VISUALIZATION OF DATA

VISUALIZING RESULTS

- earlier saw examples of different orders of growth of procedures
- used graphs to provide an intuitive sense of differences
- example of leveraging an existing library, rather than writing procedures from scratch
- Python provides libraries for (among other topics):
  - graphing
  - numerical computation
  - stochastic computation
- want to explore idea of using existing library procedures to guide processing and exploration of data

USING PYLAB

- can import library into computing environment

```
import pylab as plt
```

  - allows me to reference any library procedure as `plt.<procName>`

my own shorthand for plotting function

- provides access to existing set of graphing/plotting procedures
- here will just show some simple examples; lots of additional information available in documentation associated with `pylab`
- will see many other examples and details of these ideas if you opt to take 6.00.2x

taken as being the X and Y values of some function

SIMPLE EXAMPLE

- basic function plots two lists as x and y values
  - other data structures more powerful, use lists to demonstrate
- first, let's generate some example data

array lets you do some processing very straightforwardly

```
mySamples = []
myLinear = []
myQuadratic = []
myCubic = []
myExponential = []
```

separate out the X values, which are my samples, from a linear function over those X values (Y values)

```
for i in range(0, 30):
    mySamples.append(i)
    myLinear.append(i)
    myQuadratic.append(i**2)
    myCubic.append(i**3)
    myExponential.append(1.5**i)
```

selected 1.5 to keep displays visible, more likely value for order of growth example would be 2

SIMPLE EXAMPLE

- to generate a plot, call

X values Y values

```
plt.plot(mySamples, myLinear)
```

- arguments are lists of values (for now)
  - lists must be of the same length

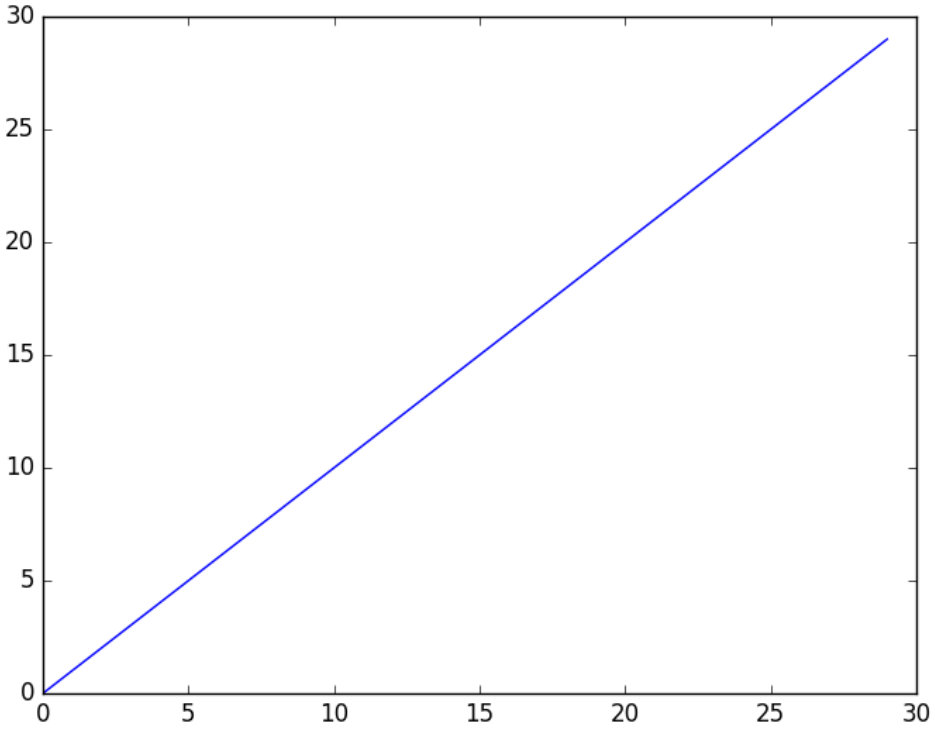
could be other (more powerful) data structures

- calling function in an iPython (interactive) console will generate plots within that console

nice if I actually want to do the manipulation

- calling function in a Python console will create a separate window in which plot is displayed

EXAMPLE DISPLAY




```
plt.plot(mySamples, myLinear)
```

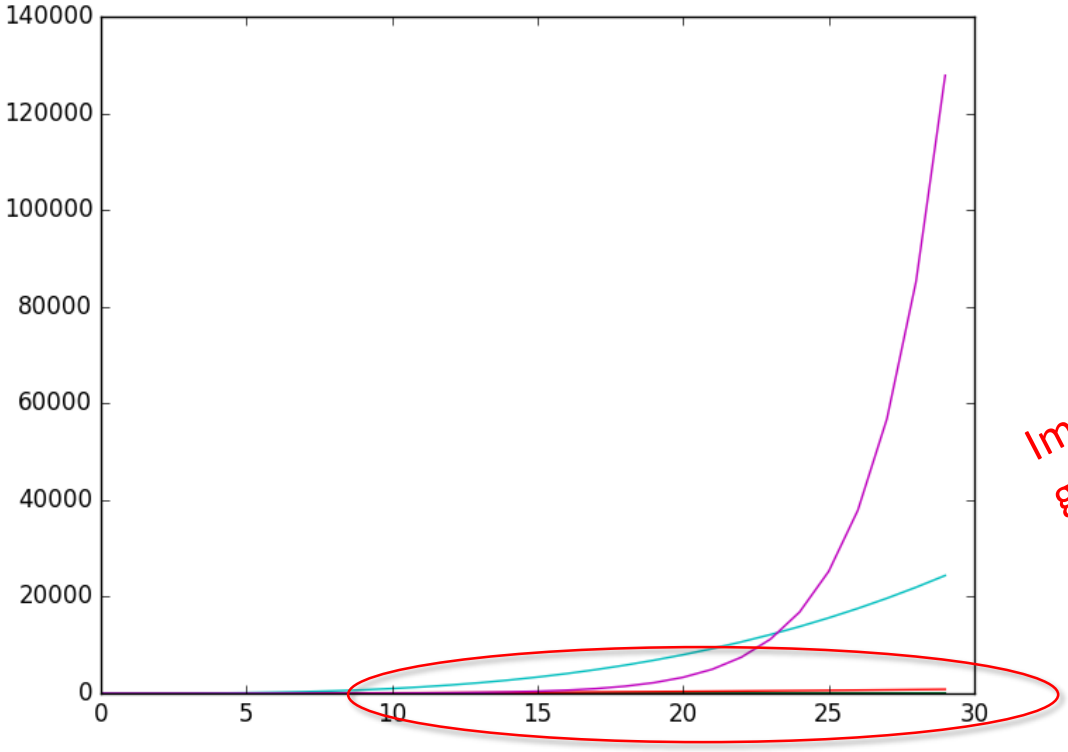
OVERLAPPING DISPLAYS

- suppose we want to display all of the graphs of the different orders of growth
- we could just call:

keeping the same x values here because I want to have the same x-coordinate

```
plt.plot(mySamples, myLinear)
plt.plot(mySamples, myQuadratic)
plt.plot(mySamples, myCubic)
plt.plot(mySamples, myExponential)
```

EXAMPLE OVERLAY DISPLAY



Impossible to see linear graph, or even quadratic graph

```
plt.plot(mySamples, myLinear)
plt.plot(mySamples, myQuadratic)
```

```
plt.plot(mySamples, myCubic)
plt.plot(mySamples, myExponential)
```

OVERLAPPING DISPLAYS

- not very helpful, can't really see anything but the biggest of the plots because the scales are so different
- can we graph each one separately?
- call

```
plt.figure(<arg>)
```

gives a name to this figure; allows us to reference for future use

  - creates a new display with that name if one does not already exist
  - if a display with that name exists, reopens it for processing

EXAMPLE CODE

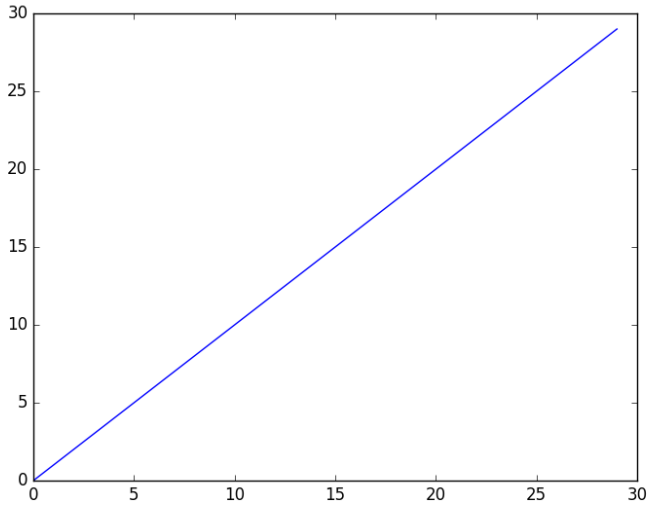
creating four different displays/figures, each one with its own plot inside

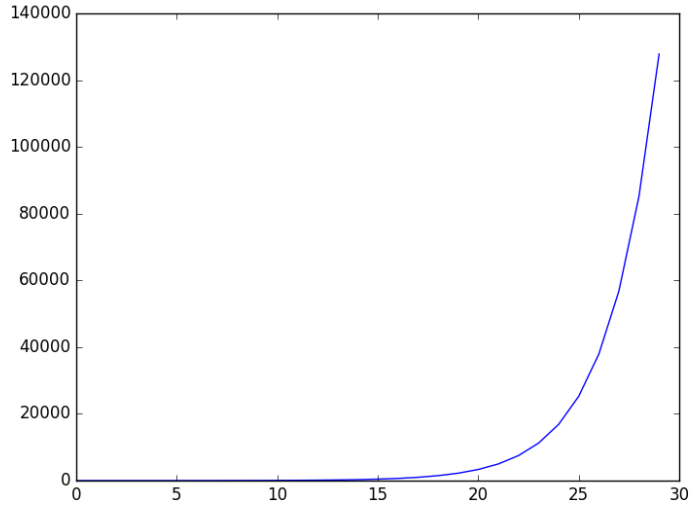
```
plt.figure('lin')
plt.plot(mySamples, myLinear)
plt.figure('quad')
plt.plot(mySamples, myQuadratic)
plt.figure('cube')
plt.plot(mySamples, myCubic)
plt.figure('expo')
plt.plot(mySamples, myExponential)
```

SEPARATE PLOTS

The scale here is automatically set to be the largest y value

calling plt.figure figure of lin opened up a window, or a graph, with the name lin, inside of which I plotted my samples and my linear.






```
plt.figure('lin')
plt.plot(mySamples, myLinear)
```

```
plt.figure('expo')
plt.plot(mySamples,
myExponential)
```

PROVIDING LABELS

- Should really label the axes

```
plt.figure('lin')
plt.xlabel('sample points')
plt.ylabel('linear function')
plt.plot(mySamples, myLinear)
plt.figure('quad')
plt.plot(mySamples, myQuadratic)
plt.figure('cube')
plt.plot(mySamples, myCubic)
plt.figure('expo')
plt.plot(mySamples, myExponential)
plt.figure('quad')
plt.ylabel('quadratic function')
```

open up a figure

functions to label axes

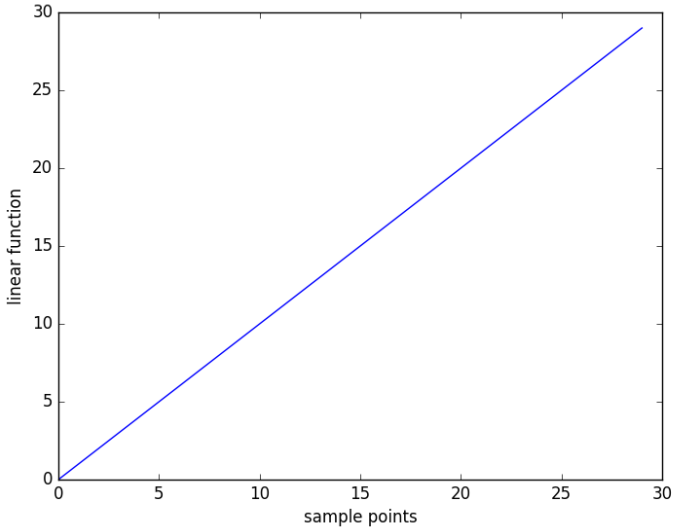
putting an x and y label on that graph, make sure I do the labels inside of the appropriate windows

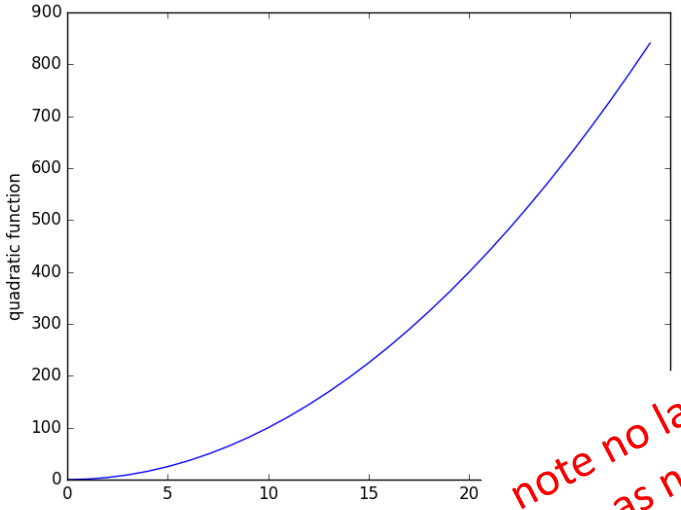
do the plotting

create/open up other figures

note you must make figure active before invoking labeling

LABELED AXES





note no label on x axis as no invocation while that display was active

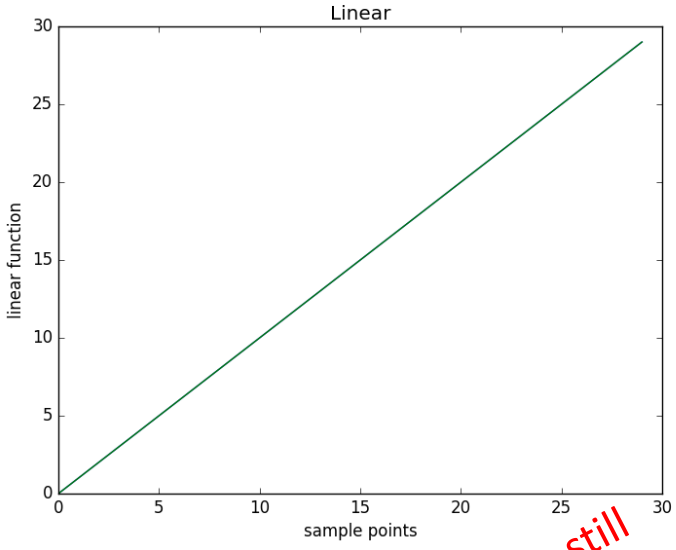
ADDING TITLES

```
plt.figure('lin')
plt.plot(mySamples, myLinear)
plt.figure('quad')
plt.plot(mySamples, myQuadratic)
plt.figure('cube')
plt.plot(mySamples, myCubic)
plt.figure('expo')
plt.plot(mySamples, myExponential)
```

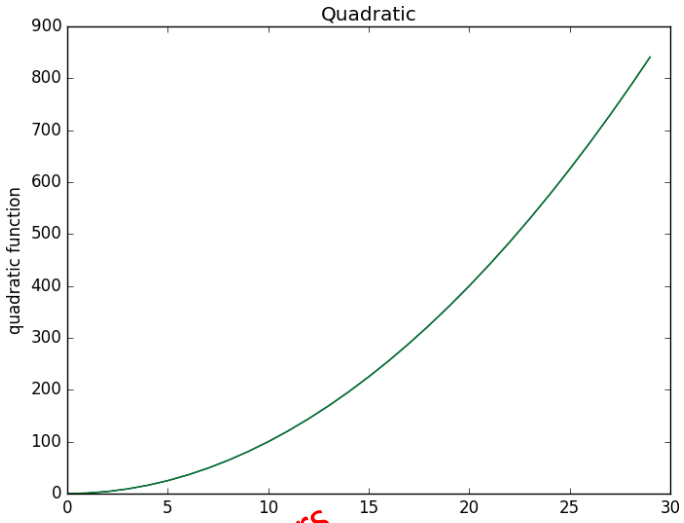
reopen each figure, put a label as title

```
plt.figure('lin')
plt.title('Linear')
plt.figure('quad')
plt.title('Quadratic')
plt.figure('cube')
plt.title('Cubic')
plt.figure('expo')
plt.title('Exponential')
```

TITLED DISPLAYS



why are axes still labeled?



why are colors the same in the two plots?

CLEANING UP WINDOWS

- we are reusing a previously created display window
- need to clear it before redrawing
  I had done earlier calls where I created those windows with those names, and I'd done things in them
- because we are calling plot in a new version of a window, system starts with first choice of color (hence the same); we can control (see later)

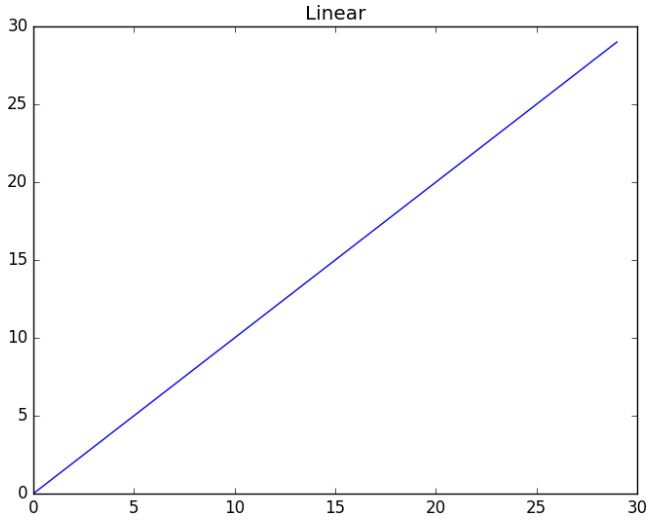
CLEANING WINDOWS

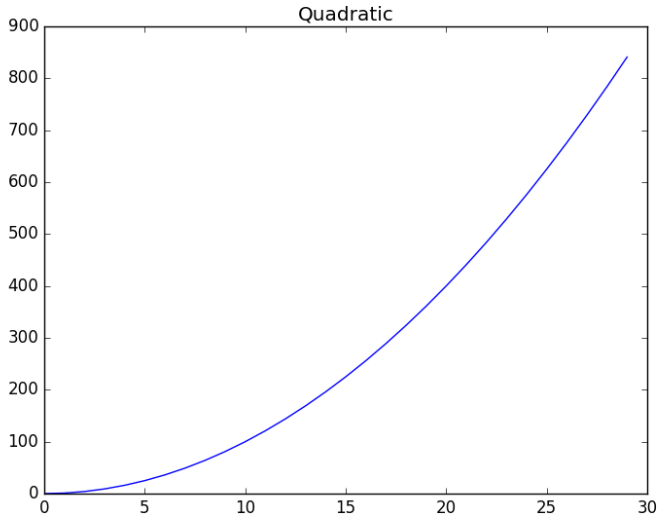
when I open up a figure, in case I've had an earlier version of it open previously, I'm going to clear it.

```
plt.figure('lin')
plt.clf()
plt.plot(mySamples, myLinear)
plt.figure('quad')
plt.clf()
plt.plot(mySamples, myQuadratic)
plt.figure('cube')
plt.clf()
plt.plot(mySamples, myCubic)
plt.figure('expo')
plt.clf()
plt.plot(mySamples, myExponential)
```

```
plt.figure('lin')
plt.title('Linear')
plt.figure('quad')
plt.title('Quadratic')
plt.figure('cube')
plt.title('Cubic')
plt.figure('expo')
plt.title('Exponential')
```

CLEARED DISPLAYS





COMPARING RESULTS

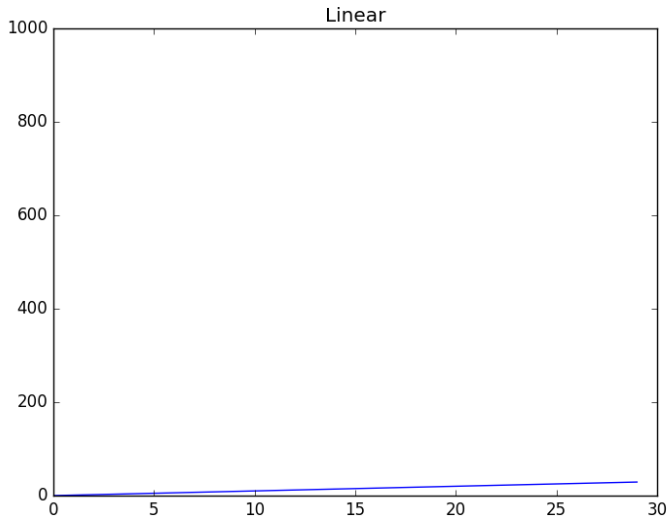
- now suppose we would like to compare different plots
- in particular, the scales on the graphs are very different
- one option is to explicitly set limits on the axis or axes
- a second option is to plot multiple functions on the same display but to choose which ones I want to display

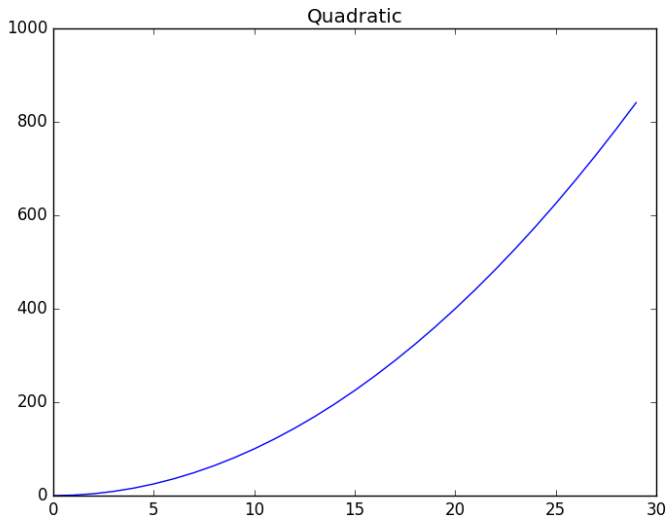
CHANGING LIMITS ON AXES

```
plt.figure('lin')
plt.clf()
plt.ylim(0,1000)
plt.plot(mySamples, myLinear)
plt.figure('quad')
plt.clf()
plt.ylim(0,1000)
plt.plot(mySamples, myQuadratic)
plt.figure('lin')
plt.title('Linear')
plt.figure('quad')
plt.title('Quadratic')
```

CHANGING LIMITS ON AXES

now I can see what's the difference
between a linear function and a quadratic function





set up a figure, clear it, plot two functions inside of that figure, pick a second one, clear it, and plot another two functions inside of that frame

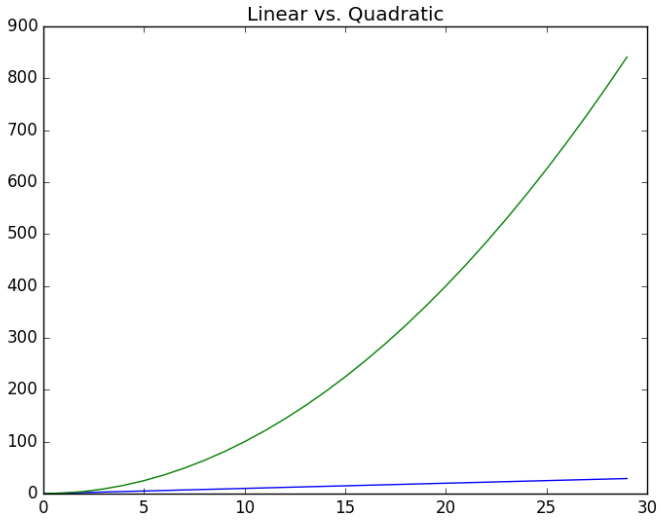
OVERLAYING PLOTS

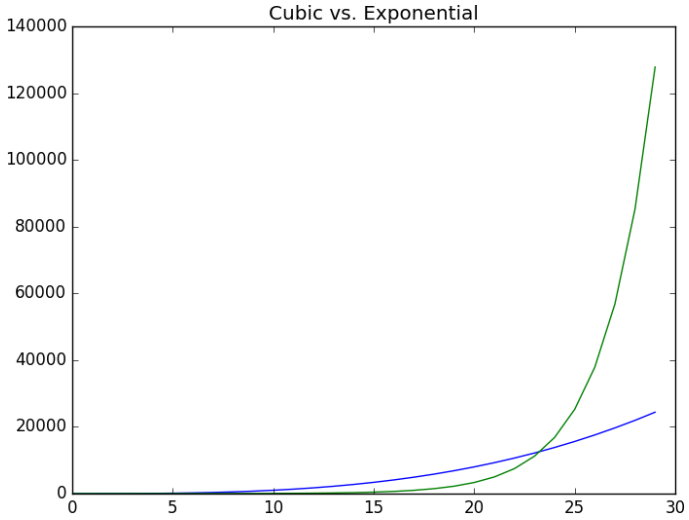
```
plt.figure('lin quad')
plt.clf()
plt.plot(mySamples, myLinear)
plt.plot(mySamples, myQuadratic)

plt.figure('cube exp')
plt.clf()
plt.plot(mySamples, myCubic)
plt.plot(mySamples, myExponential)
plt.figure('lin quad')
plt.title('Linear vs. Quadratic')
plt.figure('cube exp')
plt.title('Cubic vs. Exponential')
```

each pair of calls within the same active display window

each pair of calls within the same active display window

OVERLAYING PLOTS





ADDING MORE DOCUMENTATION

- can add a legend that identifies each plot

```
plt.figure('lin quad')
plt.clf()
plt.plot(mySamples, myLinear, label = 'linear')
plt.plot(mySamples, myQuadratic, label = 'quadratic')
plt.legend(loc = 'upper left')
plt.title('Linear vs. Quadratic')

plt.figure('cube exp')
plt.clf()
plt.plot(mySamples, myCubic, label = 'cubic')
plt.plot(mySamples, myExponential, label = 'exponential')
plt.legend()
plt.title('Cubic vs. Exponential')
```

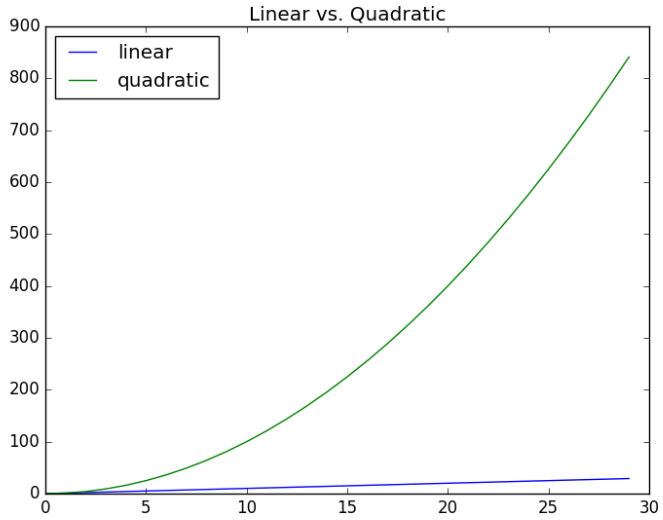
label each plot

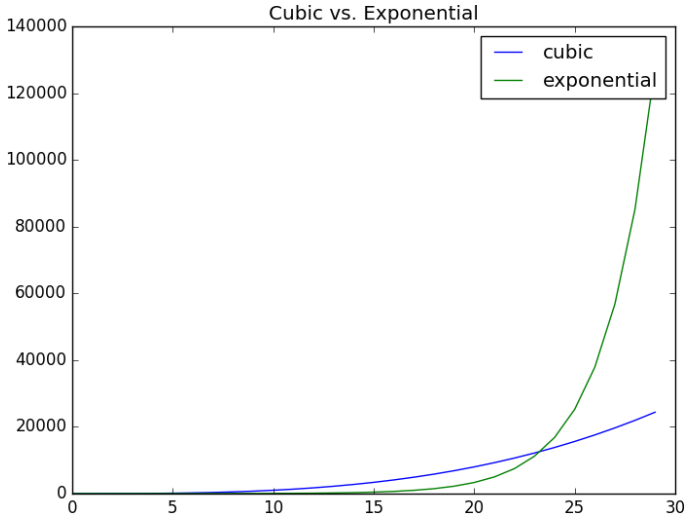
can specify a location

decide where am I going to put the legend

can use best location

ADDING MORE DOCUMENTATION





CONTROLLING DISPLAY PARAMETERS

- now suppose we want to control details of the displays themselves
- examples:
  - changing color or style of data sets
  - changing width of lines or displays
  - using subplots

CHANGING DATA DISPLAY

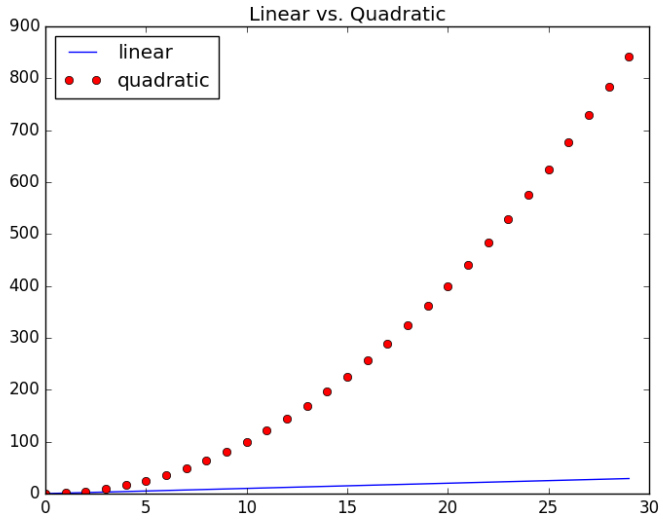
```
plt.figure('lin quad')
plt.clf()
plt.plot(mySamples, myLinear, 'b-', label = 'linear')
plt.plot(mySamples, myQuadratic,'ro', label = 'quadratic')
plt.legend(loc = 'upper left')
plt.title('Linear vs. Quadratic')

plt.figure('cube exp')
plt.clf()
plt.plot(mySamples, myCubic, 'g^', label = 'cubic')
plt.plot(mySamples, myExponential, 'r--',label = 'exponential')
plt.legend()
plt.title('Cubic vs. Exponential')
```

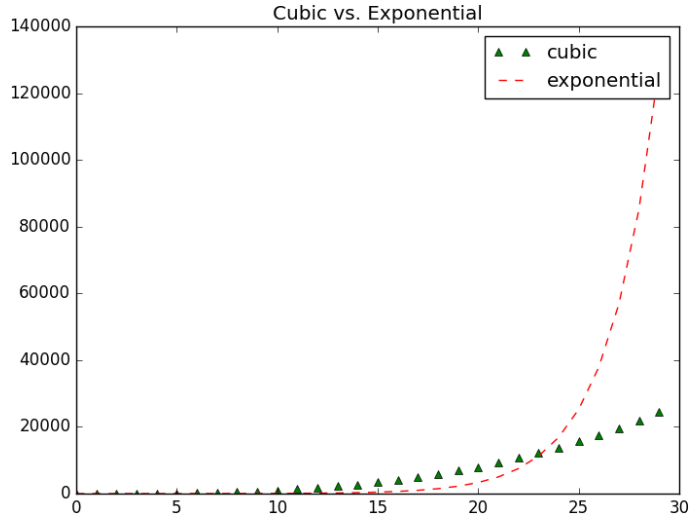
colour, style

string specifies color and style

see documentation for choices of color and style

CHANGING DATA DISPLAY



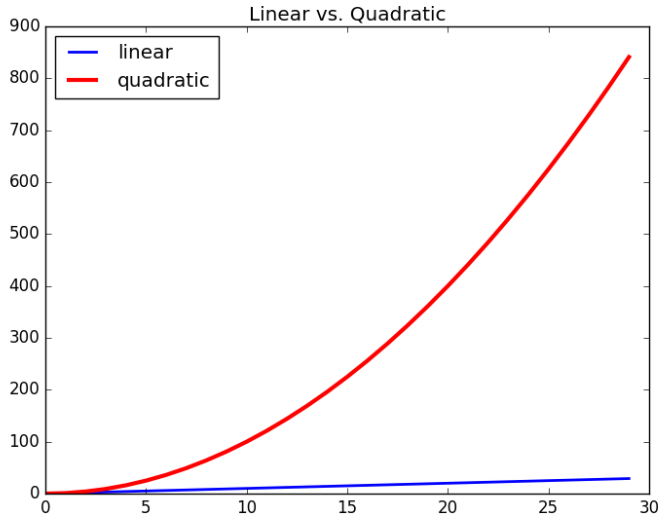


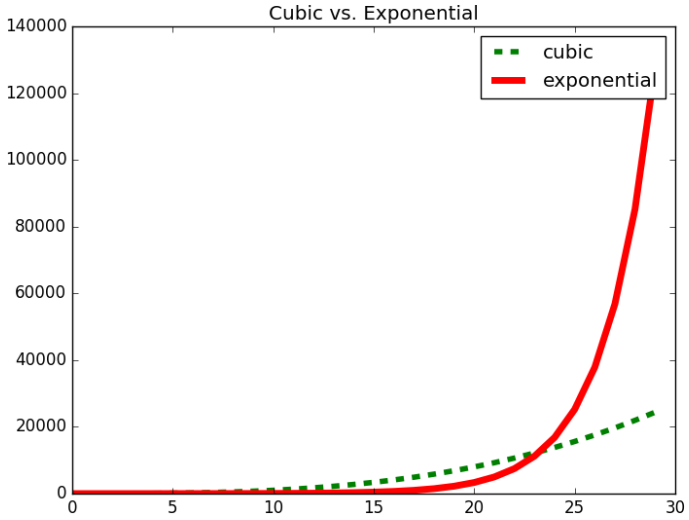
CHANGING DATA DISPLAY

```
plt.figure('lin quad')
plt.clf()
plt.plot(mySamples, myLinear, 'b-', label = 'linear', linewidth = 2.0)
plt.plot(mySamples, myQuadratic,'r', label = 'quadratic', linewidth = 3.0)
plt.legend(loc = 'upper left')
plt.title('Linear vs. Quadratic')

plt.figure('cube exp')
plt.clf()
plt.plot(mySamples, myCubic, 'g--', label = 'cubic', linewidth = 4.0)
plt.plot(mySamples, myExponential, 'r',label = 'exponential', linewidth = 5.0)
plt.legend()
plt.title('Cubic vs. Exponential')
```

keyword can change size of parameter

CHANGING DATA DISPLAY





USING SUBPLOTS

```
plt.figure('lin quad')
plt.clf()
plt.subplot(211)
plt.ylim(0,900)
plt.plot(mySamples, myLinear, 'b-', label = 'linear', linewidth = 2.0)
plt.subplot(212)
plt.ylim(0,900)
plt.plot(mySamples, myQuadratic, 'r', label = 'quadratic', linewidth = 3.0)
plt.legend(loc = 'upper left')
plt.title('Linear vs. Quadratic')

plt.figure('cube exp')
plt.clf()
plt.subplot(121)
plt.ylim(0, 140000)
plt.plot(mySamples, myCubic, 'g--', label = 'cubic', linewidth = 4.0)
plt.subplot(122)
plt.ylim(0, 140000)
plt.plot(mySamples, myExponential, 'r',label = 'exponential', linewidth = 5.0)
plt.legend()
plt.title('Cubic vs. Exponential')
```

arguments are the number of rows, number of columns inside of the plot, which location to use

display something with two rows and one column, so two graphs like this.

setting the limit within each subplot

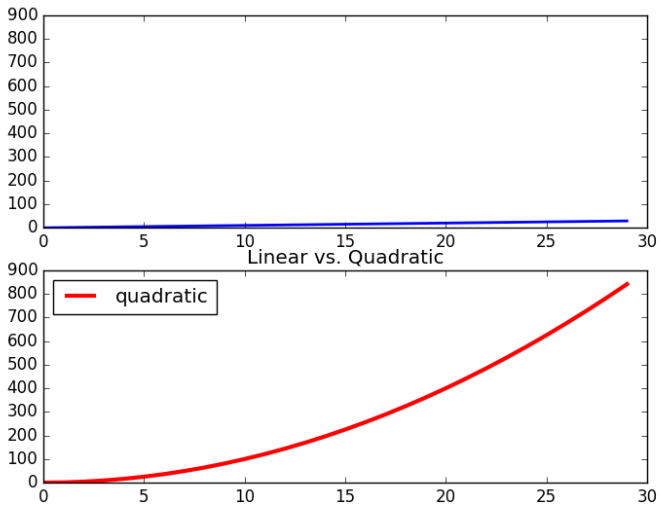
do something with one row and two columns

arguments are number of rows & cols; and which location to use

set limit within each subplot

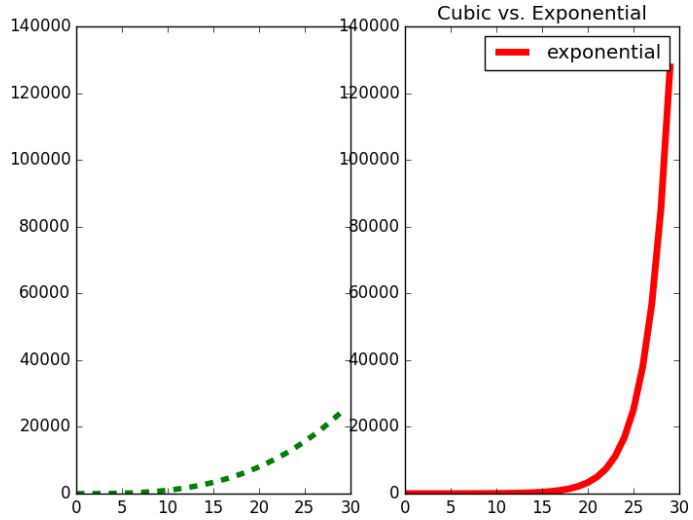
USING SUBPLOTS

one column and two rows



same y limits

one row and two columns



same y limits

CHANGING SCALES

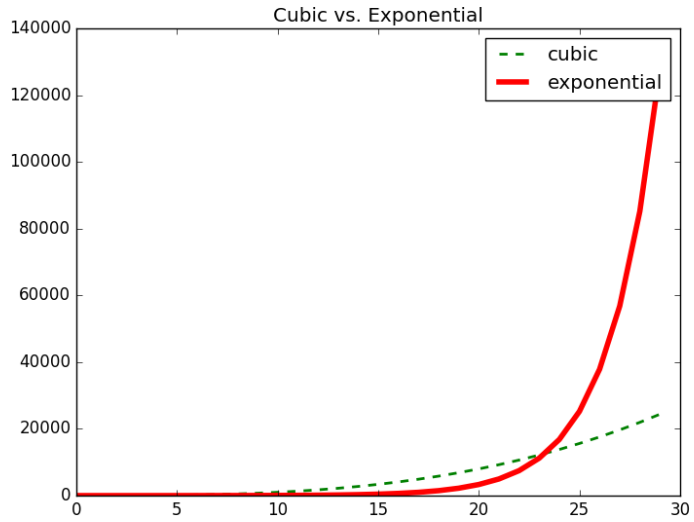
if I've got something that actually grows really rapidly, rather than plotting them linear and linear, could plot them where one of the axes is done on a log scale

```
plt.figure('cube exp log')
plt.clf()
plt.plot(mySamples, myCubic, 'g--', label = 'cubic', linewidth = 2.0)
plt.plot(mySamples, myExponential, 'r',label = 'exponential', linewidth = 4.0)
plt.yscale('log')
plt.legend()
plt.title('Cubic vs. Exponential')

plt.figure('cube exp linear')
plt.clf()
plt.plot(mySamples, myCubic, 'g--', label = 'cubic', linewidth = 2.0)
plt.plot(mySamples, myExponential, 'r',label = 'exponential', linewidth = 4.0)
plt.legend()
plt.title('Cubic vs. Exponential')
```

argument specifies type of scaling

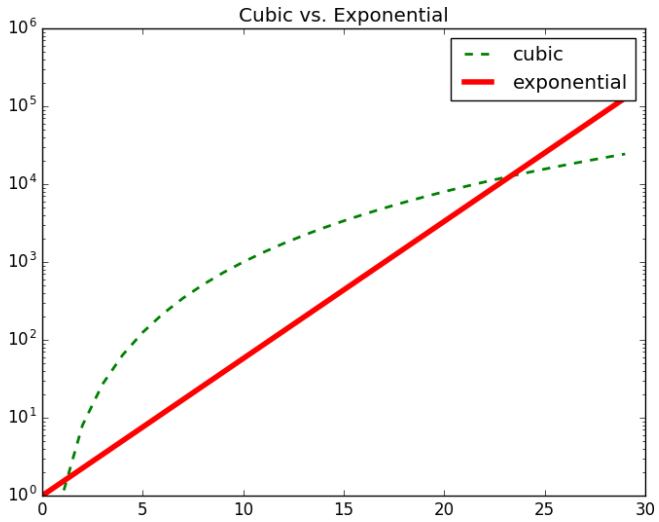
CHANGING SCALES

linear



each incremental step here is an increase of an order of magnitude

logarithmic



AN EXAMPLE

- want to explore how ability to visualize results can help guide computation
- simple example
  - planning for retirement
  - intend to save an amount `m` each month
  - expect to earn a percentage `r` of income on investments each month
  - want to explore how big a retirement fund will be compounded by time ready to retire

AN EXAMPLE: compound interest

```
def retire(monthly, rate, terms):
    savings = [0]
    base = [0]
    mRate = rate/12
    for i in range(terms):
        base += [i]
        savings += [savings[-1]*(1 + mRate) + monthly]
    return base, savings
```

set up two lists, going to be my y and x values

annual rate, but every month, so divide it by 12

label for the x-axis, so the next month

value of savings the previous month, and I add to it something that adds in the extra rate

add in the new monthly contribution

a base list, which gives me the x labels, and a savings list, which gives me the y labels

DISPLAYING RESULTS vs. MONTH

different growths in retirement accounts
as I change how much I put aside each month

list of different monthly values

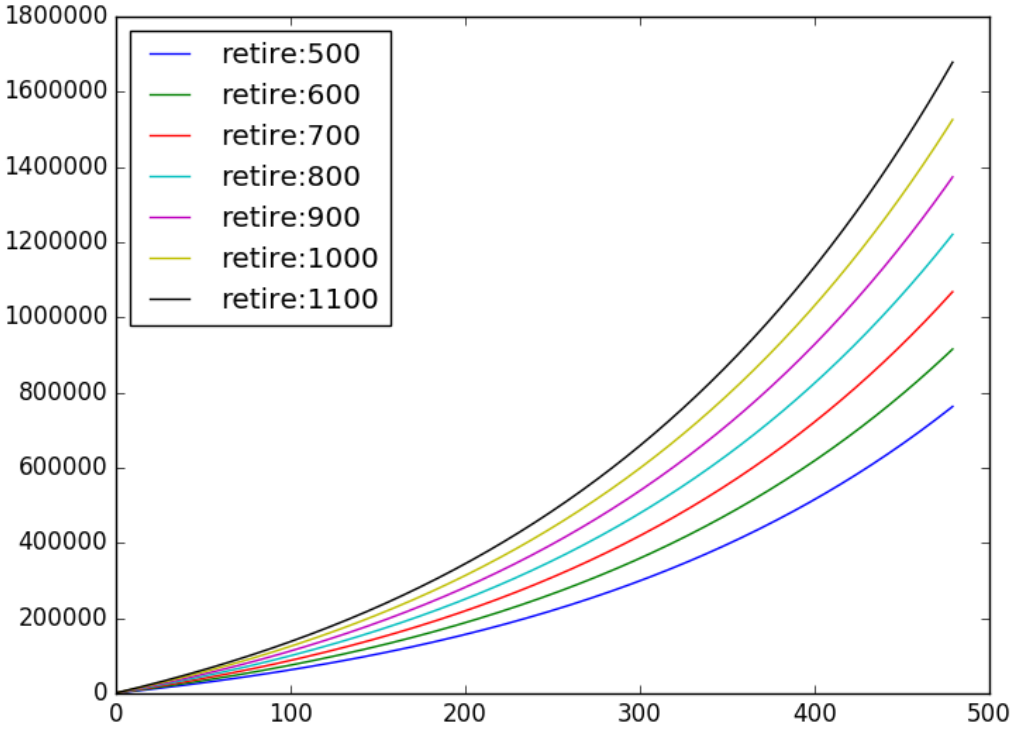
```
def displayRetireWMonthlies(monthlies, rate, terms):
    plt.figure('retireMonth')
    plt.clf()
    for monthly in monthlies:
        xvals, yvals = retire(monthly, rate, terms)
        plt.plot(xvals, yvals,
                 label = 'retire:'+str(monthly))
        plt.legend(loc = 'upper left')

displayRetireWMonthlies([500, 600, 700, 800, 900,
1000, 1100], .05, 40* 12)
```

clear frame so can reuse

plotting different versions

put informative label on each

DISPLAYING RESULTS vs. MONTH



ANALYSIS vs. CONTRIBUTION

- can see impact of increasing monthly contribution
  - ranges from about 750K to 1.67M, as monthly savings ranges from $500 to $1100

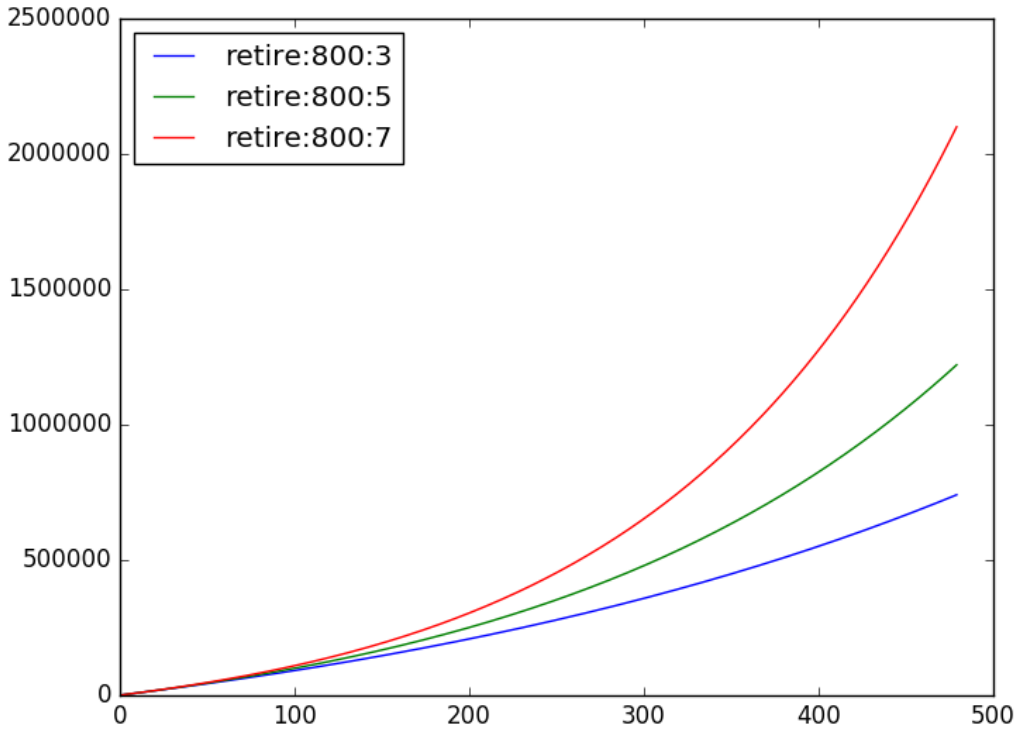
- what is effect of rate of growth of investments?

DISPLAYING RESULTS vs. RATE

```
def displayRetireWRates(month, rates, terms):
    plt.figure('retireRate')
    plt.clf()
    for rate in rates:
        xvals, yvals = retire(month, rate, terms)
        plt.plot(xvals, yvals,
                 label = 'retire:'+str(month)+ ':' + \
                         str(int(rate*100)))
        plt.legend(loc = 'upper left')

displayRetireWRates(800,[.03, .05, .07], 40*12)
```

put informative label on each

DISPLAYING RESULTS vs. RATE



ANALYSIS vs. RATE

- can also see impact of increasing expected rate of return on investments
  - ranges from about 600K to 2.1M, as rate goes from 3% to 7%

- what if we look at both effects together?

DISPLAYING RESULTS vs. BOTH

```
def displayRetireWMonthsAndRates(monthlies, rates, terms):
    plt.figure('retireBoth')
    plt.clf()
    plt.xlim(30*12, 40*12)
    for monthly in monthlies:
        for rate in rates:
            xvals, yvals = retire(monthly, rate, terms)
            plt.plot(xvals, yvals,
                     label = 'retire:'+str(monthly)+ ':' \
                             + str(int(rate*100)))
            plt.legend(loc = 'upper left')

displayRetireWMonthsAndRates([500, 700, 900, 1100],
                             [.03, .05, .07],
                             40*12)
```

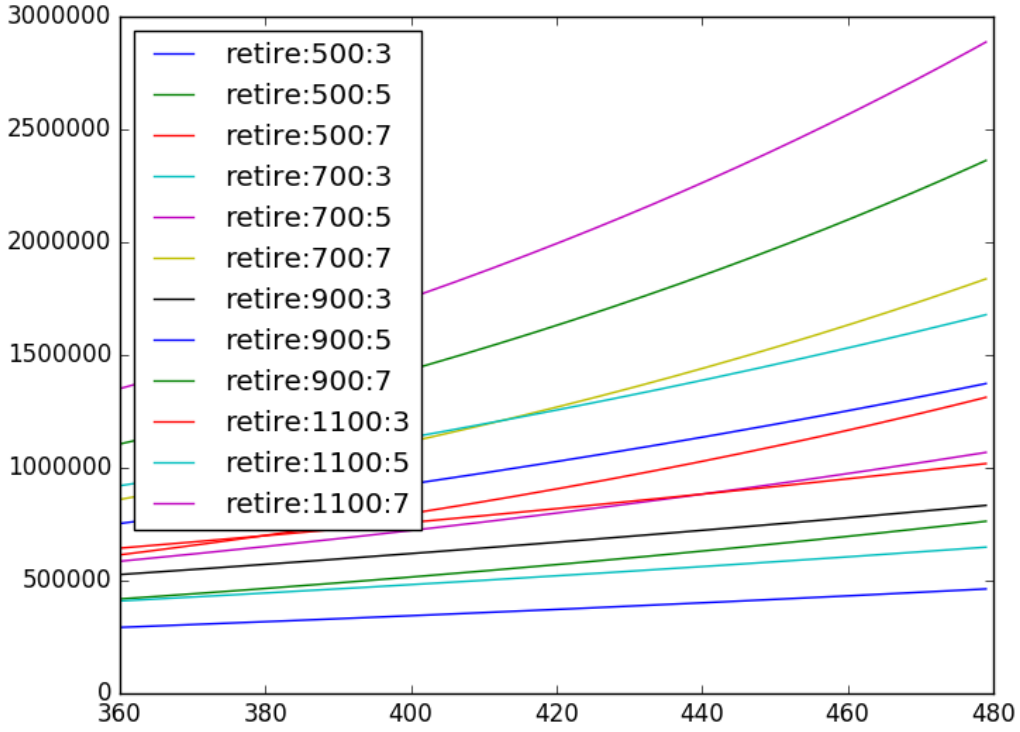
list of monthly rates, list of different rates what I expect of the return on investment

choosing the x limit, the x-axis

focus on last stages of fund

put informative label on each

DISPLAYING RESULTS vs. BOTH



DISPLAYING RESULTS vs. BOTH

- hard to distinguish because of overlap of many graphs
- could just analyze separately
- but can also try to visually separate effects

DISPLAYING RESULTS vs. BOTH

```
def displayRetireWMonthsAndRates(monthlies, rates, terms):
    plt.figure('retireBoth')
    plt.clf()
    plt.xlim(30*12, 40*12)
    monthLabels = ['r', 'b', 'g', 'k']
    rateLabels = ['-', 'o', '—']
    for i in range(len(monthlies)):
        monthly = monthlies[i]
        monthLabel = monthLabels[i%len(monthLabels)]
        for j in range(len(rates)):
            rate = rates[j]
            rateLabel = rateLabels[j%len(rateLabels)]
            xvals, yvals = retire(monthly, rate, terms)
            plt.plot(xvals, yvals,
                     monthLabel+rateLabel,
                      label = 'retire:'+str(monthly)+ ':' \
                              + str(int(rate*100)))
            plt.legend(loc = 'upper left')

displayRetireWMonthsAndRates([500, 700, 900, 1100], [.03, .05, .07],
                             40*12)
```

create sets of labels

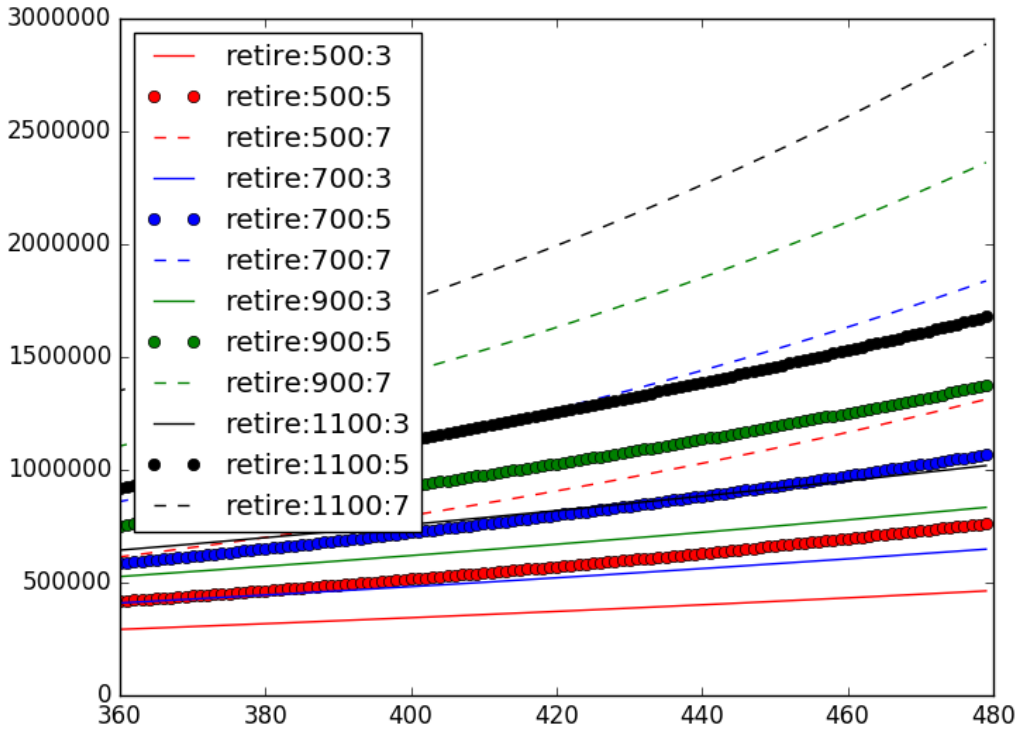
pick new label for each month choice

pick new label for each rate choice

create label for plot

need both a color and a style

DISPLAYING RESULTS vs. BOTH



DISPLAYING RESULTS vs. BOTH

- now easier to see grouping of plots
  - color encodes monthly contribute
  - format (solid, circle, dashed) encodes growth rate of investments
- interaction with plotting routines and computations allows us to explore data
  - change display range to zero in on particular areas of interest
  - change sets of values and visualize effect – then guides new choice of values to explore
  - change display parameters to highlight clustering of plots by parameter