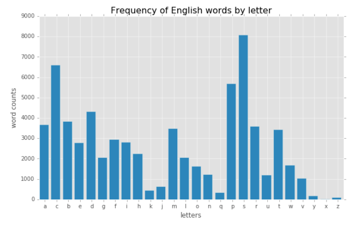
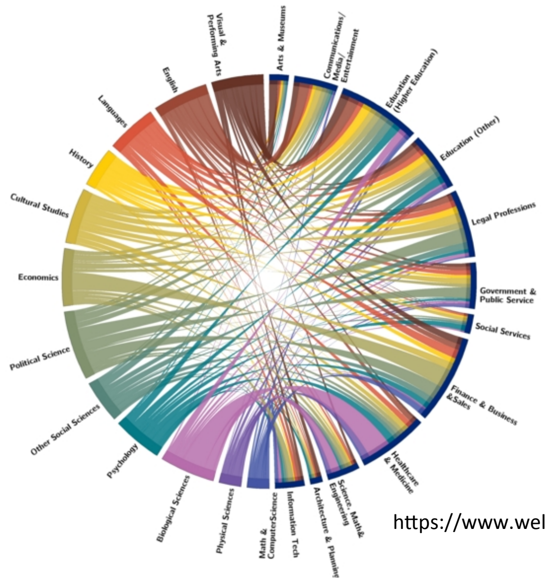
Data Visualization, matplotlib & Simple Data Analysis



CS111 Computer Programming

Department of Computer Science
Wellesley College

Visualizing data is important!



What careers do Wellesley graduates choose based on their major?

Can we generate this visualization with cs1graphics? NO. We need a tool that works with **data**.

https://www.wellesley.edu/admission/why/after

Plotting with `matplotlib`

A plot is a graphical technique for representing a **data set**, usually as a graph showing the relationship between two or more variables.

In CS111, we'll be using Python's **matplotlib** library to make plots/graphs/charts.

```
import matplotlib.pyplot as plt
import numpy as np
```

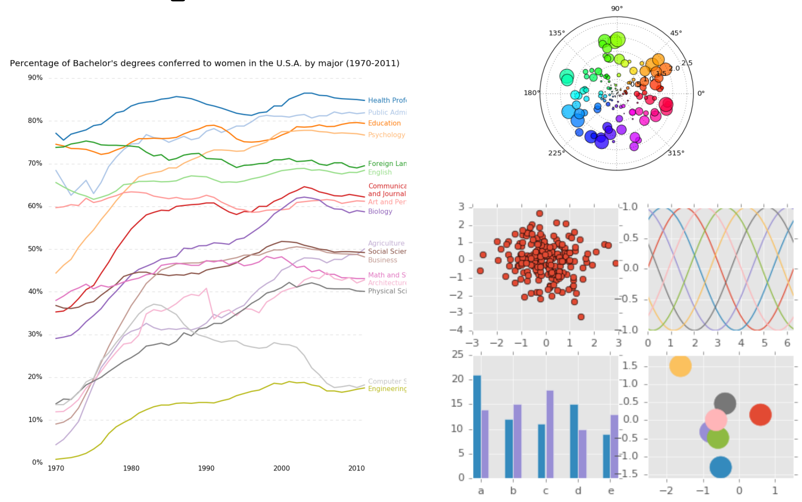
In all our examples, we will need to import the **numpy** and **matplotlib.pyplot** modules.
These come with Canopy – no need to download anything.

Resources

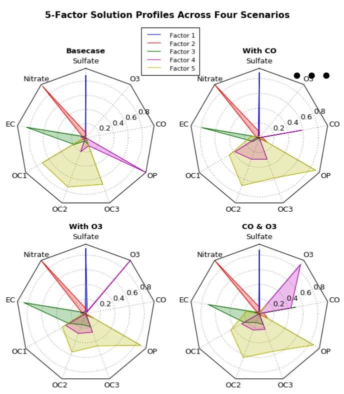
matplotlib examples: http://matplotlib.org/examples

pyplot documentation: http://matplotlib.org/api/pyplot_summary.html

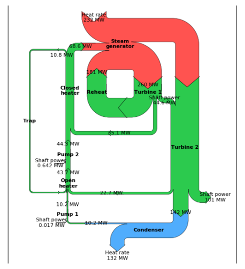
`matplotlib` can make these plots

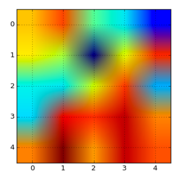


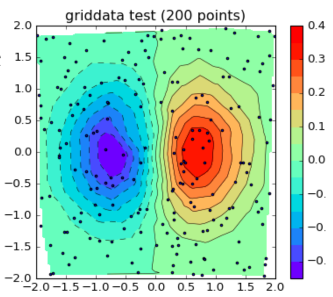
see more at http://matplotlib.org/gallery.html

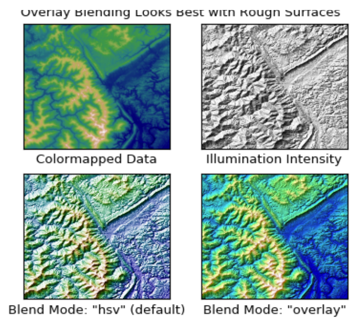


… and these

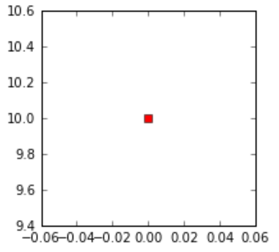






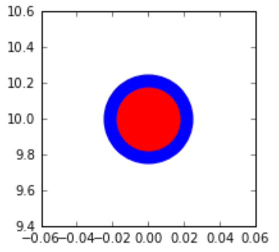

Overlay Blending Looks Best with Rough Surfaces
Colormapped Data
Illumination Intensity
Blend Mode: "hsv" (default)
Blend Mode: "overlay"

Starting simple: `plot` function



When a single value (e.g. 10) is provided, it's considered the y-value of a data point and is assigned x to 0. We can specify how the marker for the point displays.

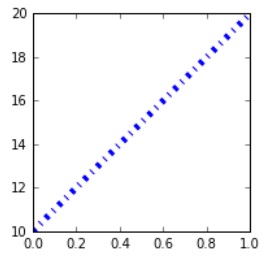
```
plt.figure(figsize=(3, 3))
plt.plot(10, color='red', marker='s')
plt.show()
```



The function **`plot`** specifies many named parameters (or keyword arguments) to control how a data point is displayed.

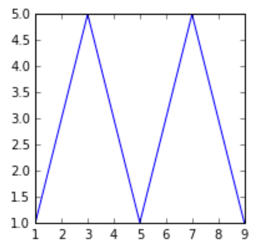
```
plt.figure(figsize=(3, 3))
plt.plot(10, color='red', marker='o',
         markersize=60,
         markeredgecolor='blue',
         markeredgewidth=10)
plt.show()
```

Plotting a line



A list of two values is displayed as line. Again, values are y-coordinates, and by default x is set to [0, 1]. Some arguments have default values, for example, line color is blue by default and the style is solid (see second plot).

```
plt.figure(figsize=(3, 3))
plt.plot([10, 20], linestyle='dashdot',
         linewidth=5)
plt.show()
```



But we can specify two lists: one with the x-coordinates and one with the y-coordinates for the data points. Then they are automatically connected by lines.

```
plt.figure(figsize=(3, 3))
plt.plot([1, 3, 5, 7, 9], [1, 5, 1, 5, 1]
plt.show()
```

The `plot` function

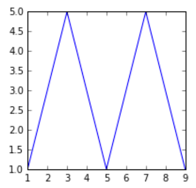
Accessing the documentation of plot via: **`help(ptl.plot)`** reveals its versatility:

```
In [447]: help(plt.plot)
Help on function plot in module matplotlib.pyplot:

plot(*args, **kwargs)
    Plot lines and/or markers to the
    :class:`~matplotlib.axes.Axes`.  *args* is a variable length
    argument, allowing for multiple *x*, *y* pairs with an
    optional format string.  For example, each of the following is
    legal::

        plot(x, y)        # plot x and y using default line style and color
        plot(x, y, 'bo')  # plot x and y using blue circle markers
        plot(y)           # plot y using x as index array 0..N-1
        plot(y, 'r+')     # ditto, but with red plusses
```

Notice string argument values such as 'bo', 'r+' and 'g-' for the marker/line appearance (first letter is the color, second character the marker or line style).

Also, many common keyword arguments have shorter names: color is c, markersize is ms, linewidth is lw, linestyle is ls, etc.

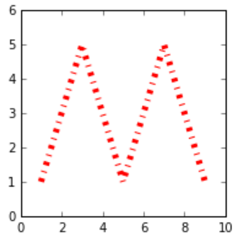
Controlling axes



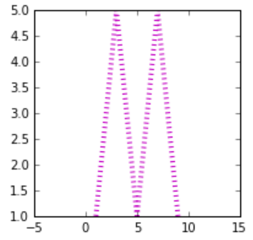
```
x = [1, 3, 5, 7, 9] and y = [1, 5, 1, 5, 1]
```

The axes automatically fit the provided range values. We can control them in different ways with the functions:

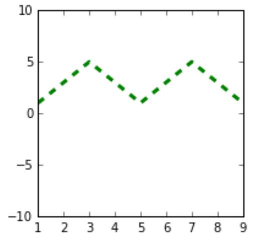
```
axis([xmin, xmax, ymin, ymax]) # also, 'off', and 'equal'
xlim((xmin, xmax))             # takes tuple or list or one or two values
ylim((ymin, ymax))
```



```
plt.plot(x, y, 'r-.', lw=5)
plt.axis([0, 10, 0, 6])
```

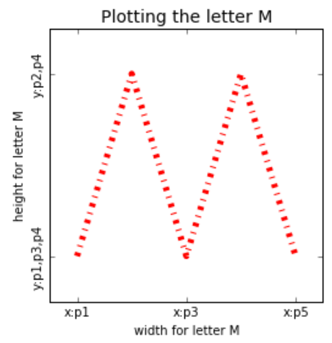


```
plt.plot(x, y, 'm:', lw=4)
plt.xlim((-5, 15))
```



```
plt.plot(x, y, 'g--', lw=3)
plt.ylim((-10, 10))
```

Decorating the Plot



The functions **xticks** and **yticks** control the location and values of ticks on axes.
We can supply text labels for the axes with **xlabel** and **ylabel** and a **title** for the plot.

```
x = [1, 3, 5, 7, 9]
y = [1, 5, 1, 5, 1]
plt.figure(figsize=(4, 4))
plt.plot(x, y, 'r-.', lw=5)
plt.axis([0, 10, 0, 6])
plt.xticks([1, 5, 9],
           ['x:p1', 'x:p3', 'x:p5'])
plt.yticks([1, 5],
           ['y:p1,p3,p4', 'y:p2,p4'],
           rotation=90)
plt.xlabel("width for letter M")
plt.ylabel("height for letter M")
plt.title("Plotting the letter M",
         fontsize=14)
plt.show()
```

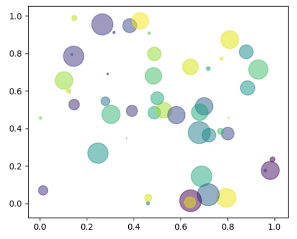
More commands and plot types

Before **plt.show**, you can use **plt.savefig("filename")** to save the plot in a file. Use **.png** as file ending. Don't put savefig after show, it saves an empty file.

This is a **scatter** plot with random points and colors. Notice **alpha** to make colors half-transparent. Uses the powerful **numpy** library.

The **plt** module specifies several dedicated functions. We'll study a few of them, for others, check examples online.

bar – bar chart (vertical)
barh – bar chart horizontal
hist – histogram
pie – pie chart
scatter – scatter splot
step – stepwise line
subplots – multiple plots in a figure



```
N = 50
x = np.random.rand(N)
y = np.random.rand(N)
colors = np.random.rand(N)
area = np.pi *(15 * np.random.rand(N))**2
plt.scatter(x, y, s=area, c=colors,
            alpha=0.5)
plt.show()
```

Plotting Overview

1. Plots are 2-dimensional.
2. We need to provide x and y coordinates for the points to be drawn.
3. We will create plots by using functions that expect two lists of values for x and y.
4. Usually we have a set of points x and we will apply a math function (square, sin, etc.) to get the corresponding y values. Thus, we need the **mapping** pattern.
5. These functions take keyword arguments that control the appearance of the data points: color, marker shape, line type, line width, etc.
6. The pyplot library (**plt** for short) and its functions create and manipulate a single figure object that it's updated every time we invoke a new function.
7. This object is implicit, we don't access it directly. This is why we can write several statements without an explicit mention of this object:

```
plt.plot(x, y)
plt.xlabel("some label")
plt.xlim((10, 50))
plt.show()
```

plt is not an object, it's a module. Verify it with **type(plt)**. You can see the list of all available functions and classes with **dir(plt)**.

Mapping & Filtering with List Comprehension

A shorthand way of implementing the **mapping** and **filtering** patterns.

THE OLD WAY

The mapping pattern.

```
squares = [ ]
for x in range(5):
    squares.append(x**2)
```

squares → `[0,1,4,9,16]`

NEW with list comprehensions

```
squares = [x**2 for x in range(5)]
```

Starts and ends w/square brackets

How to write list comprehensions?

THE OLD WAY

```
evens = [ ]
for x in range(10):
    if x%2 == 0:
        evens.append(x)
```

The filtering pattern.

```
for item in sequence:
        if conditional:
              .append(expression)
```

evens → `[0,2,4,8]`

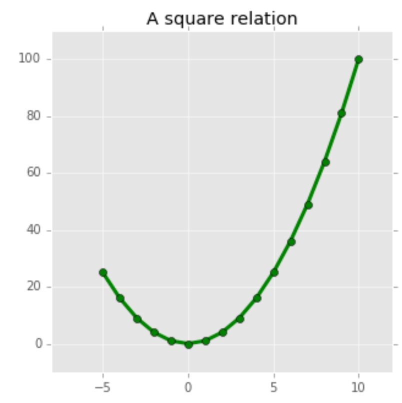
NEW with list comprehensions

```
evens = [x for x in range(10) if x%2 == 0]
```

```
[expression for item in sequence if conditional]
```

Plotting (with list comprehensions)

```
# Preparing data for plotting
xvals = range(-5, 11)
                 # [-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10]
yvals = [x**2 for x in xvals]
                 # [25,16,9,4,1,0,1,4,9,16,25,36,49,64,81,100]
```



```
plt.style.use('ggplot')
plt.figure(figsize=(5, 5))

plt.plot(xvals, yvals, 'go-', lw=3)

plt.axis([-8, 12, -10, 110])
plt.title("A square relation")
plt.show()
```

The statement:

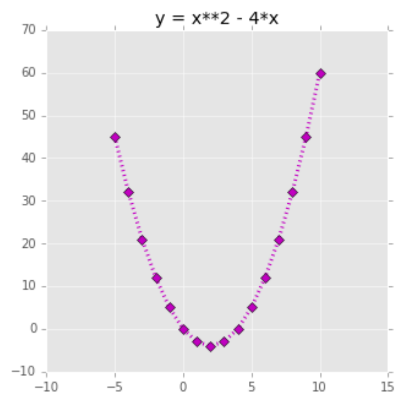
`plt.style.use('ggplot')`

controls the general style of a plot, we'll use at the start of a script file.

More plotting (with list comprehensions)

it's your turn

```
xvals = range(-5, 11)
                 # [-5,-4,-3,-2,-1,0,1,2,3,4,5,6,7,8,9,10]
```



Given the mapping function:

```
y = x**2 - 4*x
```

generate the plot that shows the relation between **x** and **y**.

To make it easier for you, we're showing you how it should look like.

The string value for the line/marker style is 'm:D' short for "magenta, dotted line, diamond marker"

Englishwords (with list comprehension)

Remember the list of English words from PS5. Here are some fun exercises to see the power of list comprehension.

```
from vocabulary import englishwords
```

Ex 1: Generate the list of lengths of all words:

```
wordLengths = [                                   ]
```

Ex 2: Generate the list of all words shown as uppercase (use the string method **`upper`**).

```
upperWords = [                                    ]
```

Ex 3: Make use of **`isVowel`** to create the list of all words that start with a vowel. (there are 12119 such words in the list). Use filtering!

```
startWithVowel = [                                ]
```

Englishwords (with list comprehension)

Ex 4: Generate the list of all words with length of 5.
(there are 4684 such words, e.g, brick, comet, genes, etc.)

```
wordLength5 = [                                   ]
```

Ex 5: Generate the list of all words that start and end with a vowel.
(there are 1788 such words, e.g., able, above, absence, etc.

```
vowelWords = [                                    ]
```

Ex 6: Generate the list of all words that start and end with the same letter.
(there are 4450 such words, e.g. yearly, suntans, scripts, etc.

```
sameStartEnd = [                                  ]
```

Analyzing English words [1]

Problem: Find the frequency of words starting with a vowel.

Solution 1: Combine a dictionary with a list comprehension.

```
vDct = {}
for v in "aeiou":
    vDct[v] = len([w for w in englishwords if w[0] == v])
```

Solution 2: Only use a dictionary.

```
vDct = {}
for w in englishwords:
    if isVowel(w[0]):
        vDct[w[0]] = vDct.get(w[0], 0) + 1
```

```
In []: vDct
Out[]: {'a': 3683, 'e': 2783, 'i': 2809, 'o': 1632, 'u': 1212}
```

Analyzing English words [2]

Problem: Find the frequency of words starting with each letter of the alphabet.

Solution 1: Combine a dictionary with a list comprehension.

```
freqDct = {}
from string import lowercase
for c in lowercase:
    freqDct[c] = len([w for w in englishwords if w[0] == c])
```

Solution 2: Only use a dictionary.

```
freqDct = {}
```

Inefficiency of nested loops

Digging Deeper

Measuring execution time. In the notebook we show two snippets of code to measure the length of execution for the two solutions of Slide 20.

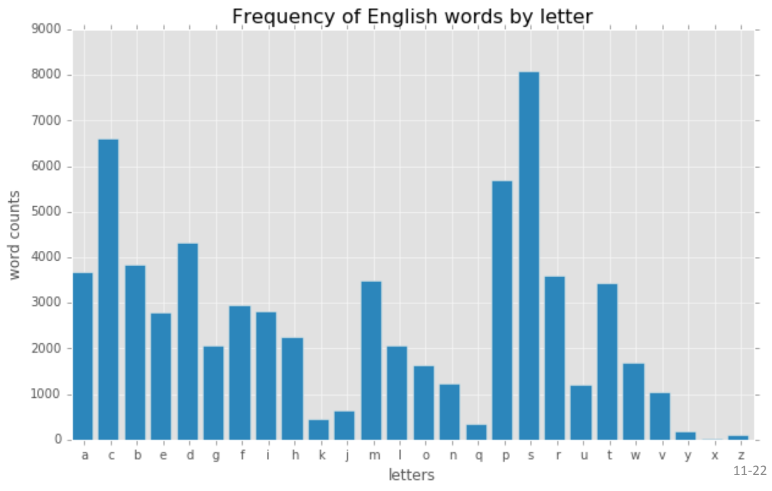
```
import time
t1 = time.time()     # starting moment
# some statements to execute
t2 = time.time()     # end moment
print t2 - t1        # elapsed time between two moments
```

Solution 1 is about 10 times slower than Solution 2. The reason is that in Solution 1 we have a hidden nested loop (within the list comprehension), thus, we are iterating 26 times over 66230 words.
In Solution 2, we are only doing one single iteration over all the words.

When possible, change your solution to contain a single loop. But, there are cases in which you cannot avoid nested loops.

Plotting the results

Task: Generate a bar chart with the frequency of words starting with each letter.



Code for the Bar Chart

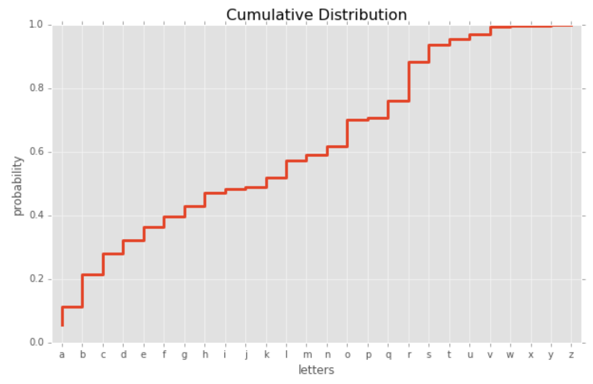
```
from numpy import arange
from string import lowercase

# get the values in alphabetical order
counts = [frDct[char] for char in lowercase]

plt.figure(figsize=(10, 6)) # make figure of certain size

plt.bar(range(26), counts) # bar chart needs indices in x
plt.xlim((0,26)) # limit the x axis to a certain range

# specify where and what to show as ticks in x axis
plt.xticks(arange(0.5, 26.5), list(lowercase))

# set labels for axes and figure title
plt.xlabel('letters')
plt.ylabel('word counts')
plt.title('Frequency of English words by letter', fontsize=16)
```

`arange` vs. **`range`**
Use **`range`** to generate integers, use **`arange`** to generate floats.

Challenge: Cumulative Distribution

it's your turn

Changing the statement:
`plt.bar(range(26), counts)` to
`plt.step(range(26), counts)`
creates a stepwise chart similar to the one below. However, this plot depicts a cumulative distribution, which is different from a histogram.



Your task: Figure out how to calculate the y-values. **Hint**: you can use a function that we studied in Lecture 9 (about list patterns). If you plug-in the new values for **`counts`** in the code from slide 11-23 and change the axis labels, you'll get this plot.