1 Review

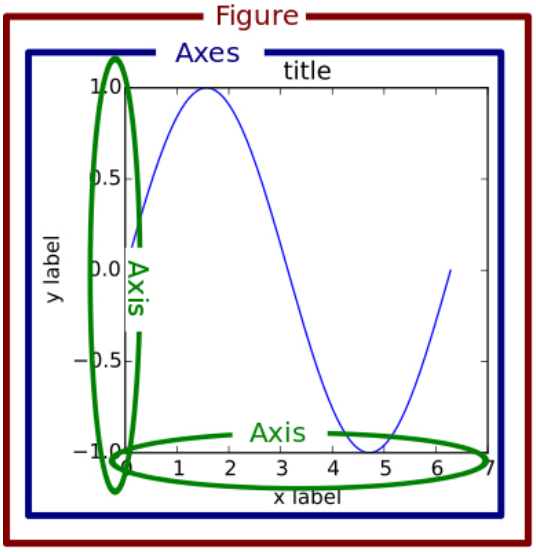
Last time:

- 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. Multiple AXIS form an AXES).
- The `Axes` contains most of the smaller objects that we care about. E.g. `title, xlabel,` etc...

3 Axes

Reference: https://matplotlib.org/stable/api/axes_api.html#plotting

- `subplots` method creates and returns a `Figure` and `Axes`(s). By default, `subplots` populates the `Figure` with one `Axes`. We can optionally specify the figure size.

- We use the `plot` method to plot our data. We can optionally specify a label
- `set_title`, `set_xlabel`, `set_ylabel`
- In order to display the `Figure`, we use `plt.show()`. This command finds and displays the current `Figure`
- Basic plot example:

```
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'$y = 2 \cdot x +1$')
fig.legend()

plt.show()
```

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):

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

Other types of plots (read the docs):

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

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!

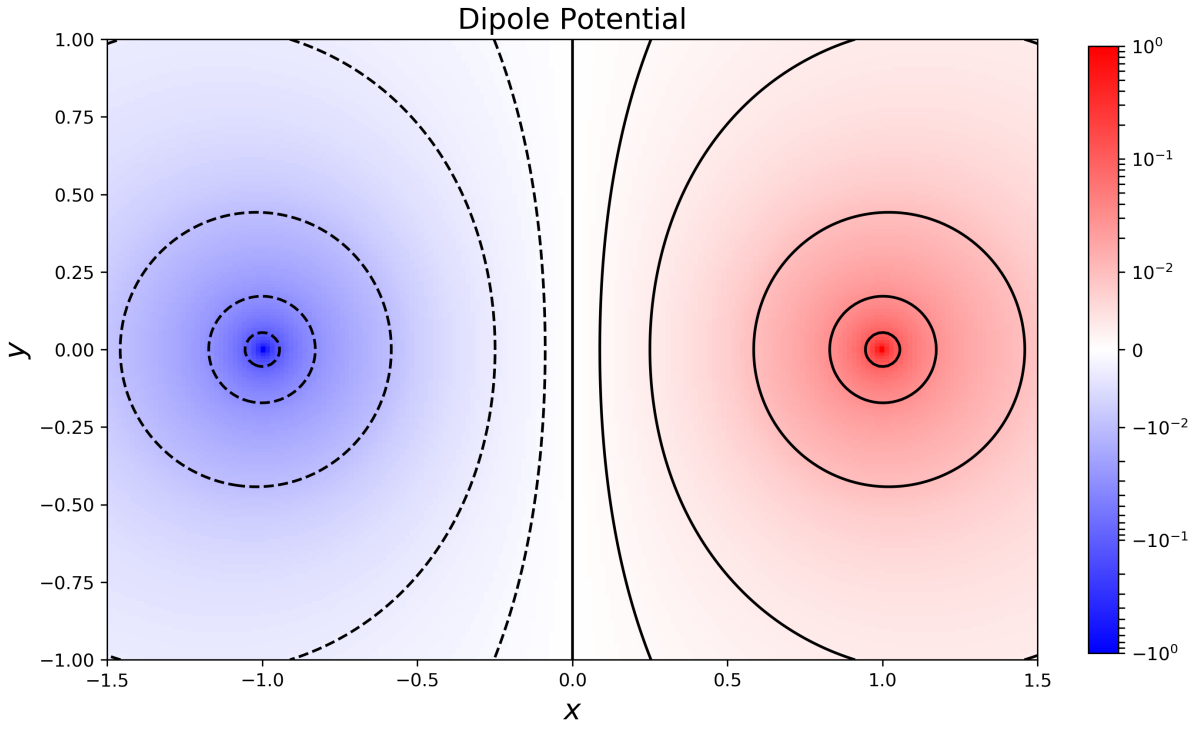
```
import matplotlib
x = np.linspace(-1.5, 1.5, 200)
y = np.linspace(-1, 1, 200)
X, Y = np.meshgrid(x,y)

# 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 deserves a separate workshop. I will only show a limited functionality.
- Reading in csv/txt file from computer/online (`bb.txt` is included as a backup):

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

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

```
>>> data
          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
```

- Some common optional arguments for `pd.read_csv`: `header=None`, `encoding = 'utf8'`

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!