# 1 Review

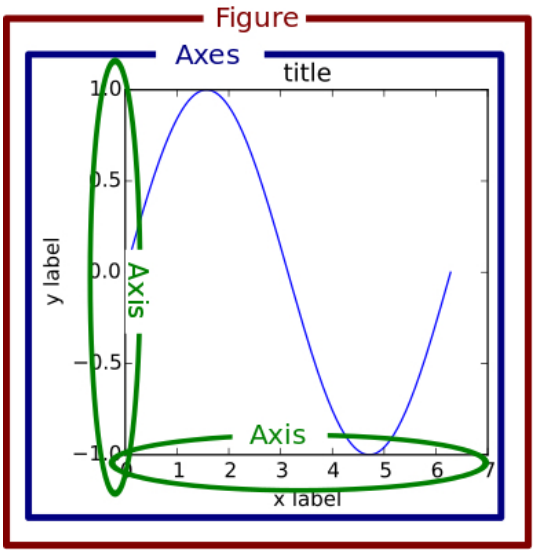
**Last time:**

- Numpy
- Questions?
- Today: Plotting with Matplotlib and Pandas

# 2 Matplotlib Intro

- Matplotlib (Matlab Plotting Library) is a package for creating plots and figures
- Importing matplotlib:

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




- `Figure`: container for a matplotlib graphic. A figure contains multiple `Axes` objects.
- `Axes`: an individual plot. (Note: not be confused with AXIS).
- The `Axes` contains the data to be plotted as well as the `title, xlabel, legend` etc...

# 3 A Basic Plot

```
fig, ax = plt.subplots(figsize=(8,6))

x = np.linspace(0, 10, 20)
y1 = 2*x+1
y2 = 3*x+1
```

```
ax.plot(x, y1, label='a line')
ax.plot(x, y2, label='a steeper line')
ax.set_title('A title!')
ax.set_xlabel('x')
ax.set_ylabel(r'$y = 2 \cdot x +1$')
ax.legend()

plt.show()
```

- The `pyplot.subplots` method creates and returns a `Figure` and `Axes`(s). `pyplot` is a state-based interface: it retains a reference to the `Figure` objected handed to you, so when you call `pyplot` later on, it knows which figures to make the changes.
- We can optionally specify the figure size in `pyplot.subplots`.
- To populate the plot, we edit the `Axes` object (`ax`).
- We use the `Axes.plot` method to plot our data. We can optionally specify a label
- `Axes.set_title`, `Axes.set_xlabel`, `Axes.set_ylabel`, `Axes.legend`
- In order to display the `Figure`, we use the `pyplot.show` function. This displays all open figures. After the show command, the displayed figures are closed (`pyplot`'s internal state no longer tracks the figure).

**ax.plot format:**

- `ax.plot(x, y, [format])`

| Character | Color |
|---|---|
| 'b' | Blue |
| 'g' | Green |
| 'r' | Red |
| 'b' | Blue |
| 'c' | Cyan |
| 'm' | Magenta |
| 'y' | Yellow |
| 'k' | Black |
| 'b' | Blue |
| 'w' | White |

| Character | Description |
|---|---|
| '.' | Point marker |
| 'o' | Circle marker |
| 'x' | X marker |
| 'D' | Diamond marker |
| 'H' | Hexagon marker |
| 's' | Square marker |
| '+' | Plus marker |

| Character | Description |
|---|---|
| '-' | Solid line |
| '—' | Dashed line |
| '-.' | Dash-dot line |
| ':' | Dotted line |
| 'H' | Hexagon marker |

- `plot` has other properties, e.g. linewidth, markersize, etc...(read the docs)

**Additional Axes Methods (Demo)**:

- `Axes.grid()`
- `Axes.set_xlim(min, max)`, `Axes.set_ylim(min, max)`
- `Axes.xscale(value)`, `Axes.yscale(value)`, e.g. `Axes.xscale(`log')`
- `Axes.axhline(y)`, `Axes.axvline(y)`
- `Axes.errorbar(x, y, yerr=None, xerr=None, capsize=None)`

**Other types of plots** (read the docs):

- Bar and Histogram
- Pie
- Box and wisker
- etc...

**Histogram**

```
x = np.random.normal(size=10000)
fig, ax = plt.subplots()
ax.hist(x, bins=30)
plt.show()
```

```
x = np.random.uniform(size=10000)
fig, ax = plt.subplots()
ax.hist(x, bins=[0,0.1,0.2,0.3,0.6,0.7,0.8,0.9,1])
plt.show()
```

-
-

# 4 Subplots

- Recall: we use the `subplots` function to create a `Figure`. By default, this creates one `Axes`. However, we can specify a grid of `Axes`: `ax.subplots(rows, cols)`
- `subplots` returns the figure and array of `Axes`
- Example:

```
fig, ax = plt.subplots(2, 3, figsize=(8,6))
ax[0][1].plot(x,y1)
ax[1][0].plot(x,y2)
plt.show()
```

- We can arrange the `Axes` in more complicated manners. Read the docs...

# 5 2D Plots

**Plotting a 2d function:** $z(x, y) = x + y$

X

| | | | |
|---|---|---|---|
| 0 | 1 | 2 | 3 |
| 0 | 1 | 2 | 3 |
| 0 | 1 | 2 | 3 |

Y

| | | | |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |

COORDINATE

| | | | |
|---|---|---|---|
| 0,0 | 1,0 | 2,0 | 3,0 |
| 0,1 | 1,1 | 2,1 | 3,1 |
| 0,2 | 1,2 | 2,2 | 3,2 |

Z = X + Y

| | | | |
|---|---|---|---|
| 0 | 1 | 2 | 3 |
| 1 | 2 | 3 | 4 |
| 2 | 3 | 4 | 5 |

- How do we generate $x$, $y$, and $z$? Numpy!

```
x = np.arange(4)
y = np.arange(3)
X, Y = np.meshgrid(x,y)
Z = X + Y

>>> X
array([[0, 1, 2, 3],
       [0, 1, 2, 3],
       [0, 1, 2, 3]])
>>> Y
array([[0, 0, 0, 0],
       [1, 1, 1, 1],
       [2, 2, 2, 2]])
>>> Z
array([[0, 1, 2, 3],
       [1, 2, 3, 4],
       [2, 3, 4, 5]])
```

- Two ways to plot: `imshow` and `pcolormesh`
- `imshow(Z)`: assumes values are equally spaced (for plotting images and 2d functions).

```
+--------+--------+
| Z[0,0] | Z[0,1] |
+--------+--------+
| Z[1,0] | Z[1,1] |
+--------+--------+
```

- `pcolormesh(X, Y, C)`: does not assumed equally spaced values. `X` and `Y` specify the quadrilateral corners. This is a mesh (cells do not have to be evenly spaced)!

```
(X[i+1, j], Y[i+1, j])          (X[i+1, j+1], Y[i+1, j+1])
                       +--------+
```

```
                          | C[i,j] |
                          +--------+
(X[i, j], Y[i, j])          (X[i, j+1], Y[i, j+1]),
```

- We will use `imshow`:

```
fig, ax = plt.subplots(figsize=(8, 5))
image = ax.imshow(Z)
plt.show()
```

- Color-map: key for how to map a value to a color. Matplotlib has many built-in cmaps and you can define your own.

```
# default color map
fig, ax = plt.subplots(figsize=(8, 5))
image = ax.imshow(Z)
plt.colorbar(image)
plt.show()

# example of a monotone cmap
fig, ax = plt.subplots(figsize=(8, 5))
image = ax.imshow(Z, cmap='Purples')
plt.colorbar(image)
plt.show()
```

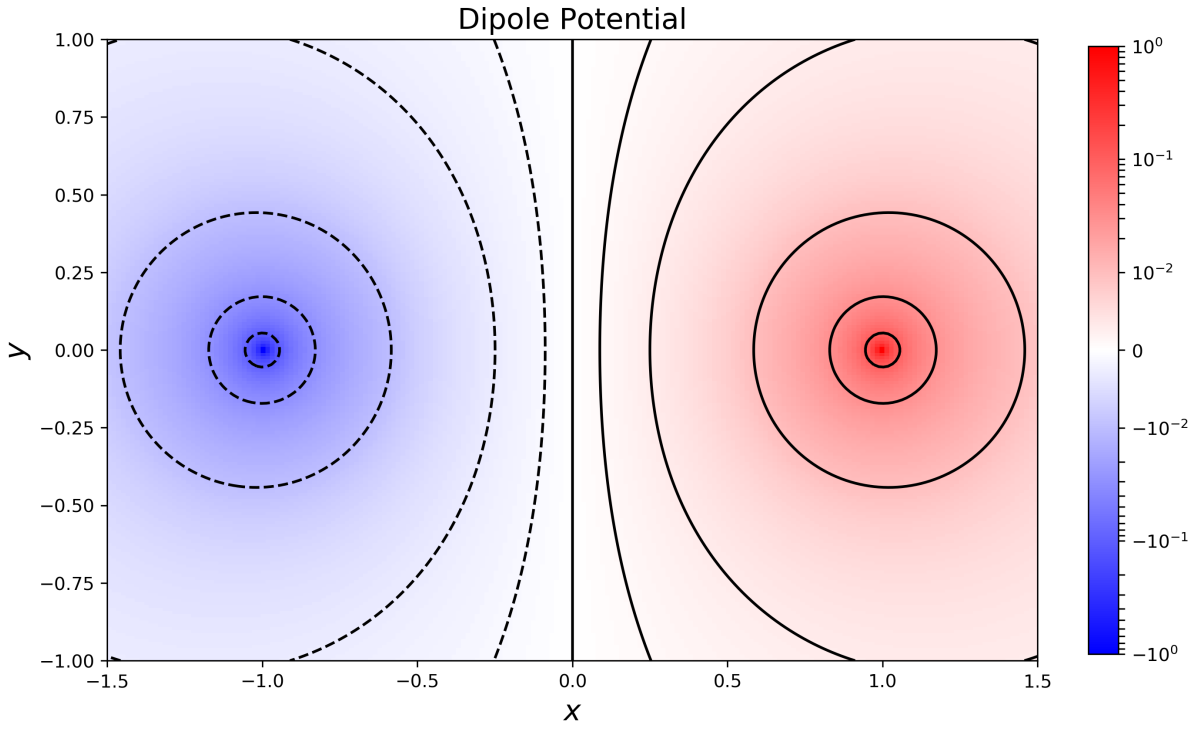
- We can also plot contours using `ax.contour([X, Y], Z, [levels])`

# 6 (Optional) Example: Plotting a Dipole Potential

**Note**: this demo includes many optional arguments/features not covered in lecture. It's impossible cover nor remember everything. Searching the docs is an important skill!

```
import matplotlib
x = np.linspace(-1.5, 1.5, 200)
y = np.linspace(-1, 1, 200)
X, Y = np.meshgrid(x,y)

# calculate dipole potential
R1 = np.sqrt((X-1)**2 + Y**2)
R2 = np.sqrt((X+1)**2 + Y**2)
Z = (1/R1 - 1/R2)
Z /= np.max(Z) # normalize

fig, ax = plt.subplots(figsize=(10, 7))
image = ax.imshow(Z, origin='lower', cmap='bwr',
                  extent=[np.min(x), np.max(x), np.min(y), np.max(y)],
```

```
                    norm=matplotlib.colors.SymLogNorm(0.01))
eqipots = [-0.1, -0.03, -0.01, -0.003, -0.001, 0,
           0.001, 0.003, 0.01, 0.03, 0.1]
ax.contour(X, Y, Z, eqipots, colors='k')

ax.set_title('Dipole Potential', fontsize=16)
ax.set_xlabel(r'$x$', fontsize=16)
ax.set_ylabel(r'$y$', fontsize=16)

plt.colorbar(image, fraction=.03)
plt.savefig('dipole.png', dpi=300, bbox_inches='tight')
plt.show()
```




# 7 Save Figure

- `plt.savefig(name)`
- Recommend args: `dpi=300, bbox_inches='tight'`
- If you want to show and save figure, you must save BEFORE showing
- Example:

```
plt.savefig('fig.png',dpi=300,bbox_inches='tight')
```

# 8 Pandas

- Pandas is a package for reading and cleaning data. This is a topic that could fill many lectures itself. I will only show a limited functionality.
- Reading in csv/txt file from computer/online (`bb.txt` is included as a backup). Some common optional arguments for `pd.read_csv`: `header=None`, `encoding = `utf8'`.

```
import pandas as pd
# data frame
df = pd.read_csv('https://www.ocf.berkeley.edu/~yizhu/bb.txt',
                     delimiter=',', skiprows=0)

lam = df['Lambda (nm)']
I = df['Specific Intensity (W/m^3*Sr)']

>>> df
          Lambda (nm)  Specific Intensity (W/m^3*Sr)
0      300.000000                     7.940206e+12
1      303.517588                     8.338975e+12
2      307.035176                     8.756094e+12
3      310.552764                     8.857883e+12
4      314.070352                     9.422244e+12
..            ...                              ...
195    985.929648                     9.643322e+12
196    989.447236                     9.643796e+12
197    992.964824                     9.547717e+12
198    996.482412                     9.461644e+12
199   1000.000000                     9.485265e+12

[200 rows x 2 columns]

>>>lam
0        300.000000
1        303.517588
2        307.035176
3        310.552764
4        314.070352
           ...
195      985.929648
196      989.447236
197      992.964824
198      996.482412
199     1000.000000
Name: Lambda (nm), Length: 200, dtype: float64
```

- Data structures in `pandas`: `Series` and `DataFrame`.
- `Series`: a 1-dimensional ndarray of data. Each element in the series has a label (index). Example: `lam` is a `Series` indexed by 0, 1, 2, .... Indices do not have to be unique.
- `DataFrame`: 2-dimension array storing tabular data. Tabular data is data arranged in a table form. Each row has the same columns as the other rows, in the same order. Each row is indexed by a label.
- Indexing data frames is a surprisingly complex topic. We will refer you to some resources from Data 100.

# 9 Conclusion

This is the end of the Python lecture series. This series is by no means comprehensive, but intended to prepare you to further learn/explore Python on your own. Remember:

- Read the documentation
- Read the error tracebacks
- Google, StackOverflow, etc... is your friend
- Don't hesistate to reach out to the ULAB staff for help!