

## 04.03-Errorbars

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*This notebook contains an excerpt from the [Python Data Science Handbook](#) by Jake VanderPlas; the content is available [on GitHub](#).*

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### 1 Visualizing Errors

For any scientific measurement, accurate accounting for errors is nearly as important, if not more important, than accurate reporting of the number itself. For example, imagine that I am using some astrophysical observations to estimate the Hubble Constant, the local measurement of the expansion rate of the Universe. I know that the current literature suggests a value of around 71 (km/s)/Mpc, and I measure a value of 74 (km/s)/Mpc with my method. Are the values consistent? The only correct answer, given this information, is this: there is no way to know.

Suppose I augment this information with reported uncertainties: the current literature suggests a value of around  $71 \pm 2.5$  (km/s)/Mpc, and my method has measured a value of  $74 \pm 5$  (km/s)/Mpc. Now are the values consistent? That is a question that can be quantitatively answered.

In visualization of data and results, showing these errors effectively can make a plot convey much more complete information.

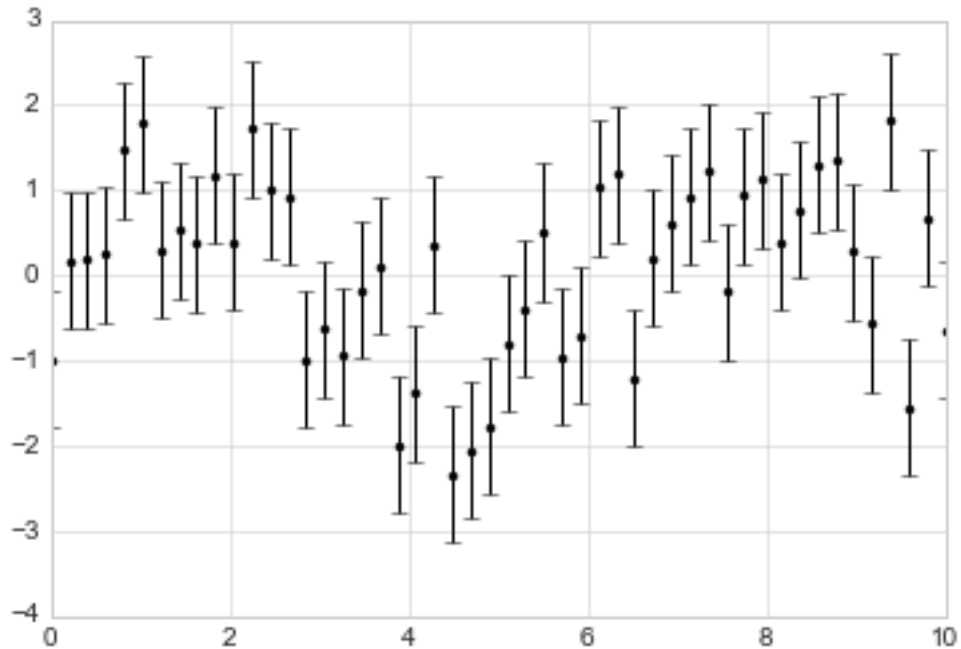
#### 1.1 Basic Errorbars

A basic errorbar can be created with a single Matplotlib function call:

```
In [1]: %matplotlib inline
import matplotlib.pyplot as plt
plt.style.use('seaborn-whitegrid')
import numpy as np

In [2]: x = np.linspace(0, 10, 50)
dy = 0.8
y = np.sin(x) + dy * np.random.randn(50)

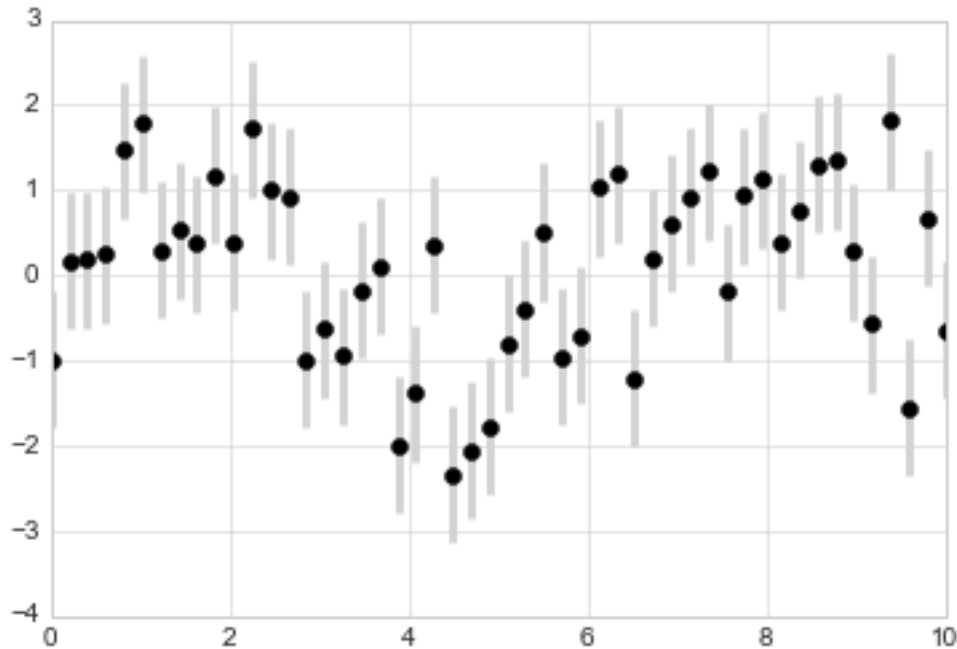
plt.errorbar(x, y, yerr=dy, fmt='.k');
```



Here the `fmt` is a format code controlling the appearance of lines and points, and has the same syntax as the shorthand used in `plt.plot`, outlined in [Simple Line Plots](#) and [Simple Scatter Plots](#).

In addition to these basic options, the `errorbar` function has many options to fine-tune the outputs. Using these additional options you can easily customize the aesthetics of your errorbar plot. I often find it helpful, especially in crowded plots, to make the errorbars lighter than the points themselves:

```
In [3]: plt.errorbar(x, y, yerr=dy, fmt='o', color='black',  
                    ecolor='lightgray', elinewidth=3, capsize=0);
```



In addition to these options, you can also specify horizontal errorbars (`xerr`), one-sided errorbars, and many other variants. For more information on the options available, refer to the docstring of `plt.errorbar`.

## 1.2 Continuous Errors

In some situations it is desirable to show errorbars on continuous quantities. Though Matplotlib does not have a built-in convenience routine for this type of application, it's relatively easy to combine primitives like `plt.plot` and `plt.fill_between` for a useful result.

Here we'll perform a simple *Gaussian process regression*, using the Scikit-Learn API (see [Introducing Scikit-Learn](#) for details). This is a method of fitting a very flexible non-parametric function to data with a continuous measure of the uncertainty. We won't delve into the details of Gaussian process regression at this point, but will focus instead on how you might visualize such a continuous error measurement:

```
In [4]: from sklearn.gaussian_process import GaussianProcess

# define the model and draw some data
model = lambda x: x * np.sin(x)
xdata = np.array([1, 3, 5, 6, 8])
ydata = model(xdata)

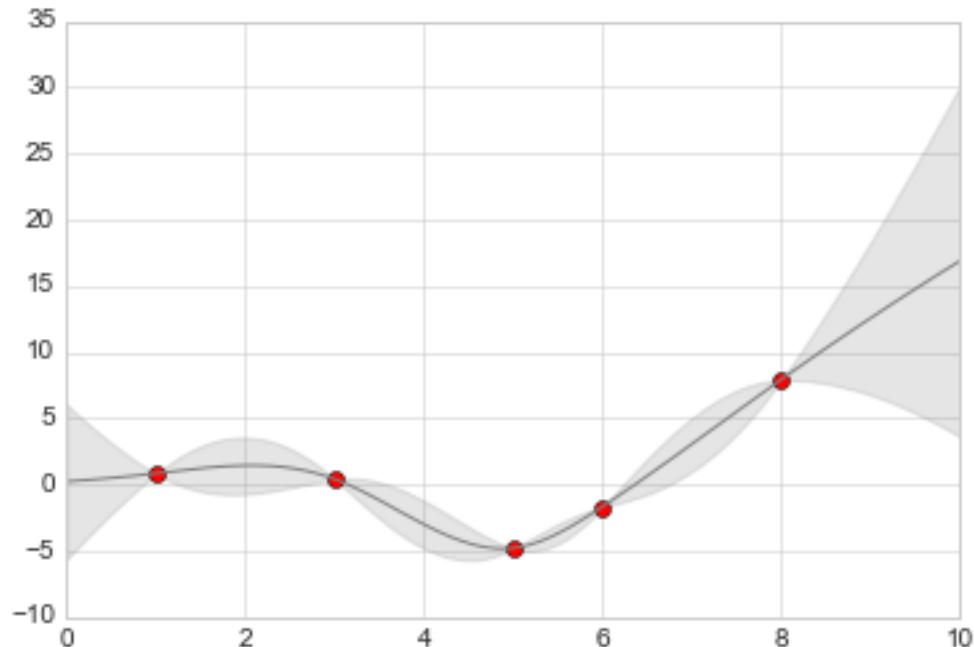
# Compute the Gaussian process fit
gp = GaussianProcess(corr='cubic', theta0=1e-2, thetaL=1e-4, thetaU=1E-1,
                    random_start=100)
gp.fit(xdata[:, np.newaxis], ydata)
```

```
xfit = np.linspace(0, 10, 1000)
yfit, MSE = gp.predict(xfit[:, np.newaxis], eval_MSE=True)
dyfit = 2 * np.sqrt(MSE) # 2*sigma ~ 95% confidence region
```

We now have `xfit`, `yfit`, and `dyfit`, which sample the continuous fit to our data. We could pass these to the `plt.errorbar` function as above, but we don't really want to plot 1,000 points with 1,000 errorbars. Instead, we can use the `plt.fill_between` function with a light color to visualize this continuous error:

```
In [5]: # Visualize the result
plt.plot(xdata, ydata, 'or')
plt.plot(xfit, yfit, '-', color='gray')

plt.fill_between(xfit, yfit - dyfit, yfit + dyfit,
                 color='gray', alpha=0.2)
plt.xlim(0, 10);
```



Note what we've done here with the `fill_between` function: we pass an `x` value, then the lower `y`-bound, then the upper `y`-bound, and the result is that the area between these regions is filled.

The resulting figure gives a very intuitive view into what the Gaussian process regression algorithm is doing: in regions near a measured data point, the model is strongly constrained and this is reflected in the small model errors. In regions far from a measured data point, the model is not strongly constrained, and the model errors increase.

For more information on the options available in `plt.fill_between()` (and the closely related `plt.fill()` function), see the function docstring or the Matplotlib documentation.

Finally, if this seems a bit too low level for your taste, refer to [Visualization With Seaborn](#), where we discuss the Seaborn package, which has a more streamlined API for visualizing this type of continuous errorbar.

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