(title='Linear scale example',plot_width=400, plot_height=400,
y_axis_type="log")
```

Output



Twin Axes

In certain situations, it may be needed to show multiple axes representing varying ranges on a single plot figure. The figure object can be so configured by defining **extra_x_range** and **extra_y_range** properties. While adding new glyph to the figure, these named ranges are used.

We try to display a sine curve and a straight line in same plot. Both glyphs have y axes with different ranges. The x and y data series for sine curve and line are obtained by the following:

```
from numpy import pi, arange, sin, linspace

x = arange(-2*pi, 2*pi, 0.1)

y = sin(x)

y2 = linspace(0, 100, len(y))
```

Here, plot between x and y represents sine relation and plot between x and y2 is a straight line. The Figure object is defined with explicit y_range and a line glyph representing sine curve is added as follows:

```
fig = figure(title='Twin Axis Example', y_range=(-1.1, 1.1))

fig.line(x, y, color="red")
```

We need an extra y range. It is defined as:

```
fig.extra_y_ranges = {"y2": Range1d(start=0, end=100)}
```

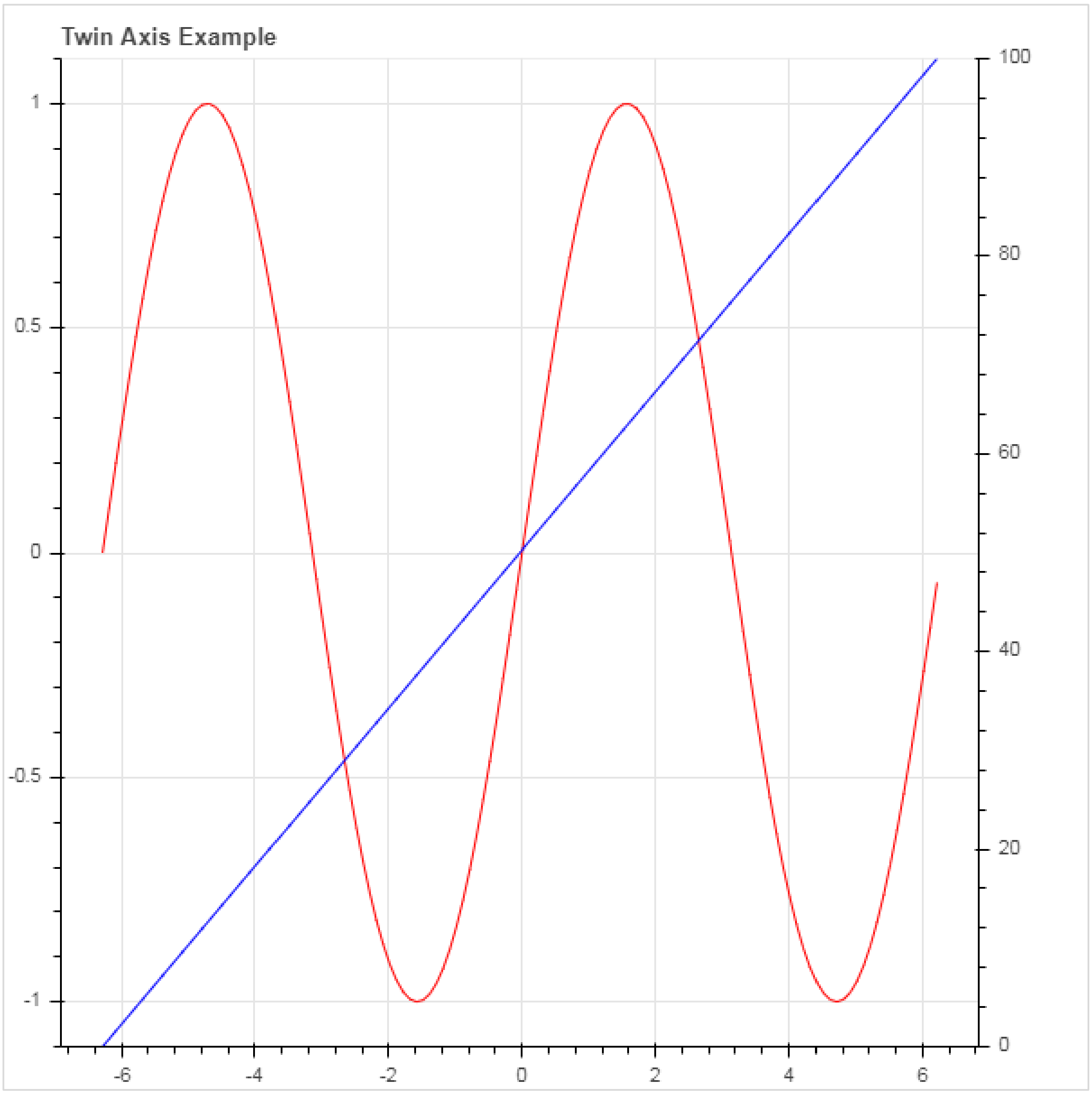
To add additional y axis on right side, use add_layout() method. Add a new line glyph representing x and y2 to the figure.

```
fig.add_layout(LinearAxis(y_range_name="y2"), 'right')
fig.line(x, y2, color="blue", y_range_name="y2")
```

This will result in a plot with twin y axes. Complete code and the output is as follows:

```
from numpy import pi, arange, sin, linspace
x = arange(-2*pi, 2*pi, 0.1)
y = sin(x)
y2 = linspace(0, 100, len(y))

from bokeh.plotting import output_file, figure, show
from bokeh.models import LinearAxis, Range1d
fig = figure(title='Twin Axis Example', y_range=(-1.1, 1.1))
fig.line(x, y, color="red")
fig.extra_y_ranges = {"y2": Range1d(start=0, end=100)}
fig.add_layout(LinearAxis(y_range_name="y2"), 'right')
fig.line(x, y2, color="blue", y_range_name="y2")

show(fig)
```

Output


Twin Axis Example
1
0.5
0
-0.5
-1
100
80
60
40
20
0
-6
-4
-2
0
2
4
6

14. Bokeh — Annotations and Legends

Annotations are pieces of explanatory text added to the diagram. Bokeh plot can be annotated by way of specifying plot title, labels for x and y axes as well as inserting text labels anywhere in the plot area.

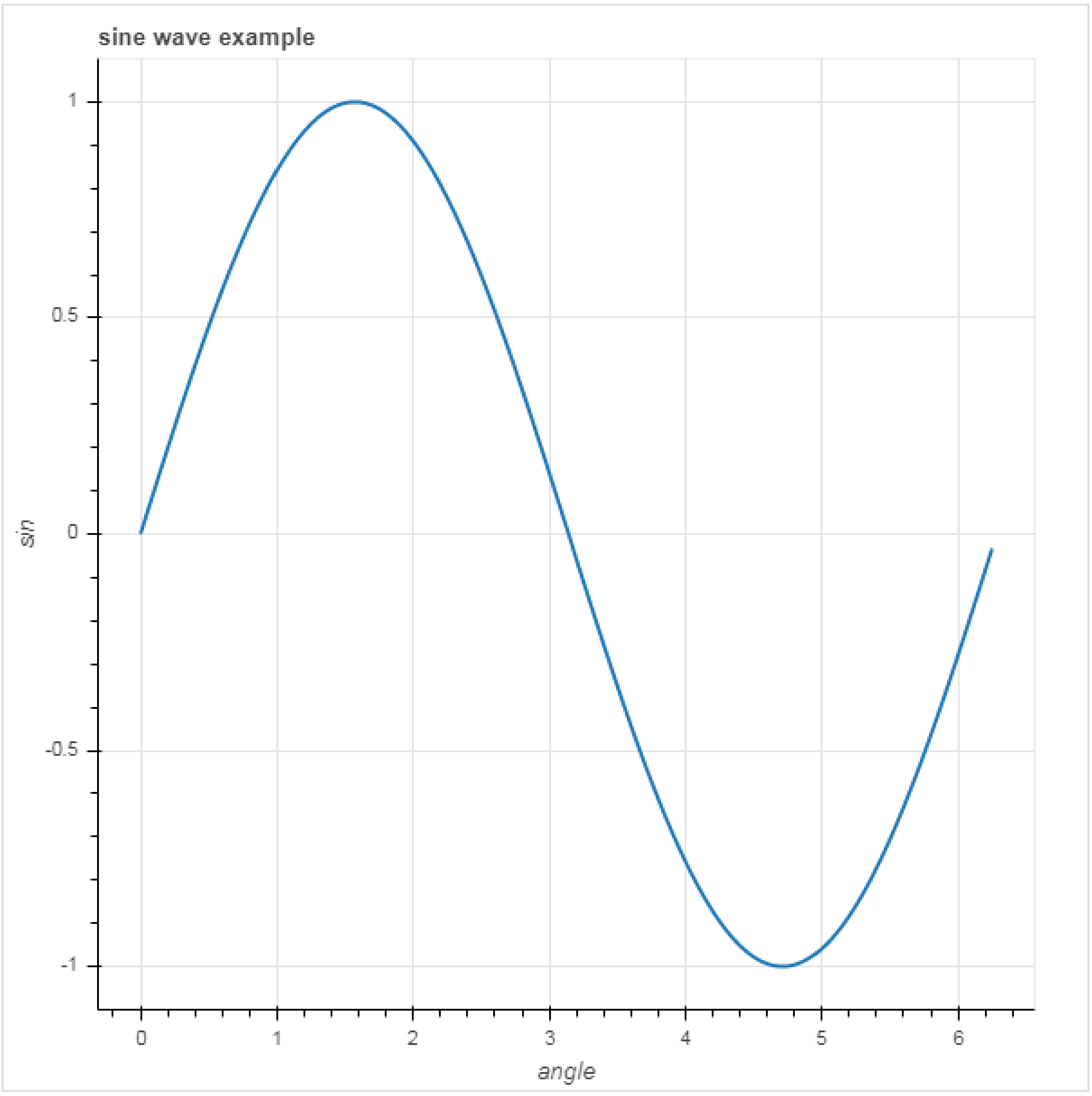
Plot title as well as x and y axis labels can be provided in the Figure constructor itself.

```
fig=figure(title, x_axis_label, y_axis_label)
```

In the following plot, these properties are set as shown below:

```
from bokeh.plotting import figure, output_file, show

import numpy as np

import math

x=np.arange(0, math.pi*2, 0.05)

y=np.sin(x)

fig = figure(title="sine wave example", x_axis_label='angle',
y_axis_label='sin')

fig.line(x, y,line_width=2)

show(p)
```

Output



The title’s text and axis labels can also be specified by assigning appropriate string values to corresponding properties of figure object.

```
fig.title.text="sine wave example"
fig.xaxis.axis_label='angle'
fig.yaxis.axis_label='sin'
```

It is also possible to specify location, alignment, font and color of title.

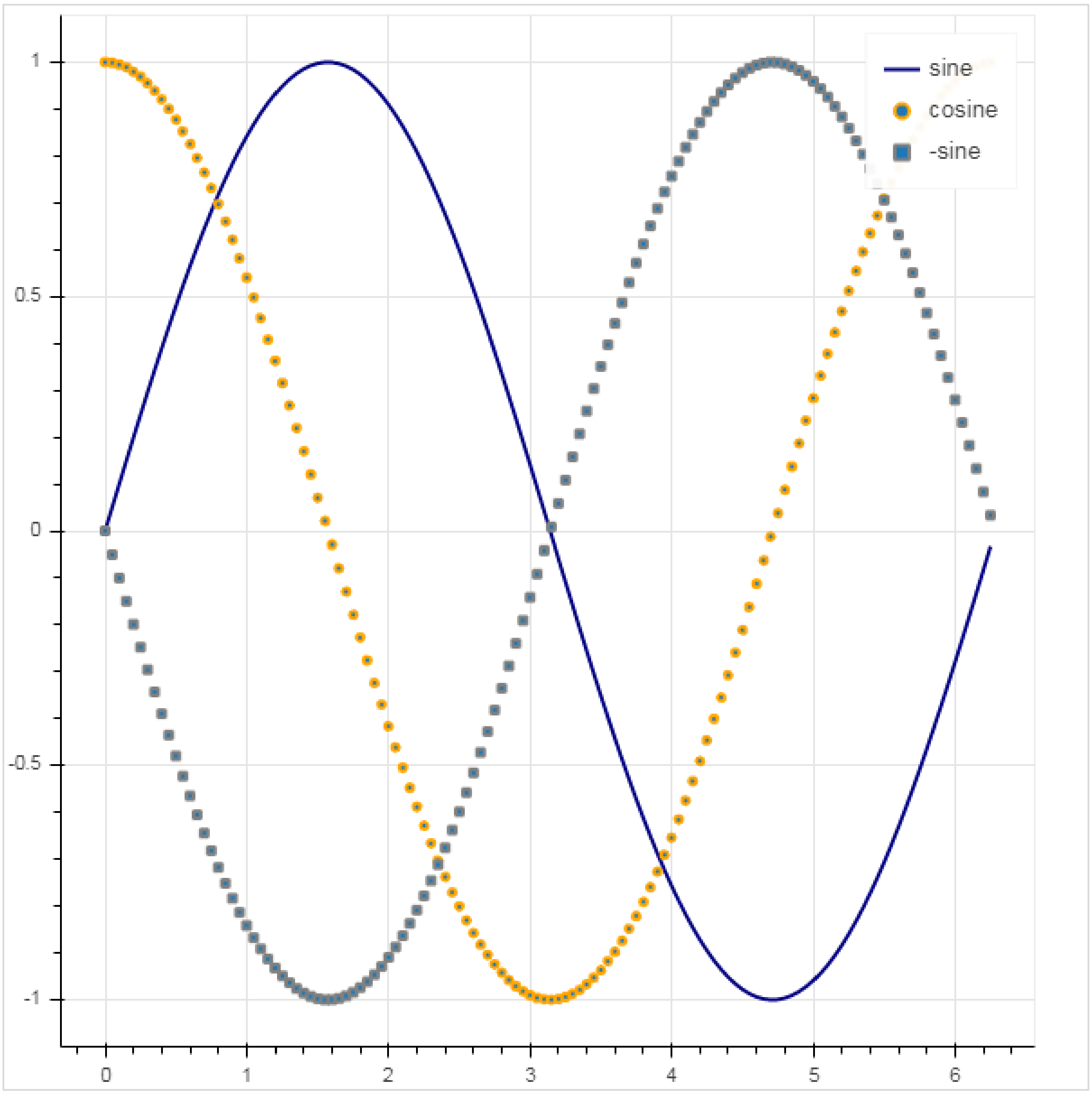
```
fig.title.align = "right"
fig.title.text_color = "orange"
fig.title.text_font_size = "25px"
fig.title.background_fill_color = "blue"
```

Adding legends to the plot figure is very easy. We have to use legend property of any glyph method.

Below we have three glyph curves in the plot with three different legends:

```
from bokeh.plotting import figure, output_file, show
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
fig=figure()
fig.line(x, np.sin(x),line_width=2, line_color='navy', legend='sine')
fig.circle(x,np.cos(x), line_width=2, line_color='orange', legend='cosine')
fig.square(x,-np.sin(x),line_width=2, line_color='grey', legend='-sine')

show(fig)
```

Output



sine
cosine
-sine
1
0.5
0
-0.5
-1
0
1
2
3
4
5
6

15. Bokeh — Pandas

In all the examples above, the data to be plotted has been provided in the form of Python lists or numpy arrays. It is also possible to provide the data source in the form of pandas DataFrame object.

DataFrame is a two-dimensional data structure. Columns in the dataframe can be of different data types. The Pandas library has functions to create dataframe from various sources such as CSV file, Excel worksheet, SQL table, etc.

For the purpose of following example, we are using a CSV file consisting of two columns representing a number x and 10^x. The test.csv file is as below:

```
x,pow
0.0,1.0
0.5263157894736842,3.3598182862837818
1.0526315789473684,11.28837891684689
1.5789473684210527,37.926901907322495
2.1052631578947367,127.42749857031335
2.631578947368421,428.1332398719391
3.1578947368421053,1438.449888287663
3.6842105263157894,4832.930238571752
4.2105263157894735,16237.76739188721
4.7368421052631575,54555.947811685146
```

We shall read this file in a dataframe object using read_csv() function in pandas.

```
import pandas as pd
df=pd.read_csv('test.csv')
print (df)
```

The dataframe appears as below:

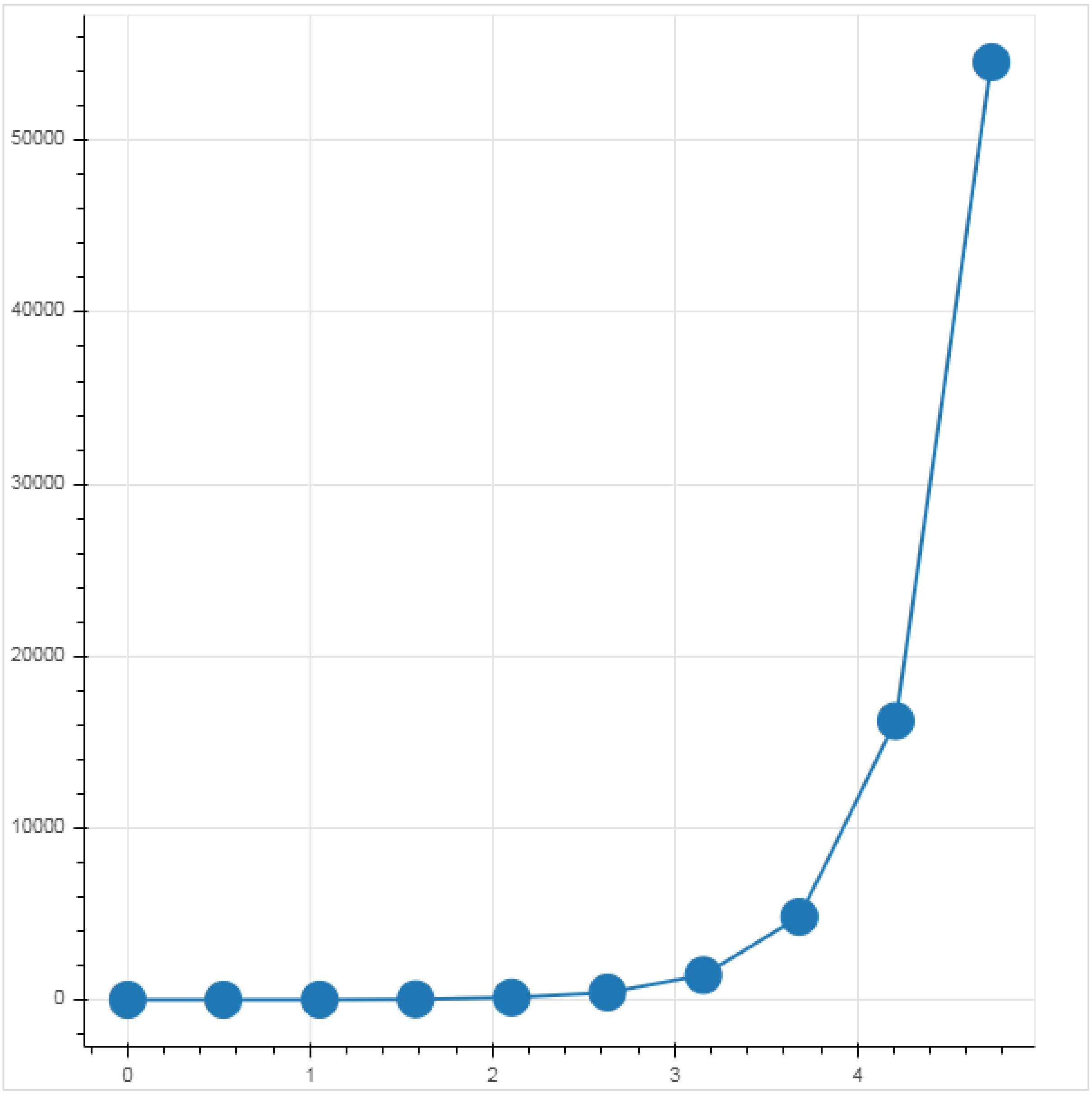
```
x           pow
0  0.000000      1.000000
1  0.526316      3.359818
2  1.052632     11.288379
3  1.578947     37.926902
```

```
4   2.105263    127.427499
5   2.631579    428.133240
6   3.157895   1438.449888
7   3.684211   4832.930239
8   4.210526  16237.767392
9   4.736842  54555.947812
```

The ‘x’ and ‘pow’ columns are used as data series for line glyph in bokeh plot figure.

```
from bokeh.plotting import figure, output_file, show
p = figure()
x=df['x']
y=df['pow']
p.line(x,y,line_width=2)
p.circle(x, y,size=20)
show(p)
```

Output


50000
40000
30000
20000
10000
0
0
1
2
3
4

16. Bokeh — ColumnDataSource

Most of the plotting methods in Bokeh API are able to receive data source parameters through ColumnDatasource object. It makes sharing data between plots and 'DataTables'.

A ColumnDatasource can be considered as a mapping between column name and list of data. A Python dict object with one or more string keys and lists or numpy arrays as values is passed to ColumnDataSource constructor.

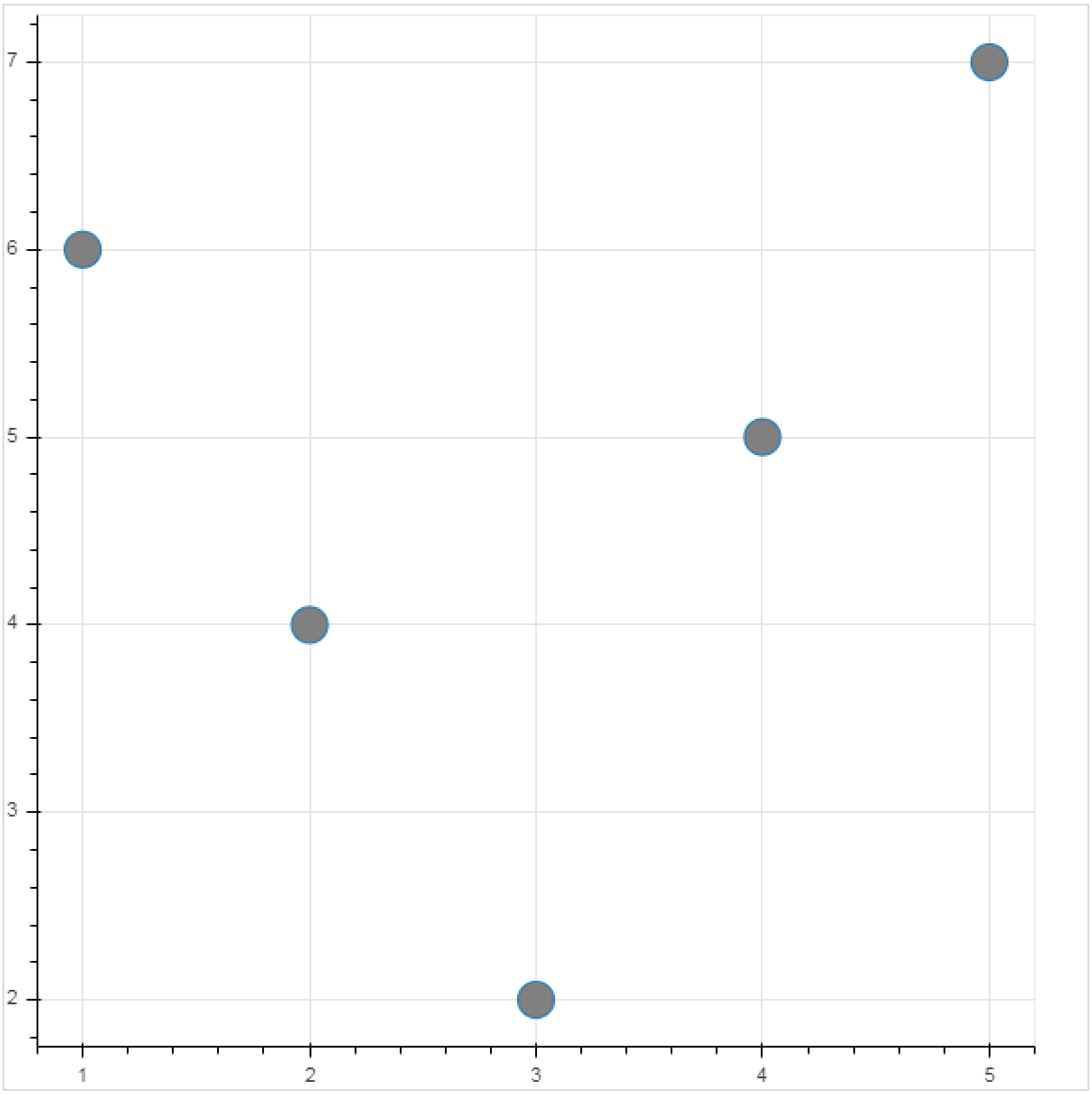
Below is the example:

```
from bokeh.models import ColumnDataSource
data={'x':[1, 4, 3, 2, 5],
      'y':[6, 5, 2, 4, 7]}
cds=ColumnDataSource(data=data)
```

This object is then used as value of source property in a glyph method. Following code generates a scatter plot using ColumnDataSource.

```
from bokeh.plotting import figure, output_file, show
from bokeh.models import ColumnDataSource
data={'x':[1, 4, 3, 2, 5],
      'y':[6, 5, 2, 4, 7]}
cds=ColumnDataSource(data=data)
fig = figure()
fig.scatter(x='x', y='y',source=cds, marker="circle", size=20,
fill_color="grey")
show(fig)
```

Output

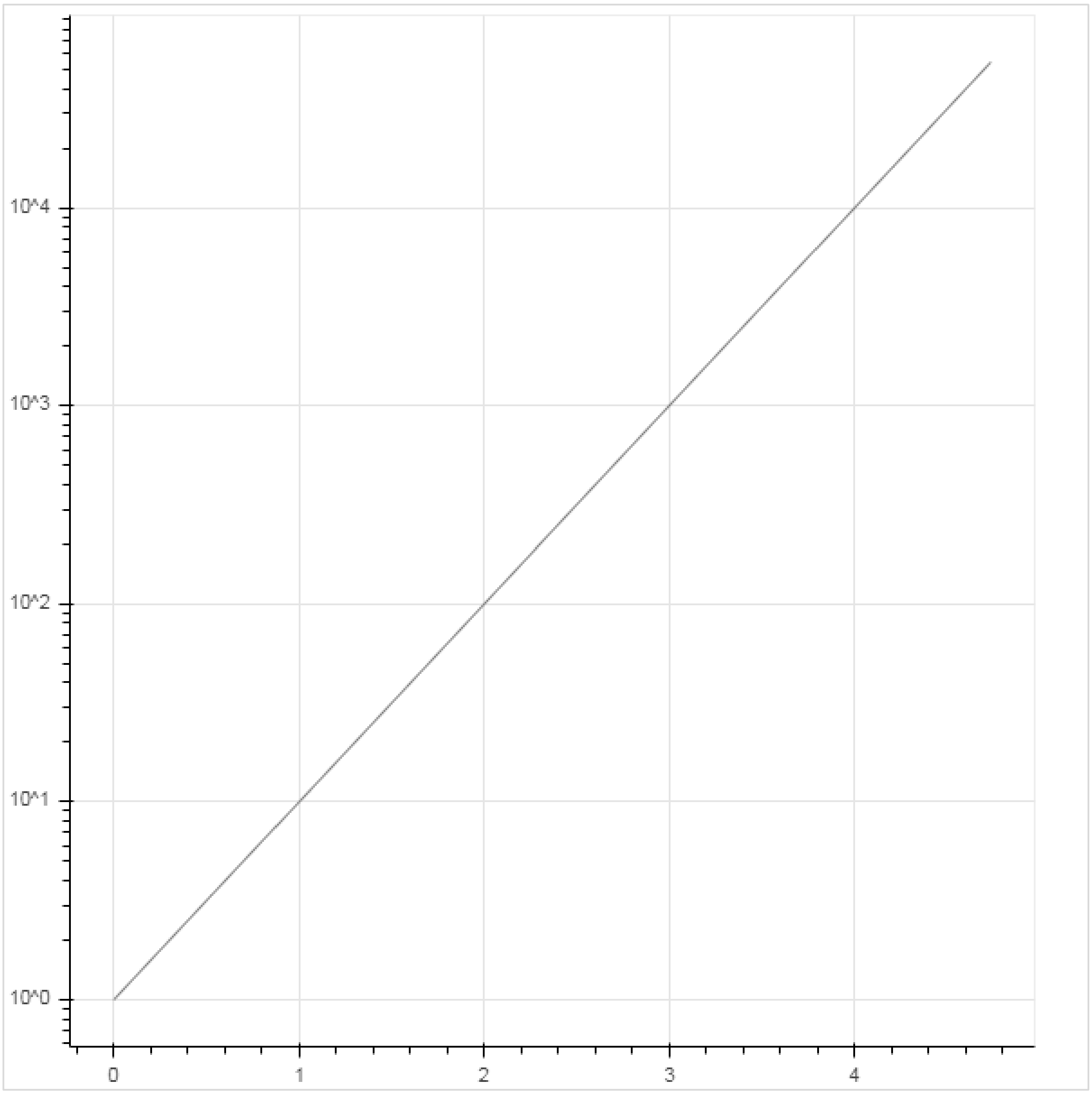


Instead of assigning a Python dictionary to **ColumnDataSource**, we can use a Pandas DataFrame for it.

Let us use 'test.csv' (used earlier in this section) to obtain a DataFrame and use it for getting ColumnDataSource and rendering line plot.

```
from bokeh.plotting import figure, output_file, show
import pandas as pd
from bokeh.models import ColumnDataSource
df=pd.read_csv('test.csv')
cds=ColumnDataSource(df)
fig = figure(y_axis_type='log')
fig.line(x='x', y='pow',source=cds,  line_color="grey")
show(fig)
```

Output



17. Bokeh — Filtering Data

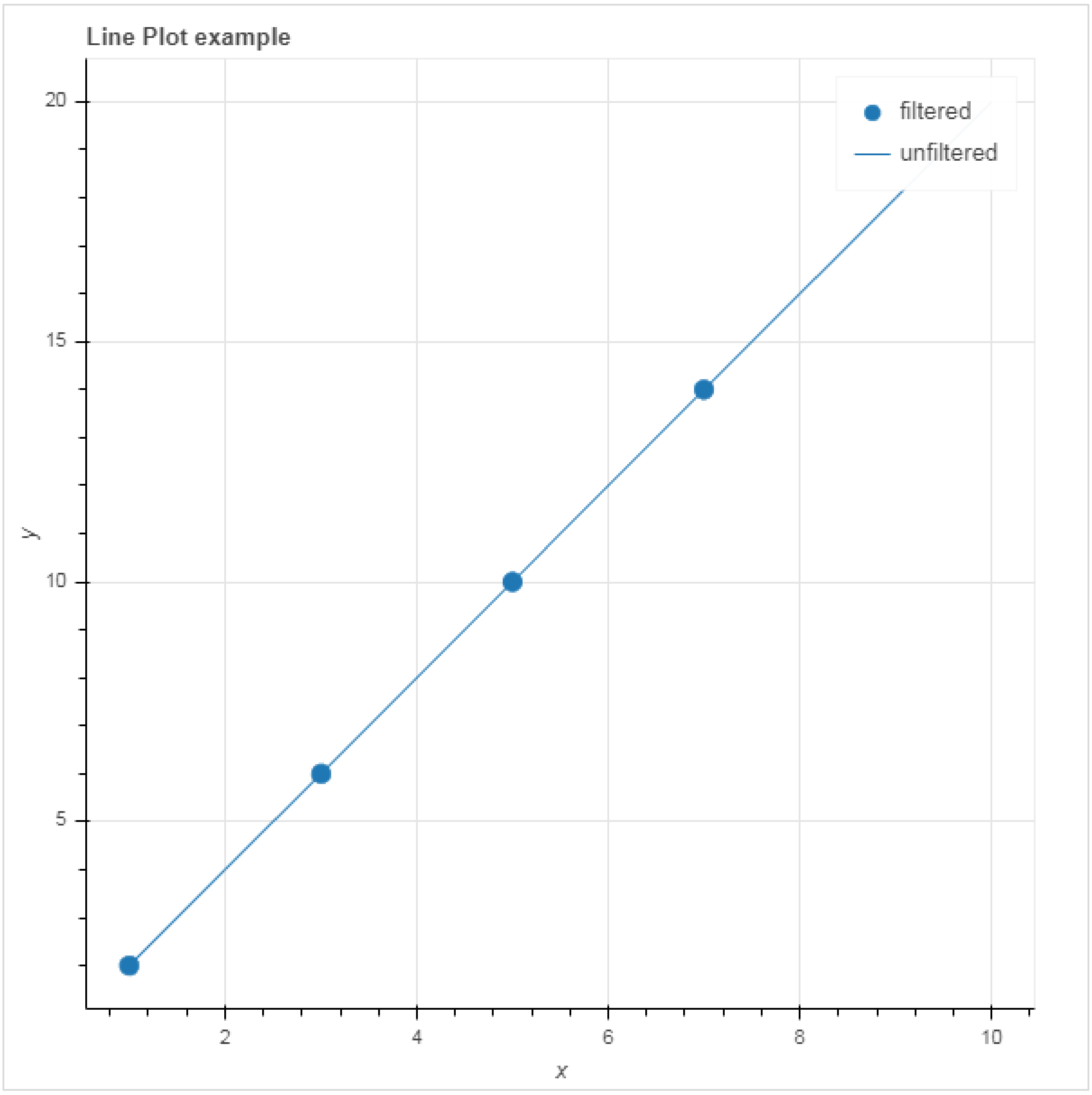
Often, you may want to obtain a plot pertaining to a part of data that satisfies certain conditions instead of the entire dataset. Object of the CDSView class defined in bokeh.models module returns a subset of ColumnDatasource under consideration by applying one or more filters over it.

IndexFilter is the simplest type of filter. You have to specify indices of only those rows from the dataset that you want to use while plotting the figure.

Following example demonstrates use of IndexFilter to set up a CDSView. The resultant figure shows a line glyph between x and y data series of the ColumnDataSource. A view object is obtained by applying index filter over it. The view is used to plot circle glyph as a result of IndexFilter.

```
from bokeh.models import ColumnDataSource, CDSView, IndexFilter

from bokeh.plotting import figure, output_file, show


source = ColumnDataSource(data=dict(x=list(range(1,11)),
y=list(range(2,22,2))))

view = CDSView(source=source, filters=[IndexFilter([0, 2, 4,6])])

fig=figure(title='Line Plot example', x_axis_label='x', y_axis_label='y')

fig.circle(x="x", y="y", size=10,  source=source, view=view, legend='filtered')

fig.line(source.data['x'],source.data['y'], legend='unfiltered')

show(fig)
```

Output



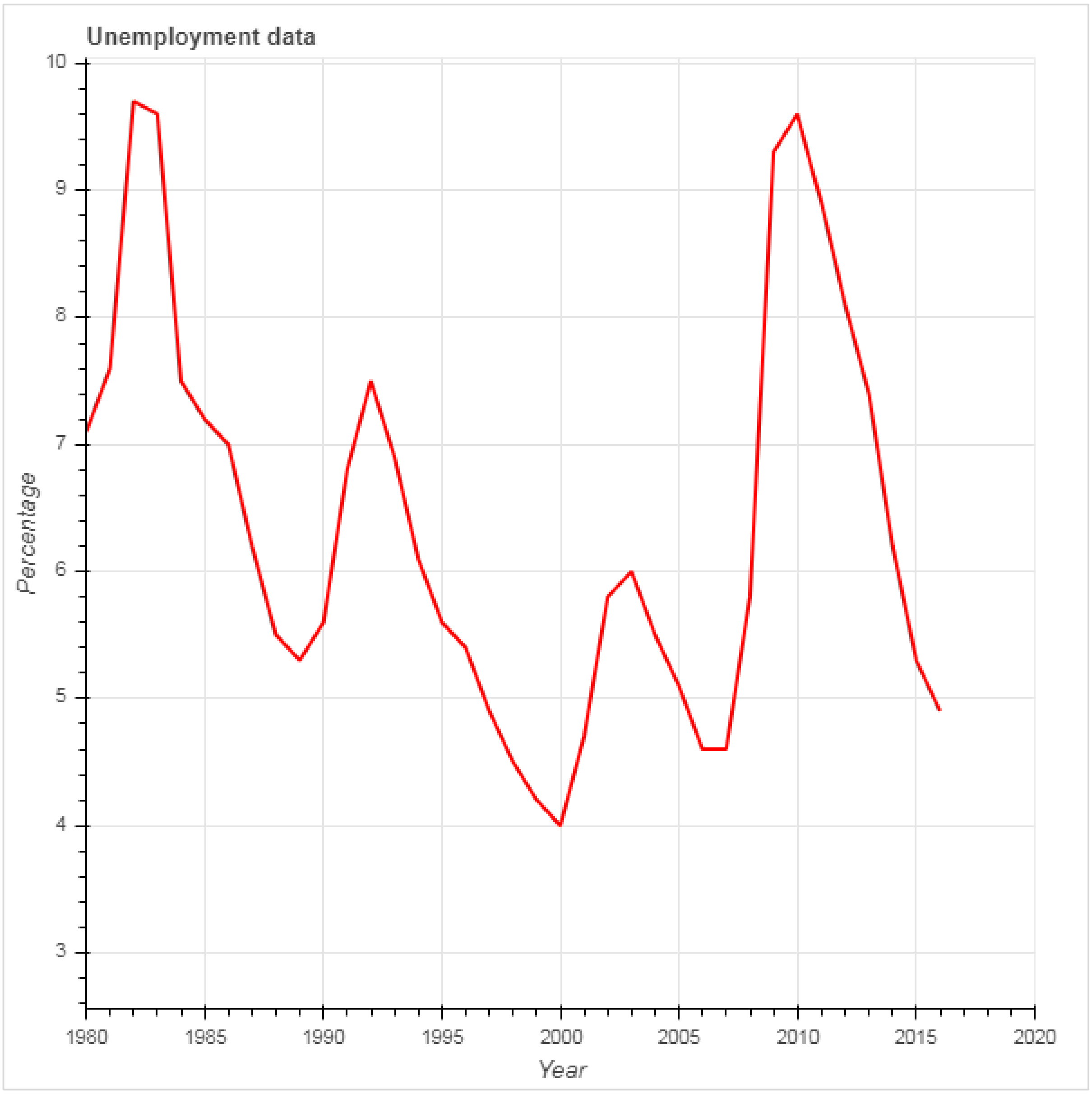
To choose only those rows from the data source, that satisfy a certain Boolean condition, apply a BooleanFilter.

A typical Bokeh installation consists of a number of sample data sets in sampledata directory. For following example, we use **unemployment1948** dataset provided in the form of unemployment1948.csv. It stores year wise percentage of unemployment in USA since 1948. We want to generate a plot only for year 1980 onwards. For that purpose, a CDSView object is obtained by applying BooleanFilter over the given data source.

```
from bokeh.models import ColumnDataSource, CDSView, BooleanFilter
from bokeh.plotting import figure, show
from bokeh.sampledata.unemployment1948 import data
source = ColumnDataSource(data)
booleans = [True if int(year) >= 1980 else False for year in
source.data['Year']]
```

```
print (booleans)
view1 = CDSView(source=source, filters=[BooleanFilter(booleans)])
p = figure(title="Unemployment data", x_range=(1980,2020), x_axis_label='Year',
y_axis_label='Percentage')
p.line(x='Year', y='Annual', source=source, view=view1, color='red',
line_width=2)
show(p)
```

Output



To add more flexibility in applying filter, Bokeh provides a CustomJSFilter class with the help of which the data source can be filtered with a user defined JavaScript function.

The example given below uses the same USA unemployment data. Defining a CustomJSFilter to plot unemployment figures of year 1980 and after.

```
from bokeh.models import ColumnDataSource, CDSView, CustomJSFilter
from bokeh.plotting import figure, show
from bokeh.sampledata.unemployment1948 import data
source = ColumnDataSource(data)
custom_filter = CustomJSFilter(code='''
var indices = [];

for (var i = 0; i < source.get_length(); i++){
    if (parseInt(source.data['Year'][i]) >= 1980){
        indices.push(true);
    } else {
        indices.push(false);
    }
}
return indices;
''')
view1 = CDSView(source=source, filters=[custom_filter])

p = figure(title="Unemployment data", x_range=(1980,2020), x_axis_label='Year',
y_axis_label='Percentage')
p.line(x='Year', y='Annual', source=source, view=view1, color='red',
line_width=2)
show(p)
```

18. Bokeh — Layouts

Bokeh visualizations can be suitably arranged in different layout options. These layouts as well as sizing modes result in plots and widgets resizing automatically as per the size of browser window. For consistent appearance, all items in a layout must have same sizing mode. The widgets (buttons, menus, etc.) are kept in a separate widget box and not in plot figure.

First type of layout is Column layout which displays plot figures vertically. The **column() function** is defined in **bokeh.layouts** module and takes following signature:

```
from bokeh.layouts import column
col=column(children, sizing_mode)
```

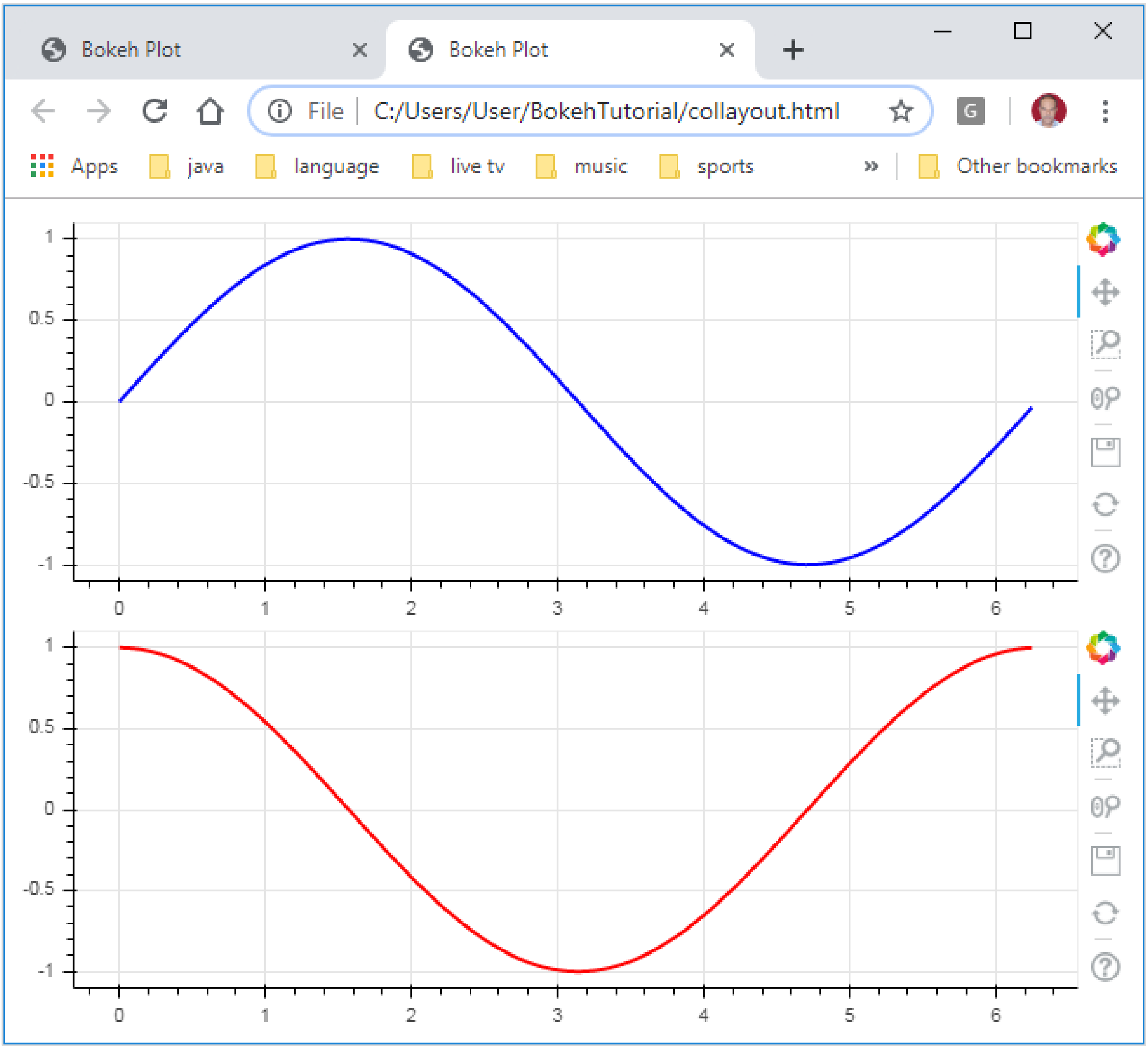
children: List of plots and/or widgets.

sizing_mode: determines how items in the layout resize. Possible values are "fixed", "stretch_both", "scale_width", "scale_height", "scale_both". Default is “fixed”.

Following code produces two Bokeh figures and places them in a column layout so that they are displayed vertically. Line glyphs representing sine and cos relationship between x and y data series is displayed in Each figure.

```
from bokeh.plotting import figure, output_file, show
from bokeh.layouts import column
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
y1=np.sin(x)
y2=np.cos(x)
fig1 = figure(plot_width=200, plot_height=200)
fig1.line(x, y1,line_width=2, line_color='blue')
fig2 = figure(plot_width=200, plot_height=200)
fig2.line(x, y2,line_width=2, line_color='red')
c=column(children=[fig1, fig2], sizing_mode='stretch_both')
show(c)
```

Output



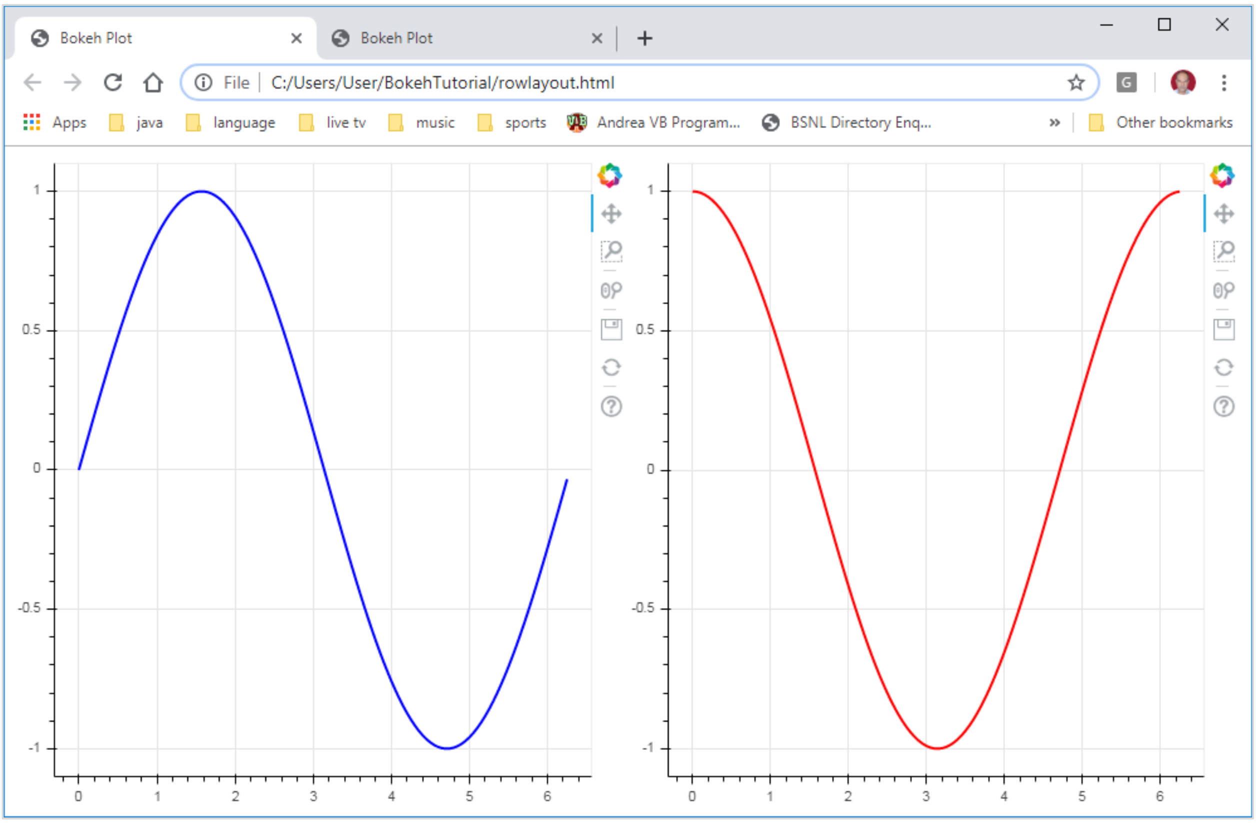
Similarly, Row layout arranges plots horizontally, for which **row() function** as defined in bokeh.layouts module is used. As you would think, it also takes two arguments (similar to **column() function**) – children and sizing_mode.

The sine and cos curves as shown vertically in above diagram are now displayed horizontally in row layout with following code:

```
from bokeh.plotting import figure, output_file, show
from bokeh.layouts import row
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
y1=np.sin(x)
y2=np.cos(x)
fig1 = figure(plot_width=200, plot_height=200)
```

```
fig1.line(x, y1,line_width=2, line_color='blue')
fig2 = figure(plot_width=200, plot_height=200)
fig2.line(x, y2,line_width=2, line_color='red')
r=row(children=[fig1, fig2], sizing_mode='stretch_both')
show(r)
```

Output



The Bokeh package also has grid layout. It holds multiple plot figures (as well as widgets) in a two dimensional grid of rows and columns. The **gridplot() function** in bokeh.layouts module returns a grid and a single unified toolbar which may be positioned with the help of toolbar_location property.

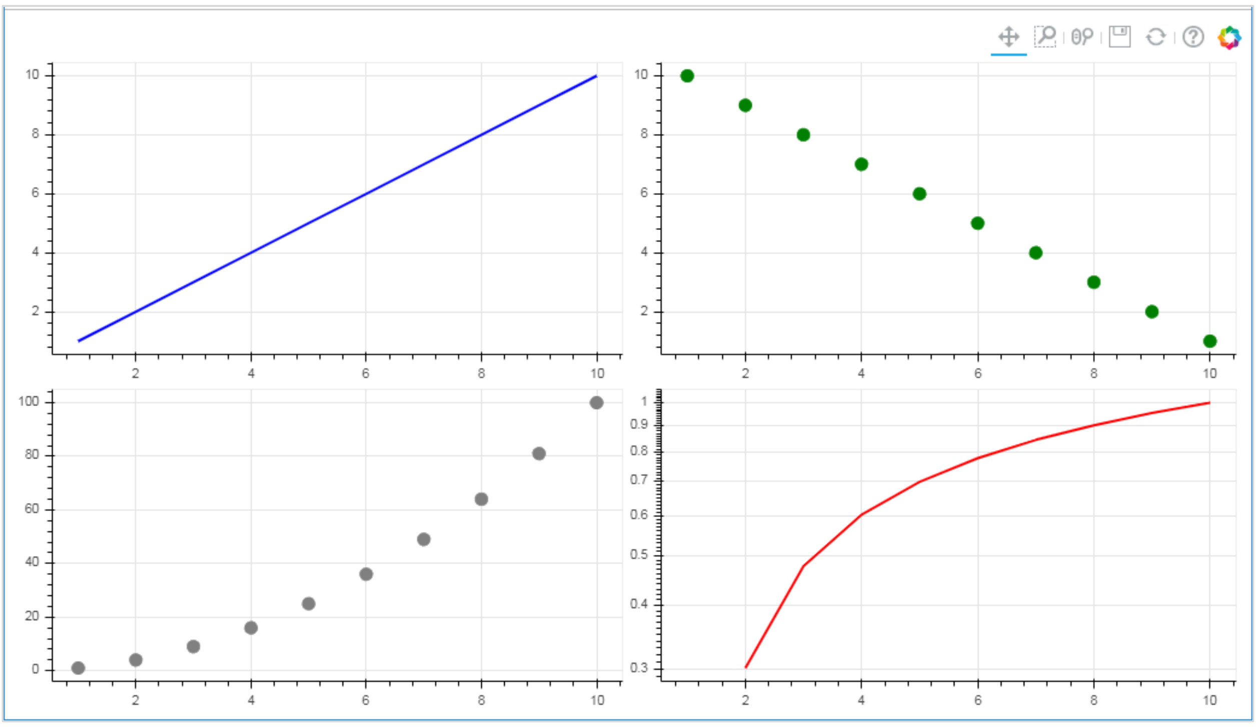
This is unlike row or column layout where each plot shows its own toolbar. The grid() function too uses children and sizing_mode parameters where children is a list of lists. Ensure that each sublist is of same dimensions.

In the following code, four different relationships between x and y data series are plotted in a grid of two rows and two columns.

```
from bokeh.plotting import figure, output_file, show
from bokeh.layouts import gridplot
import math
x=list(range(1,11))
```

```
y1=x
y2=[11-i for i in x]
y3=[i*i for i in x]
y4=[math.log10(i) for i in x]

fig1 = figure(plot_width=200, plot_height=200)
fig1.line(x, y1,line_width=2, line_color='blue')
fig2 = figure(plot_width=200, plot_height=200)
fig2.circle(x, y2,size=10, color='green')
fig3=figure(plot_width=200, plot_height=200)
fig3.circle(x,y3, size=10, color='grey')
fig4=figure(plot_width=200, plot_height=200, y_axis_type='log')
fig4.line(x,y4, line_width=2, line_color='red')
grid = gridplot(children=[[fig1, fig2], [fig3,fig4]],
sizing_mode='stretch_both')
show(grid)
```

Output



19. Bokeh — Plot Tools

When a Bokeh plot is rendered, normally a tool bar appears on the right side of the figure. It contains a default set of tools. First of all, the position of toolbar can be configured by toolbar_location property in figure() function. This property can take one of the following values:

- "above"
- "below"
- "left"
- "right"
- "None"

For example, following statement will cause toolbar to be displayed below the plot:

```
Fig=figure(toolbar_location="below")
```

This toolbar can be configured according to the requirement by adding required from various tools defined in bokeh.models module. For example:

```
Fig.add_tools(WheelZoomTool())
```

The tools can be classified under following categories:

- Pan/Drag Tools
- Click/Tap Tools
- Scroll/Pinch Tools

Tool	Description	Icon
BoxSelectTool Name : 'box_select'	allows the user to define a rectangular selection region by left-dragging a mouse	⬚
BoxZoomTool name: 'box_zoom'	allows the user to define a rectangular region to zoom the plot bounds too, by left-dragging a mouse	🔍
LassoSelectTool name: 'lasso_select'	allows the user to define an arbitrary region for selection by left-dragging a mouse	➰
PanTool name: 'pan', 'xpan', 'ypan',	allows the user to pan the plot by left-dragging a mouse	✥
TapTool name: 'tap	allows the user to select at single points by clicking a left mouse button	◎

WheelZoomTool name: 'wheel_zoom', 'xwheel_zoom', 'ywheel_zoom'	zoom the plot in and out, centered on the current mouse location.	⚲
WheelPanTool name: 'xwheel_pan', 'ywheel_pan'	translate the plot window along the specified dimension without changing the window's aspect ratio.	✥
ResetTool name: 'reset'	restores the plot ranges to their original values.	🔄
SaveTool name: 'save	allows the user to save a PNG image of the plot.	💾
ZoomInTool name: 'zoom_in', 'xzoom_in', 'yzoom_in'	The zoom-in tool will increase the zoom of the plot in x, y or both coordinates	+⚲
ZoomOutTool name: 'zoom_out', 'xzoom_out', 'yzoom_out'	The zoom-out tool will decrease the zoom of the plot in x, y or both coordinates	−⚲
CrosshairTool name: 'crosshair'	draws a crosshair annotation over the plot, centered on the current mouse position.	⌖

20. Bokeh — Styling Visual Attributes

The default appearance of a Bokeh plot can be customised by setting various properties to desired value. These properties are mainly of three types:

Line properties

Following table lists various properties related to line glyph.

line_color	color is used to stroke lines with
line_width	This is used in units of pixels as line stroke width
line_alpha	Between 0 (transparent) and 1 (opaque) this acts as a floating point
line_join	how to join together the path segments. Defined values are: 'miter' (miter_join), 'round' (round_join), 'bevel' (bevel_join)
line_cap	how to terminate the path segments. Defined values are: 'butt' (butt_cap), 'round' (round_cap), 'square' (square_cap)
line_dash	This is used for a line style. Defined values are: 'solid', 'dashed', 'dotted', 'dotdash', 'dashdot'
line_dash_offset	The distance into the line_dash in pixels that the pattern should start from

Fill properties

Various fill properties are listed below:

fill_color	This is used to fill paths with
fill_alpha	Between 0 (transparent) and 1 (opaque), this acts as a floating point

Text properties

There are many text related properties as listed in the following table:

text_font	font name, e.g., 'times', 'helvetica'
text_font_size	font size in px, em, or pt, e.g., '12pt', '1.5em'

text_font_style	font style to use 'normal' 'italic' 'bold'
text_color	This is used to render text with
text_alpha	Between 0 (transparent) and 1 (opaque), this is a floating point
text_align	horizontal anchor point for text - 'left', 'right', 'center'
text_baseline	vertical anchor point for text 'top', 'middle', 'bottom', 'alphabetic', 'hanging'

21. Bokeh — Customising legends

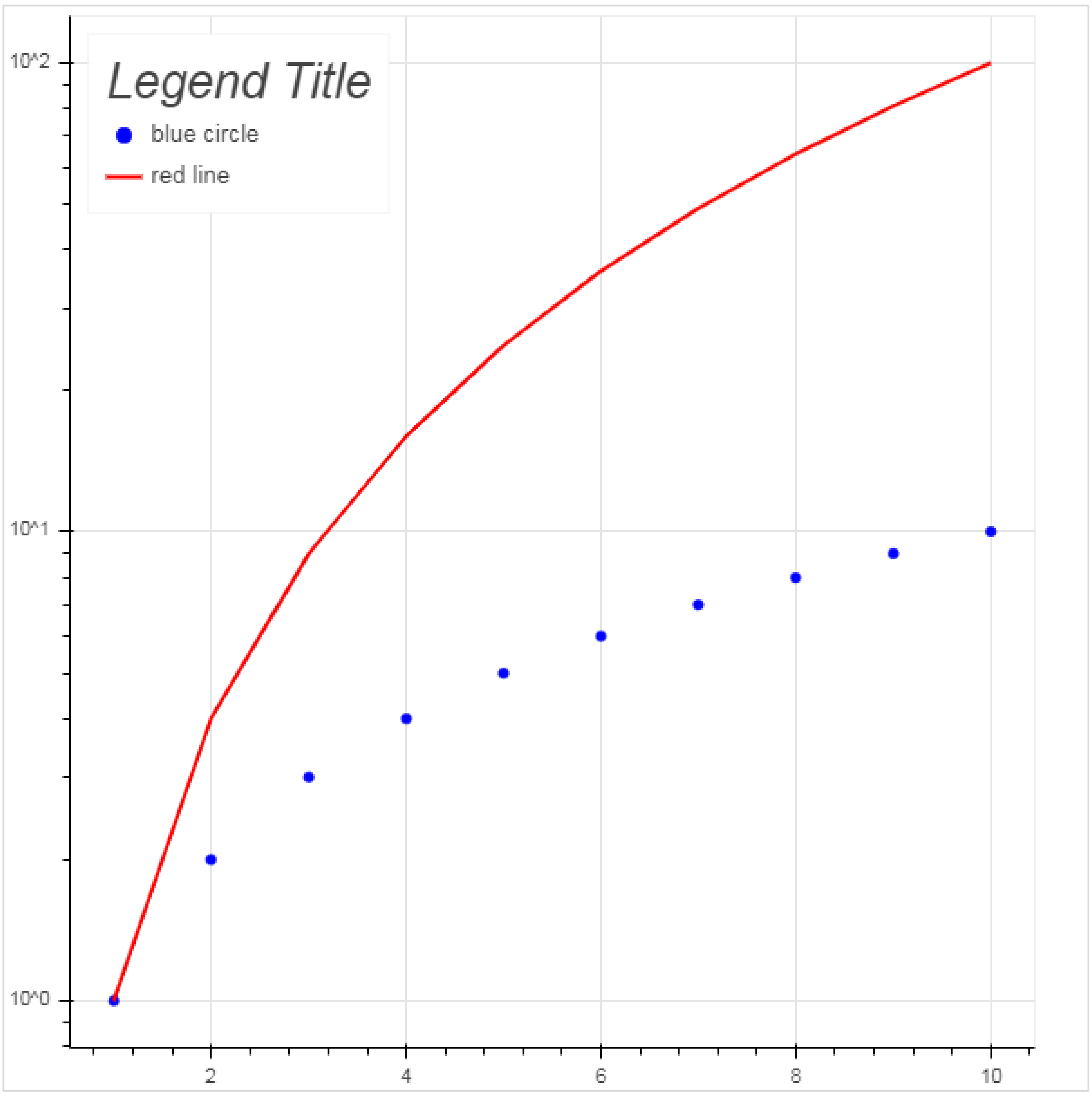
Various glyphs in a plot can be identified by legend property appear as a label by default at top-right position of the plot area. This legend can be customised by following attributes:

legend.label_text_font	change default label font to specified font name
legend.label_text_font_size	font size in points
legend.location	set the label at specified location.
legend.title	set title for legend label
legend.orientation	set to horizontal (default) or vertical
legend.clicking_policy	specify what should happen when legend is clicked hide: hides the glyph corresponding to legend mute: mutes the glyph corresponding to legend

Example code for legend customisation is as follows:

```
from bokeh.plotting import figure, output_file, show
import math
x2=list(range(1,11))
y4=[math.pow(i,2) for i in x2]
y2=[math.log10(pow(10,i)) for i in x2]
fig = figure(y_axis_type='log')
fig.circle(x2, y2,size=5, color='blue', legend='blue circle')
fig.line(x2,y4, line_width=2, line_color='red', legend='red line')
fig.legend.location='top_left'
fig.legend.title='Legend Title'
fig.legend.title_text_font='Arial'
fig.legend.title_text_font_size='20pt'
show(fig)
```

Output


Legend Title
blue circle
red line
10^2
10^1
10^0
2
4
6
8
10

22. Bokeh — Adding Widgets

The bokeh.models.widgets module contains definitions of GUI objects similar to HTML form elements, such as button, slider, checkbox, radio button, etc. These controls provide interactive interface to a plot. Invoking processing such as modifying plot data, changing plot parameters, etc., can be performed by custom JavaScript functions executed on corresponding events.

Bokeh allows call back functionality to be defined with two methods:

- Use the **CustomJS callback** so that the interactivity will work in standalone HTML documents.
- Use **Bokeh server** and set up event handlers.

In this section, we shall see how to add Bokeh widgets and assign JavaScript callbacks.

Button

This widget is a clickable button generally used to invoke a user defined call back handler. The constructor takes following parameters:

```
Button(label, icon, callback)
```

The label parameter is a string used as button's caption and callback is the custom JavaScript function to be called when clicked.

In the following example, a plot and Button widget are displayed in Column layout. The plot itself renders a line glyph between x and y data series.

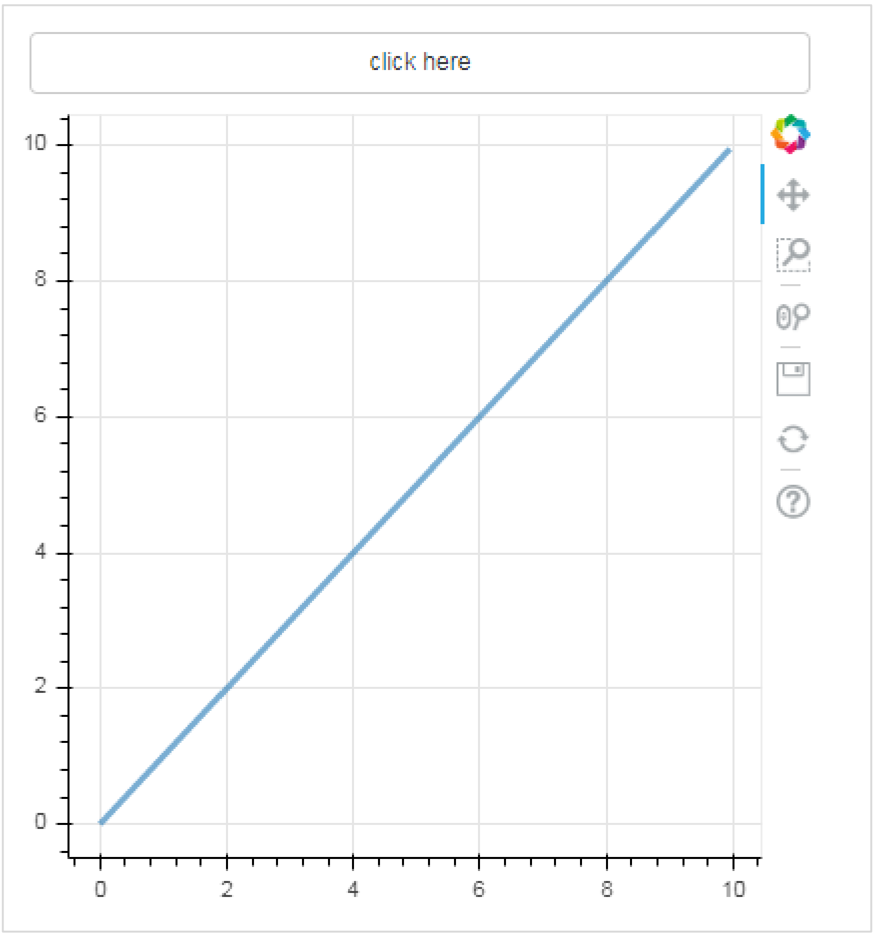
A custom JavaScript function named 'callback' has been defined using **CutomJS() function**. It receives reference to the object that triggered callback (in this case the button) in the form variable cb_obj.

This function alters the source ColumnDataSource data and finally emits this update in source data.

```
from bokeh.layouts import column
from bokeh.models import CustomJS, ColumnDataSource
from bokeh.plotting import Figure, output_file, show
from bokeh.models.widgets import Button

x = [x*0.05 for x in range(0, 200)]
y = x


source = ColumnDataSource(data=dict(x=x, y=y))
```

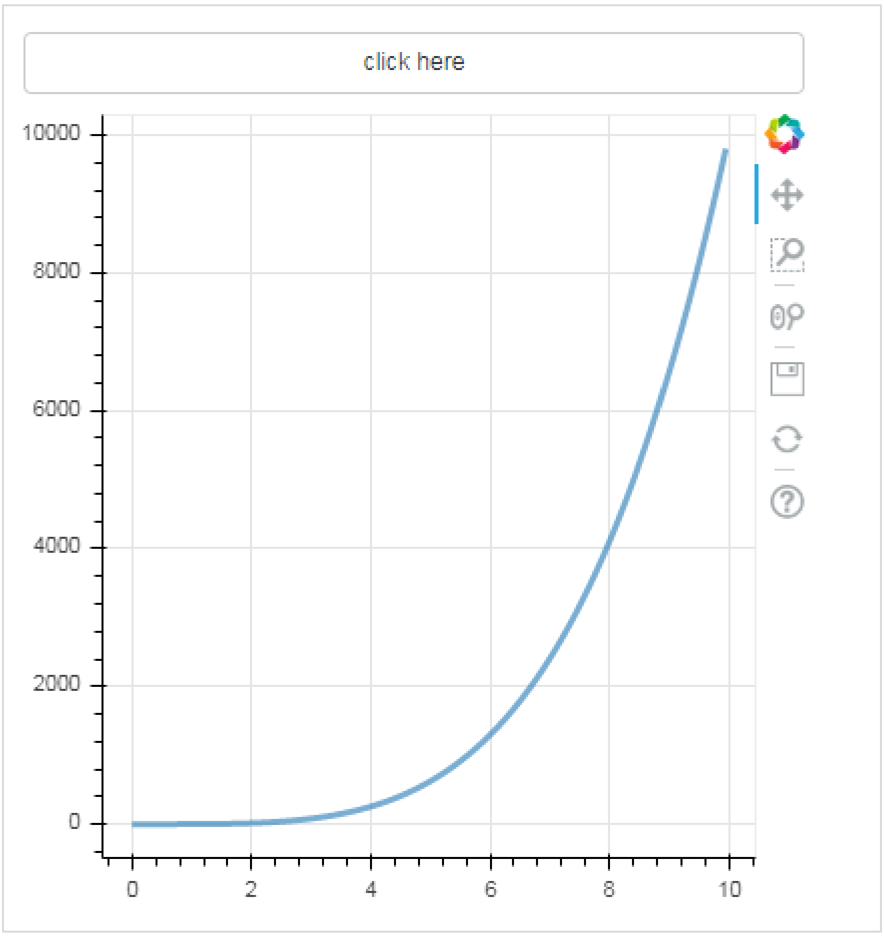
```
plot = Figure(plot_width=400, plot_height=400)
plot.line('x', 'y', source=source, line_width=3, line_alpha=0.6)

callback = CustomJS(args=dict(source=source), code="""
    var data = source.data;
    x = data['x']
    y = data['y']
    for (i = 0; i < x.length; i++) {
        y[i] = Math.pow(x[i], 4)
    }
    source.change.emit();
""")


btn = Button(label="click here", callback=callback, name="1")
layout = column(btn , plot)

show(layout)
```

Output (initial)



Click on the button on top of the plot and see the updated plot figure which looks as follows:

Output (after click)



Slider

With the help of a slider control it is possible to select a number between start and end properties assigned to it.

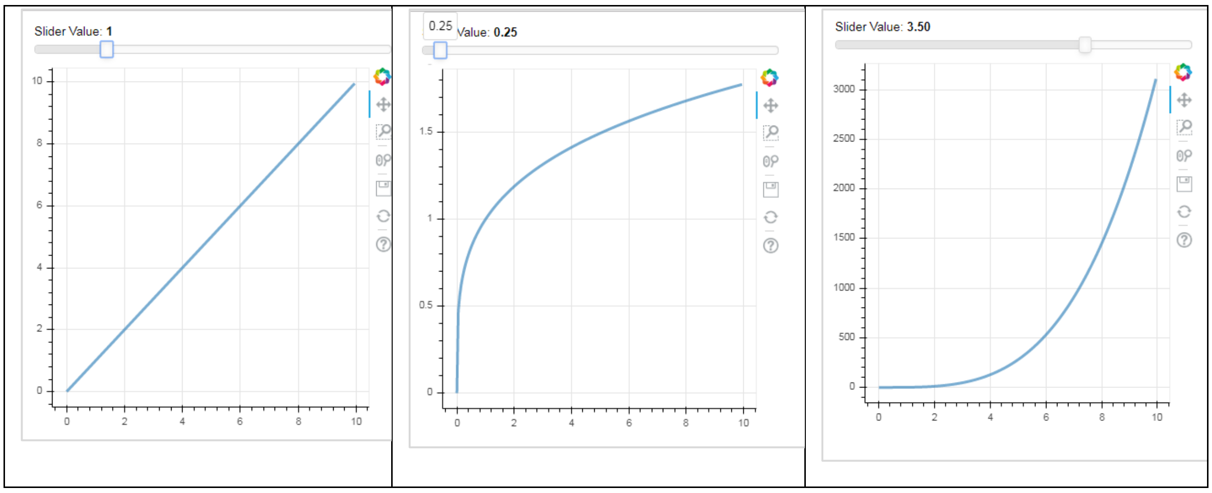
```
Slider(start, end, step, value)
```

In the following example, we register a callback function on slider's on_change event. Slider's instantaneous numeric value is available to the handler in the form of cb_obj.value which is used to modify the ColumnDatasource data. The plot figure continuously updates as you slide the position.

```
from bokeh.layouts import column
from bokeh.models import CustomJS, ColumnDataSource
from bokeh.plotting import Figure, output_file, show
from bokeh.models.widgets import Slider

x = [x*0.05 for x in range(0, 200)]
y = x

source = ColumnDataSource(data=dict(x=x, y=y))
```

```
plot = Figure(plot_width=400, plot_height=400)
plot.line('x', 'y', source=source, line_width=3, line_alpha=0.6)

handler = CustomJS(args=dict(source=source), code="""
        var data = source.data;
        var f = cb_obj.value
        var x = data['x']
        var y = data['y']
        for (var i = 0; i < x.length; i++) {
            y[i] = Math.pow(x[i], f)
        }
        source.change.emit();
    """)

slider = Slider(start=0.0, end=5, value=1, step=.25, title="Slider Value")
slider.js_on_change('value', handler)

layout = column(slider, plot)
show(layout)
```

Output



RadioGroup

This widget presents a collection of mutually exclusive toggle buttons showing circular buttons to the left of caption.

```
RadioGroup(labels, active)
```

Where, labels is a list of captions and active is the index of selected option.

Select

This widget is a simple dropdown list of string items, one of which can be selected. Selected string appears at the top window and it is the value parameter.

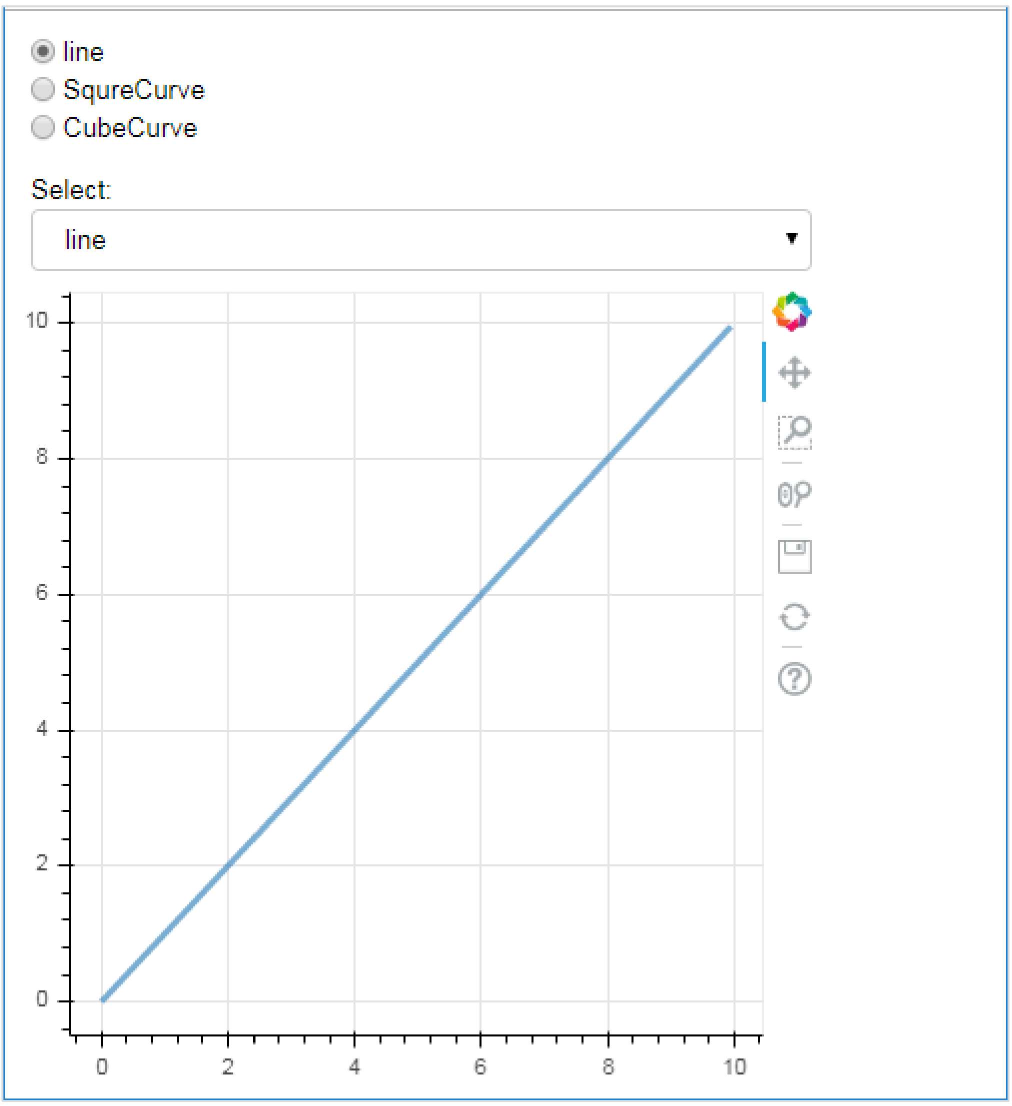
```
Select(options, value)
```

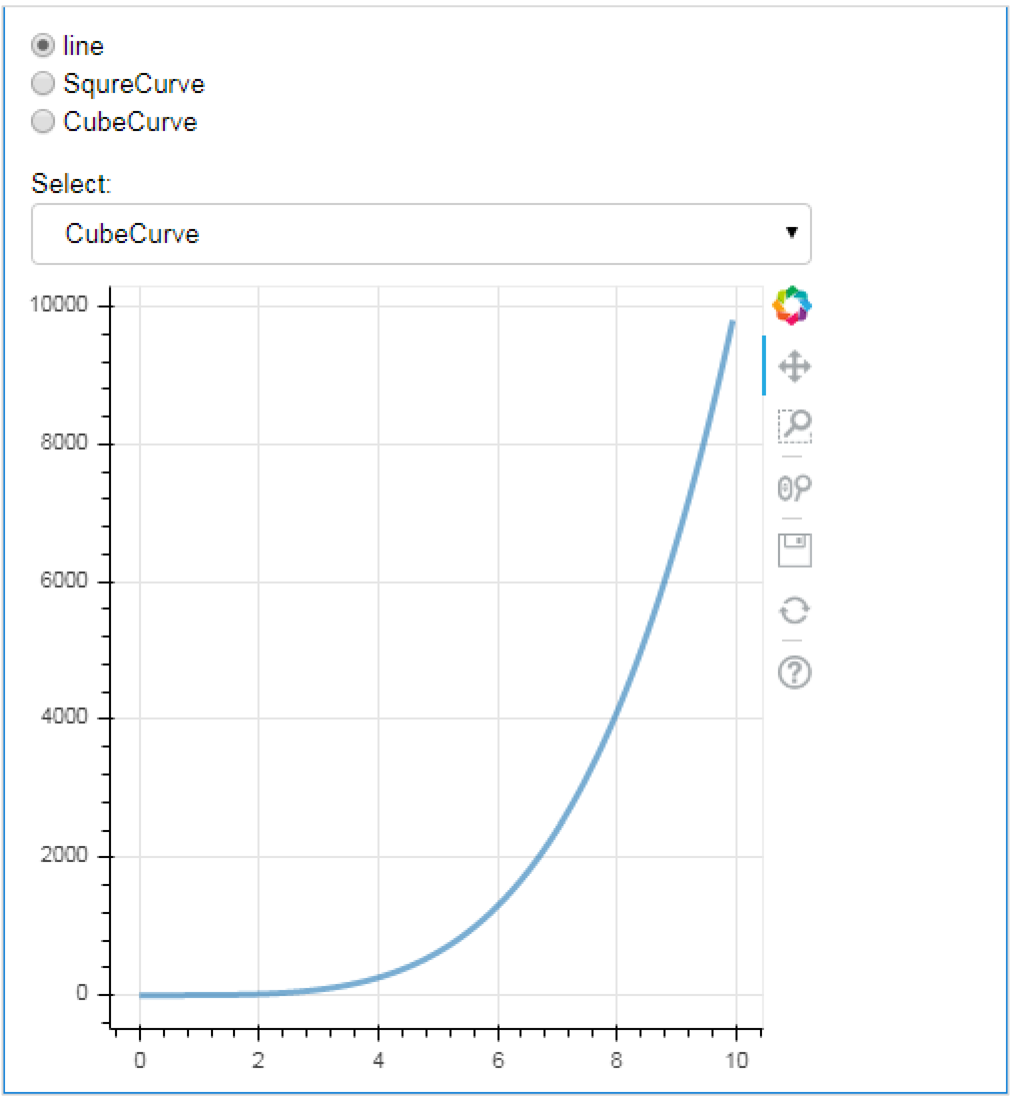
The list of string elements in the dropdown is given in the form of options list object.

Following is a combined example of radio button and select widgets, both providing three different relationships between x and y data series. The **RadioGroup** and **Select widgets** are registered with respective handlers through on_change() method.

```
from bokeh.layouts import column
from bokeh.models import CustomJS, ColumnDataSource
from bokeh.plotting import Figure, output_file, show
from bokeh.models.widgets import RadioGroup, Select



x = [x*0.05 for x in range(0, 200)]
y = x

source = ColumnDataSource(data=dict(x=x, y=y))

plot = Figure(plot_width=400, plot_height=400)
plot.line('x', 'y', source=source, line_width=3, line_alpha=0.6)

radiohandler = CustomJS(args=dict(source=source), code="""
    var data = source.data;
    console.log('Tap event occurred at x-position: ' + cb_obj.active);
    //plot.title.text=cb_obj.value;
    x = data['x']
    y = data['y']

    if (cb_obj.active==0)
    {
    for (i = 0; i < x.length; i++) {
        y[i] = x[i];
    }
    }
    if (cb_obj.active==1)
    {
    for (i = 0; i < x.length; i++) {
        y[i] = Math.pow(x[i], 2)
    }
    }
    if (cb_obj.active==2)
    {
    for (i = 0; i < x.length; i++) {
        y[i] = Math.pow(x[i], 4)
    }
    }
    source.change.emit();
""")

selecthandler = CustomJS(args=dict(source=source), code="""
    var data = source.data;
    console.log('Tap event occurred at x-position: ' + cb_obj.value);
    //plot.title.text=cb_obj.value;
    x = data['x']
    y = data['y']
    if (cb_obj.value=="line")
    {
    for (i = 0; i < x.length; i++) {
        y[i] = x[i];
    }
    }
    if (cb_obj.value=="SquareCurve")
    {

    for (i = 0; i < x.length; i++) {

        y[i] = Math.pow(x[i], 2)
    }
    }
    if (cb_obj.value=="CubeCurve")
    {
    for (i = 0; i < x.length; i++) {
        y[i] = Math.pow(x[i], 4)
    }
    }
    source.change.emit();
""")


radio = RadioGroup(
        labels=["line", "SqureCurve", "CubeCurve"], active=0)
radio.js_on_change('active', radiohandler)
select = Select(title="Select:", value='line', options=["line", "SquareCurve",
"CubeCurve"])
select.js_on_change('value', selecthandler)


layout = column(radio, select, plot)
show(layout)
```

Output


[✓ line]
SqureCurve
CubeCurve
Select:
line
0
2
4
6
8
10
0
2
4
6
8
10



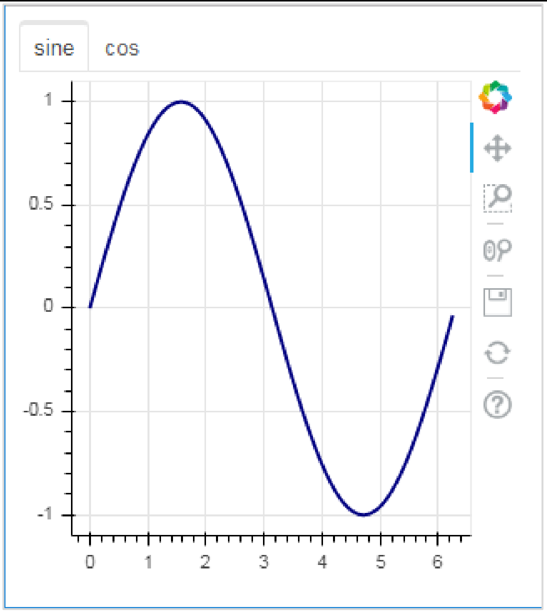
Tab widget

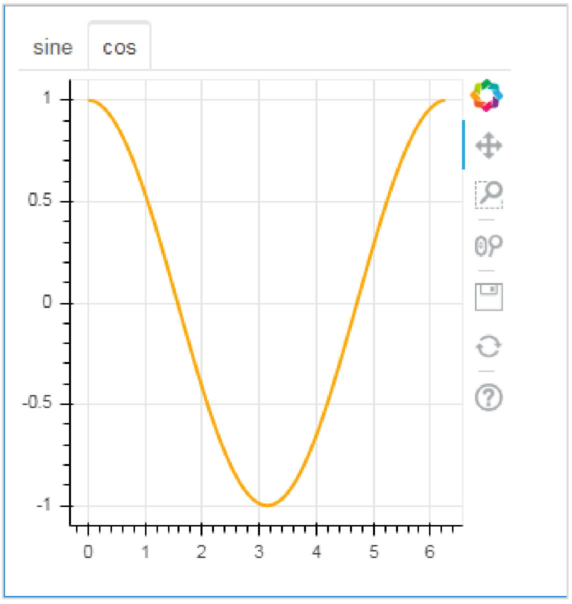
Just as in a browser, each tab can show different web page, the Tab widget is Bokeh model providing different view to each figure. In the following example, two plot figures of sine and cosine curves are rendered in two different tabs:

```
from bokeh.plotting import figure, output_file, show
from bokeh.models import Panel, Tabs
import numpy as np
import math
x=np.arange(0, math.pi*2, 0.05)
fig1=figure(plot_width=300, plot_height=300)


fig1.line(x, np.sin(x),line_width=2, line_color='navy')


tab1 = Panel(child=fig1, title="sine")
```

```
fig2=figure(plot_width=300, plot_height=300)
fig2.line(x,np.cos(x), line_width=2, line_color='orange')
tab2 = Panel(child=fig2, title="cos")

tabs = Tabs(tabs=[ tab1, tab2 ])

show(tabs)
```

Output



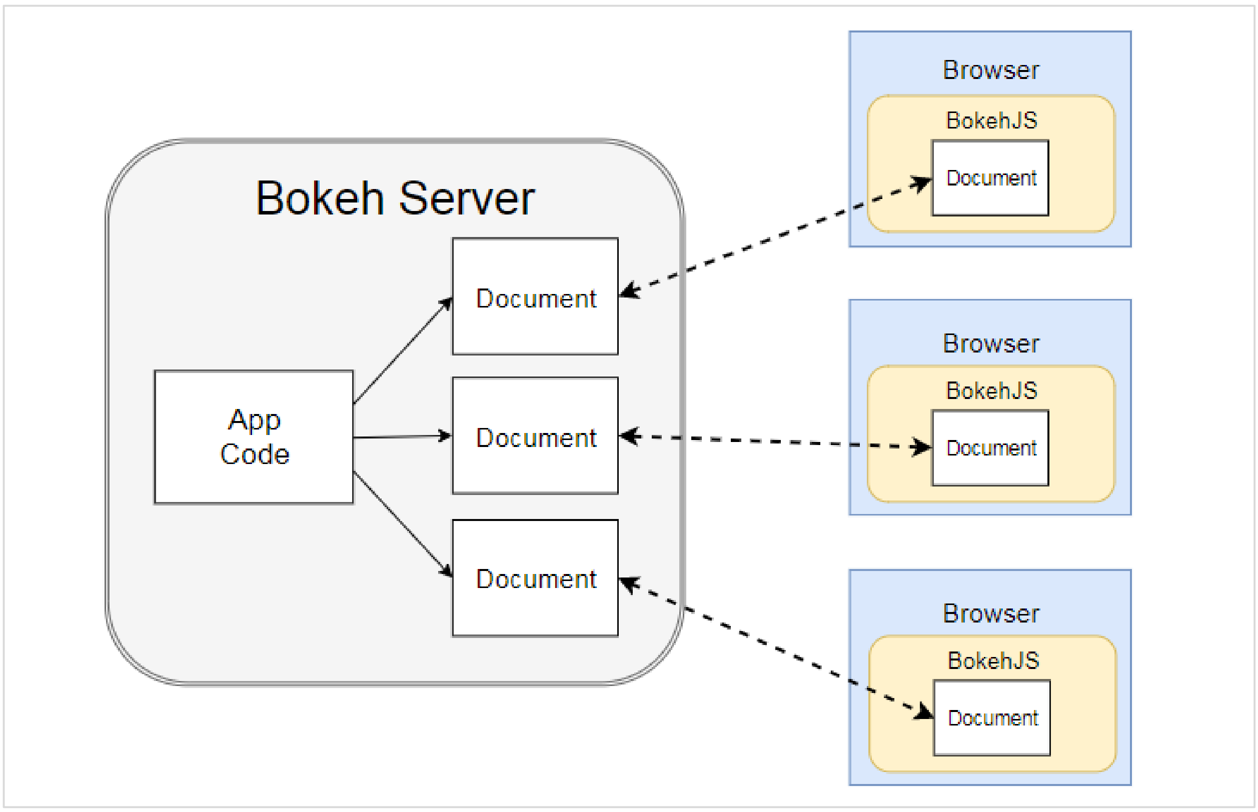


23. Bokeh — Server

Bokeh architecture has a decouple design in which objects such as plots and glyphs are created using Python and converted in JSON to be consumed by **BokehJS client library**.

However, it is possible to keep the objects in python and in the browser in sync with one another with the help of **Bokeh Server**. It enables response to User Interface (UI) events generated in a browser with the full power of python. It also helps automatically push server-side updates to the widgets or plots in a browser.

A Bokeh server uses Application code written in Python to create Bokeh Documents. Every new connection from a client browser results in the Bokeh server creating a new document, just for that session.



First, we have to develop an application code to be served to client browser. Following code renders a sine wave line glyph. Along with the plot, a slider control is also rendered to control the frequency of sine wave. The callback function **update_data()** updates **ColumnDataSource** data taking the instantaneous value of slider as current frequency.

```
import numpy as np
from bokeh.io import curdoc


from bokeh.layouts import row, column
from bokeh.models import ColumnDataSource
from bokeh.models.widgets import Slider, TextInput
from bokeh.plotting import figure

N = 200
x = np.linspace(0, 4*np.pi, N)
y = np.sin(x)
source = ColumnDataSource(data=dict(x=x, y=y))
plot = figure(plot_height=400, plot_width=400, title="sine wave")

plot.line('x', 'y', source=source, line_width=3, line_alpha=0.6)
freq = Slider(title="frequency", value=1.0, start=0.1, end=5.1, step=0.1)

def update_data(attrname, old, new):
    a = 1
    b = 0
    w = 0
    k = freq.value

    x = np.linspace(0, 4*np.pi, N)
    y = a*np.sin(k*x + w) + b

    source.data = dict(x=x, y=y)

freq.on_change('value', update_data)

curdoc().add_root(row(freq, plot, width=500))
curdoc().title = "Sliders"
```

Next, start Bokeh server by following command line:

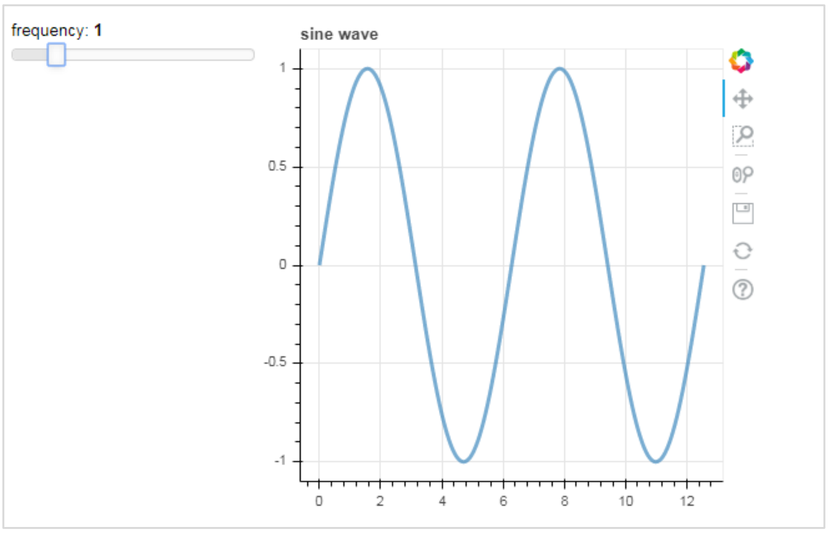
```
Bokeh serve –show sliders.py
```

Bokeh server starts running and serving the application at localhost:5006/sliders. The console log shows the following display:

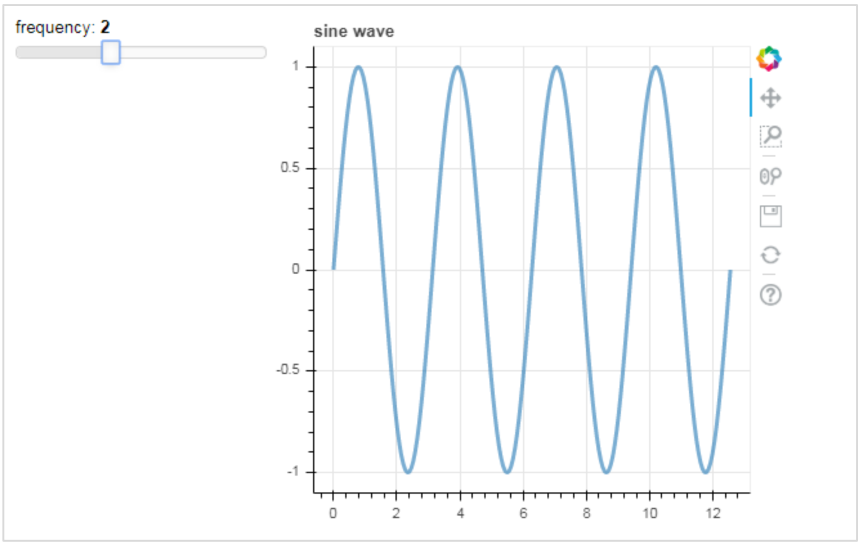
```
C:\Users\User>bokeh serve --show scripts\sliders.py
2019-09-29 00:21:35,855 Starting Bokeh server version 1.3.4 (running on Tornado
6.0.3)
2019-09-29 00:21:35,875 Bokeh app running at: http://localhost:5006/sliders
```

```
2019-09-29 00:21:35,875 Starting Bokeh server with process id: 3776
2019-09-29 00:21:37,330 200 GET /sliders (::1) 699.99ms
2019-09-29 00:21:38,033 101 GET /sliders/ws?bokeh-protocol-version=1.0&bokeh-
session-id=VDxLKOzI5Ppl9kDvEMRzZgDVyqnXzvDWsAO21bRCKRZZ (::1) 4.00ms
2019-09-29 00:21:38,045 WebSocket connection opened
2019-09-29 00:21:38,049 ServerConnection created
```

Open your favourite browser and enter above address. The Sine wave plot is displayed as follows:



You can try and change the frequency to 2 by rolling the slider.



24. Bokeh — Using Bokeh Subcommands

The Bokeh application provides a number of subcommands to be executed from command line. Following table shows the subcommands:

Html	Create HTML files for one or more applications
info	print information of Bokeh server configuration
json	Create JSON files for one or more applications
png	Create PNG files for one or more applications
sampledata	Download the bokeh sample data sets
secret	Create a Bokeh secret key for use with Bokeh server
serve	Run a Bokeh server hosting one or more applications
static	Serve static assets (JavaScript, CSS, images, fonts, etc.) used by BokeJS library
svg	Create SVG files for one or more applications

Following command generates a HTML file for Python script having a Bokeh figure.

```
C:\python37>bokeh html -o app.html app.py
```

Adding show option automatically opens the HTML file in browser. Likewise, Python script is converted to PNG, SVG, JSON files with corresponding subcommand.

To display information of Bokeh server, use info subcommand as follows:

```
C:\python37>bokeh info

Python version      :  3.7.4 (tags/v3.7.4:e09359112e, Jul  8 2019, 20:34:20)
[MSC v.1916 64 bit (AMD64)]

IPython version     :  (not installed)

Tornado version     :  6.0.3

Bokeh version       :  1.3.4

BokehJS static path :  c:\python37\lib\site-packages\bokeh\server\static

node.js version     :  (not installed)

npm version         :  (not installed)
```

In order to experiment with various types of plots, Bokeh website https://bokeh.pydata.org makes available sample datasets. They can be downloaded to local machine by sampledata subcommand.

```
C:\python37>bokeh info
```

Following datasets are downloaded in **C:\Users\User\.bokeh\data** folder:

```
AAPL.csv                                airports.csv
airports.json                           CGM.csv
FB.csv                                  gapminder_fertility.csv
gapminder_life_expectancy.csv           gapminder_population.csv
gapminder_regions.csv                   GOOG.csv
haarcascade_frontalface_default.xml     IBM.csv
movies.db                               MSFT.csv
routes.csv                              unemployment09.csv
us_cities.json                          US_Counties.csv
world_cities.csv
WPP2012_SA_DB03_POPULATION_QUINQUENNIAL.csv
```

The secret subcommand generates a secret key to be used along with serve subcommand with SECRET_KEY environment variable.

25. Bokeh — Exporting Plots

In addition to subcommands described above, Bokeh plots can be exported to PNG and SVG file format using export() function. For that purpose, local Python installation should have following dependency libraries.

PhantomJS

PhantomJS is a JavaScript API that enables automated navigation, screenshots, user behavior and assertions. It is used to run browser-based unit tests. PhantomJS is based on WebKit providing a similar browsing environment for different browsers and provides fast and native support for various web standards: DOM handling, CSS selector, JSON, Canvas, and SVG. In other words, PhantomJS is a web browser without a graphical user interface.

Pillow

Pillow, a Python Imaging Library (earlier known as PIL) is a free library for the Python programming language that provides support for opening, manipulating, and saving many different image file formats. (including PPM, PNG, JPEG, GIF, TIFF, and BMP.) Some of its features are per-pixel manipulations, masking and transparency handling, image filtering, image enhancing, etc.

The export_png() function generates RGBA-format PNG image from layout. This function uses Webkit headless browser to render the layout in memory and then capture a screenshot. The generated image will be of the same dimensions as the source layout. Make sure that the Plot.background_fill_color and Plot.border_fill_color are properties to None.

```
from bokeh.io import export_png

export_png(plot, filename="file.png")
```

It is possible that HTML5 Canvas plot output with a SVG element that can be edited using programs such as Adobe Illustrator. The SVG objects can also be converted to PDFs. Here, canvas2svg, a JavaScript library is used to mock the normal Canvas element and its methods with an SVG element. Like PNGs, in order to create a SVG with a transparent background,the Plot.background_fill_color and Plot.border_fill_color properties should be to None.

The SVG backend is first activated by setting the Plot.output_backend attribute to "svg".

```
plot.output_backend = "svg"
```

For headless export, Bokeh has a utility function, export_svgs(). This function will download all of SVG-enabled plots within a layout as distinct SVG files.

```
from bokeh.io import export_svgs


plot.output_backend = "svg"
```

```
export_svgs(plot, filename="plot.svg")
```

26. Bokeh — Embedding Plots and Apps

Plots and data in the form of standalone documents as well as Bokeh applications can be embedded in HTML documents.

Standalone document is a Bokeh plot or document not backed by Bokeh server. The interactions in such a plot is purely in the form of custom JS and not Pure Python callbacks.

Bokeh plots and documents backed by Bokeh server can also be embedded. Such documents contain Python callbacks that run on the server.

In case of standalone documents, a raw HTML code representing a Bokeh plot is obtained by file_html() function.

```
from bokeh.plotting import figure
from bokeh.resources import CDN
from bokeh.embed import file_html


fig = figure()
fig.line([1,2,3,4,5], [3,4,5,2,3])


string = file_html(plot, CDN, "my plot")
```

Return value of file_html() function may be saved as HTML file or may be used to render through URL routes in Flask app.

In case of standalone document, its JSON representation can be obtained by json_item() function.

```
from bokeh.plotting import figure
from bokeh.embed import file_html
import json
fig = figure()
fig.line([1,2,3,4,5], [3,4,5,2,3])
item_text = json.dumps(json_item(fig, "myplot"))
```

This output can be used by the Bokeh.embed.embed_item function on a webpage:

```
item = JSON.parse(item_text);
Bokeh.embed.embed_item(item);
```

Bokeh applications on Bokeh Server may also be embedded so that a new session and Document is created on every page load so that a specific, existing session is loaded. This can be accomplished with the server_document() function. It accepts the URL to a Bokeh server application, and returns a script that will embed new sessions from that server any time the script is executed.

The **server_document() function** accepts URL parameter. If it is set to ‘default’, the default URL http://localhost:5006/ will be used.

```
from bokeh.embed import server_document

script = server_document("http://localhost:5006/sliders")
```

The server_document() function returns a script tag as follows:

```
<script

    src="http://localhost:5006/sliders/autoload.js?bokeh-autoload-
element=1000&bokeh-app-path=/sliders&bokeh-absolute-
url=https://localhost:5006/sliders"

    id="1000">

</script>
```

27. Bokeh — Extending Bokeh

Bokeh integrates well with a wide variety of other libraries, allowing you to use the most appropriate tool for each task. The fact that Bokeh generates JavaScript, makes it possible to combine Bokeh output with a wide variety of JavaScript libraries, such as PhosphorJS.

Datashader (https://github.com/bokeh/datashader) is another library with which Bokeh output can be extended. It is a Python library that pre-renders large datasets as a large-sized raster image. This ability overcomes limitation of browser when it comes to very large data. Datashader includes tools to build interactive Bokeh plots that dynamically re-render these images when zooming and panning in Bokeh, making it practical to work with arbitrarily large datasets in a web browser.

Another library is Holoviews (http://holoviews.org/) that provides a concise declarative interface for building Bokeh plots, especially in Jupyter notebook. It facilitates quick prototyping of figures for data analysis.

28. Bokeh — WebGL

When one has to use large datasets for creating visualizations with the help of Bokeh, the interaction can be very slow. For that purpose, one can enable Web Graphics Library (WebGL) support.

WebGL is a JavaScript API that renders content in the browser using GPU (graphics processing unit). This standardized plugin is available in all modern browsers.

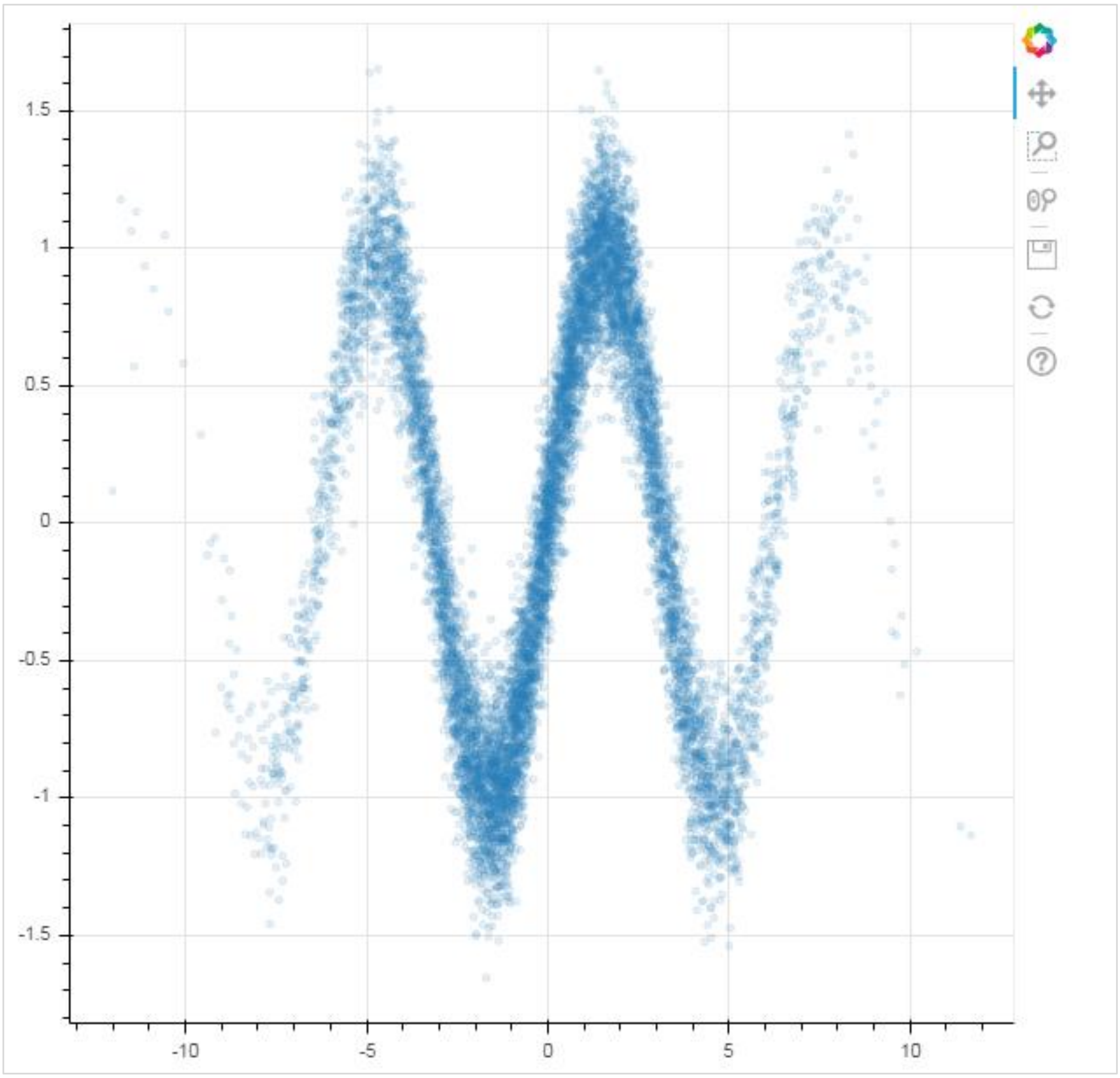
To enable WebGL, all you have to do is set output_backend property of Bokeh Figure object to 'webgl'.

```
fig= figure(output_backend="webgl")
```

In the following example, we plot a **scatter glyph** consisting of 10,000 points with the help of WebGL support.

```
import numpy as np

from bokeh.plotting import figure, show, output_file

N = 10000

x = np.random.normal(0, np.pi, N)
y = np.sin(x) + np.random.normal(0, 0.2, N)

output_file("scatterWebGL.html")

p = figure(output_backend="webgl")
p.scatter(x, y, alpha=0.1)
show(p)
```

Output


1.5
1
0.5
0
-0.5
-1
-1.5
-10
-5
0
5
10

29. Bokeh — Developing with JavaScript

The Bokeh Python library, and libraries for Other Languages such as R, Scala, and Julia, primarily interacts with BokehJS at a high level. A Python programmer does not have to worry about JavaScript or web development. However, one can use BokehJS API, to do pure JavaScript development using BokehJS directly.

BokehJS objects such as glyphs and widgets are built more or less similarly as in Bokeh Python API. Typically, any Python ClassName is available as **Bokeh.ClassName** from JavaScript. For example, a Range1d object as obtained in Python.

```
xrange = Range1d(start=-0.5, end=20.5)
```

It is equivalently obtained with BokehJS as:

```
var xrange = new Bokeh.Range1d({ start: -0.5, end: 20.5 });
```

Following JavaScript code when embedded in a HTML file renders a simple line plot in the browser.

First include all BokehJS libraries in <head>..</head> secion of web page as below:

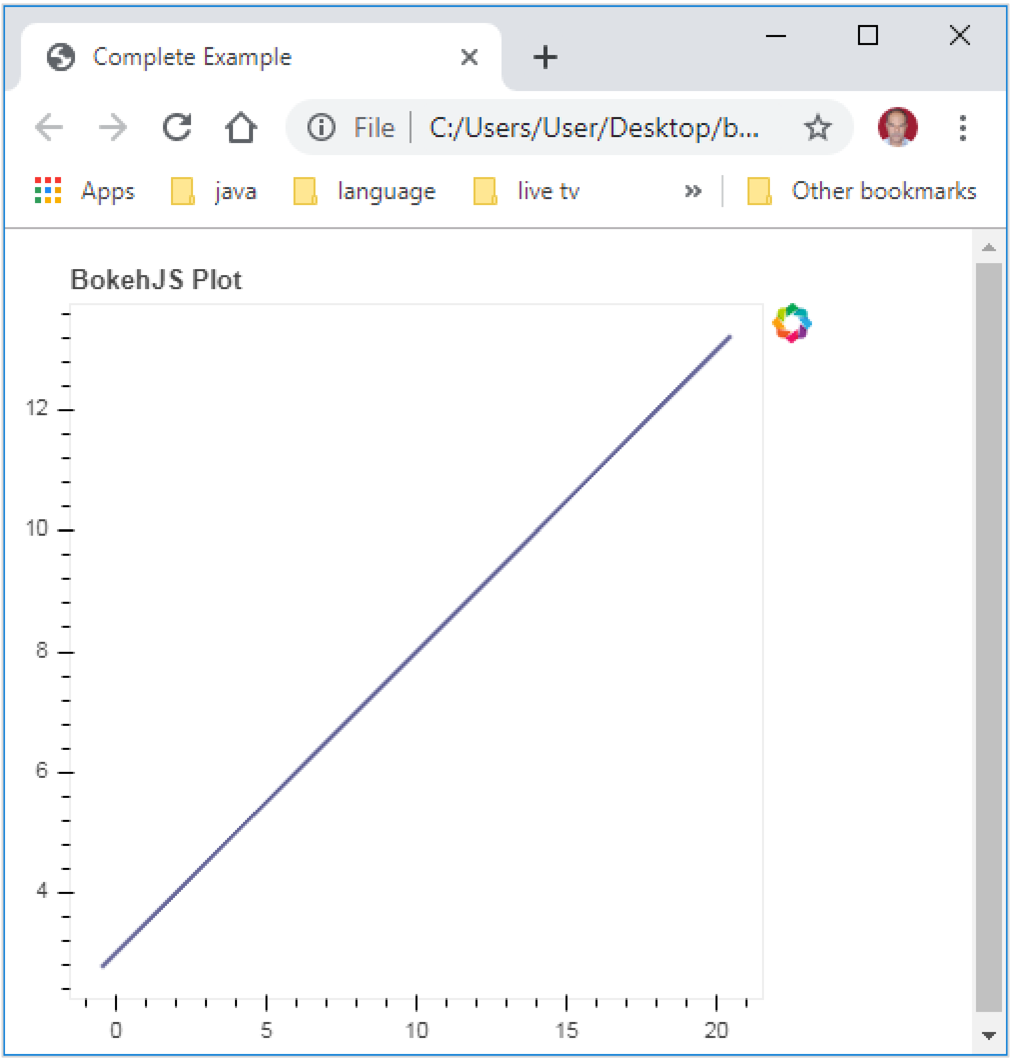
```
<head>


<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-1.3.4.min.js"></script>

<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-widgets-1.3.4.min.js"></script>

<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-tables-1.3.4.min.js"></script>

<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-gl-1.3.4.min.js"></script>

<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-api-1.3.4.min.js"></script>

<script type="text/javascript" src="https://cdn.pydata.org/bokeh/release/bokeh-api-1.3.4.min.js"></script>


</head>
```

In the body section following snippets of JavaScript construct various parts of a Bokeh Plot.

```
<script>


// create some data and a ColumnDataSource
```

```
var x = Bokeh.LinAlg.linspace(-0.5, 20.5, 10);
var y = x.map(function (v) { return v * 0.5 + 3.0; });
var source = new Bokeh.ColumnDataSource({ data: { x: x, y: y } });
// make the plot
var plot = new Bokeh.Plot({
    title: "BokehJS Plot",
    plot_width: 400,
    plot_height: 400
});

// add axes to the plot
var xaxis = new Bokeh.LinearAxis({ axis_line_color: null });
var yaxis = new Bokeh.LinearAxis({ axis_line_color: null });
plot.add_layout(xaxis, "below");
plot.add_layout(yaxis, "left");

// add a Line glyph
var line = new Bokeh.Line({
    x: { field: "x" },
    y: { field: "y" },
    line_color: "#666699",
    line_width: 2
});
plot.add_glyph(line, source);

Bokeh.Plotting.show(plot);
</script>
```

Save above code as a web page and open it in a browser of your choice.


Complete Example
File
C:/Users/User/Desktop/b...
Apps
java
language
live tv
Other bookmarks
BokehJS Plot
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10
8
6
4
0
5
10
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