

# Computational Physics

## Lecture 2

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git clone [https://github.com/ukzncompphys/lecture2\\_2017.git](https://github.com/ukzncompphys/lecture2_2017.git)

# Updates From You

- How many of you have now got python up and running?
- How many of you are using unix/linux of some form?
- Can you text edit?
- Will your laptops survive off of battery for two periods?

# Python

- Now that we're all comfortable in Unix (right?), let's learn basic python
- Python is *interpreted* - not compiled.
- Blocks are set off by indents - no END command.
- Python is *object oriented* - things know about themselves
- Python is highly extensible - just import stuff!
- Namespaces are distinct, functions remember where they came from - unless you specify otherwise.
- Python 2 vs 3 - some syntax changes. Most scientists still on 2...

# Hello World

```
Jonathans-MacBook-Pro:lecture3 sievers$ python
Python 2.7.5 (default, Sep 12 2013, 21:33:34)
[GCC 4.2.1 Compatible Apple LLVM 5.0 (clang-500.0.68)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> print 'hello world'
hello world
>>> print "hello world"
hello world
>>> ^D
Jonathans-MacBook-Pro:lecture3 sievers$
```

- Strings in python can be specified with either single or double quotes
- to show a string, just type print it!
- To start python, type “python” from a prompt
- to quit, hit ctrl-d

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat hello_world.py
print "hello world"
print 'hello world'
Jonathans-MacBook-Pro:lecture3 sievers$ python hello_world.py
hello world
hello world
Jonathans-MacBook-Pro:lecture3 sievers$
```

You can also execute scripts

# Variables

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat simple_variables.py
x=5
y=3.0
z=x+y
print 'z is ' + repr(z)
print 'z is a ' + repr(type(z))
print 'x is a ' + repr(type(x))
print 'y is a ' + repr(type(y))

Jonathans-MacBook-Pro:lecture3 sievers$ python simple_variables.py
z is 8.0
z is a <type 'float'>
x is a <type 'int'>
y is a <type 'float'>
Jonathans-MacBook-Pro:lecture3 sievers$
```

- Python has several built-in variable types. These include strings, floats, ints, boolean.
- You can create variables by assigning to them.
- You can see what type variables are with the *type* command.
- You can print their values with the *print* command. *repr* will return value as a string
- strings can be combined with '+'. Types may be automatically converted.

```
>>> z=3
>>> print 'z is ',z
z is 3
```

# Lists

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat list_example.py
mylist=['a','bc',4.0,5,['d',9]]
print mylist[0]
print mylist[2]
print mylist[-1]
Jonathans-MacBook-Pro:lecture3 sievers$ python list_example.py
a
4.0
['d', 9]
Jonathans-MacBook-Pro:lecture3 sievers$
```

- Many variables can be put together into a list
- Each member of a list is a variable (possibly another list!)
- Lists are indexed with []
- Index starts from 0
- Negative indices go from end of list

# Tuples

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat tuple_example.py
mylist=('a','bc',4.0,5,['d',9])
print mylist[0]
print mylist[2]
print mylist[-1]
mylist[2]=5.0
Jonathans-MacBook-Pro:lecture3 sievers$ python tuple_example.py
a
4.0
['d', 9]
Traceback (most recent call last):
  File "tuple_example.py", line 5, in <module>
    mylist[2]=5.0
TypeError: 'tuple' object does not support item assignment
Jonathans-MacBook-Pro:lecture3 sievers$
```

- Tuples are like lists, except you can't change them.
- Tuples are defined with ().
- Normally used to return values from functions.
- Note error message telling you what broke!

# For Loop

- For loops iterate over items. list, tuples, (some) others valid
- Indenting in python is meaningful, blocks of code *defined* by indents.
- `execfile` will run a script from within the interpreter

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat for_example.py
mylist=['a','bc',4.0,5,['d',9]]
# this is a comment!
#Note the colon to start the for loop
for x in mylist:
    print x
#when we stop indenting, we're done
print "That's all folks"

Jonathans-MacBook-Pro:lecture3 sievers$ python
Python 2.7.5 (default, Sep 12 2013, 21:33:34)
[GCC 4.2.1 Compatible Apple LLVM 5.0 (clang-500.0.68)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> execfile('for_example.py')
a
bc
4.0
5
['d', 9]
That's all folks
>>>
```

```
>>> for x in range(0,5):
...     print x
...
0
1
2
3
4
>>>
```

*range* command will make a list of a sequence of numbers. Use to make traditional *for* loop.



# Quick Example

- How would I print the first 10 squares?
- note -  $x*x$  or  $x**2$  are both the square of  $x$

```
>>> for x in range(0,10):  
...     print x**2  
...  
0  
1  
4  
9  
16  
25  
36  
49  
64  
81  
>>> █
```

# Let's do $\sin(x)$ instead

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat math_example.py
import math
from math import sin

#you *can* do this. But don't!
from math import sin as cos
for x in range(0,10):
    print [x,math.sin(x),sin(x),cos(x)]

Jonathans-MacBook-Pro:lecture3 sievers$ python math_example.py
[0, 0.0, 0.0, 0.0]
[1, 0.8414709848078965, 0.8414709848078965, 0.8414709848078965]
[2, 0.9092974268256817, 0.9092974268256817, 0.9092974268256817]
[3, 0.1411200080598672, 0.1411200080598672, 0.1411200080598672]
[4, -0.7568024953079282, -0.7568024953079282, -0.7568024953079282]
[5, -0.9589242746631385, -0.9589242746631385, -0.9589242746631385]
[6, -0.27941549819892586, -0.27941549819892586, -0.27941549819892586]
[7, 0.6569865987187891, 0.6569865987187891, 0.6569865987187891]
[8, 0.9893582466233818, 0.9893582466233818, 0.9893582466233818]
[9, 0.4121184852417566, 0.4121184852417566, 0.4121184852417566]
Jonathans-MacBook-Pro:lecture3 sievers$
```

- *sin* is not a build-in python function
- Instead, we'll have to *import* it from the math library
- Python gives you great power over how much to import, and what to call it.

# More on import

- There is a *huge* variety of stuff available in python
- See, e.g., <https://docs.python.org/2/library/> for list of standard library. Many, many more things available online.
- Some commonly used things: `os`, `sys`, `pickle`, `datetime`, `ctypes`, `threading`, `readline`, `urllib`...
- *help* will (usually) print more info, like *man* in Unix. e.g. `help(math.sin)`
- You can use *pip* to install more python packages. If you don't have sudo powers, *pip install --user <package>* should work. In ubuntu, `apt-get install` also works.
- `readline/rlcompleter` can be used to get tab-completion working in python (`ipython` also an option)

# Numpy

- Python has no built in arrays. Use NUMerical PYthon (numpy) for math functionality
- Many functions work on numpy arrays - usually much (much) faster than going through interpreter
- *numpy.arange* works like *range*, but returns numpy array instead of a list.

note - *numpy.arange* with three arguments will space values by 3<sup>rd</sup> argument.

```
Jonathans-MacBook-Pro:lecture3 sievers$ cat numpy_example.py
import numpy
x=numpy.arange(0,10)
print x**2
print 'type(x) is ' + repr(type(x))

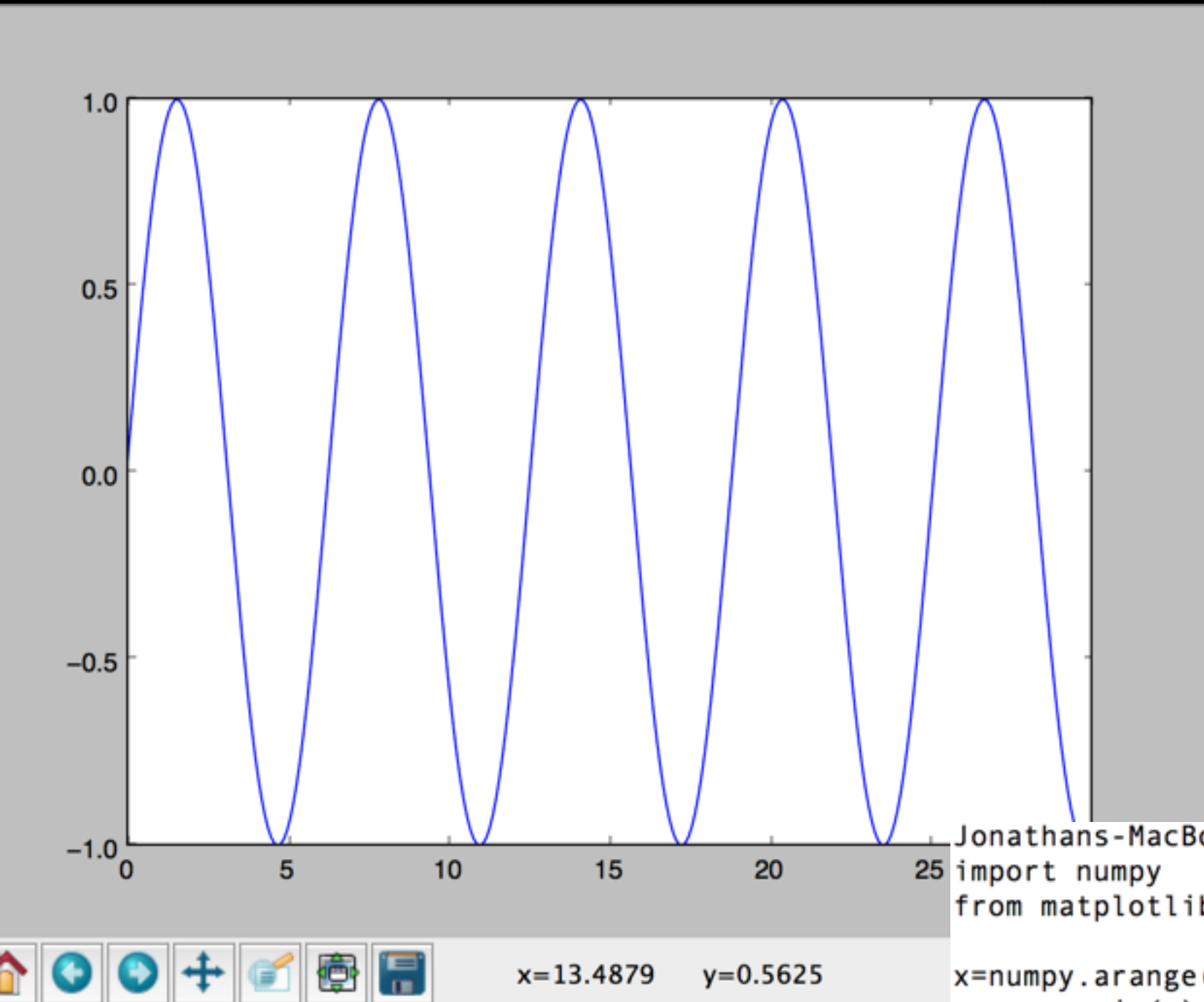
x=range(0,10)
print 'type(x) is now ' + repr(type(x))
print x**2

Jonathans-MacBook-Pro:lecture3 sievers$ python numpy_example.py
[ 0  1  4  9 16 25 36 49 64 81]
type(x) is <type 'numpy.ndarray'>
type(x) is now <type 'list'>
Traceback (most recent call last):
  File "numpy_example.py", line 8, in <module>
    print x**2
TypeError: unsupported operand type(s) for ** or pow(): 'list' and 'int'
Jonathans-MacBook-Pro:lecture3 sievers$
```

# Plotting

- Let's make a plot! Say,  $\sin(x)$  from 0 to 30
- How would we do this? To the tubes!

# Example



```
Jonathans-MacBook-Pro:lecture3 sievers$ cat matplotlib_example.py
```

```
import numpy
from matplotlib import pyplot as plt
```

```
x=numpy.arange(0,30,0.1)
y=numpy.sin(x)
```

```
plt.plot(x,y)
plt.show()
```

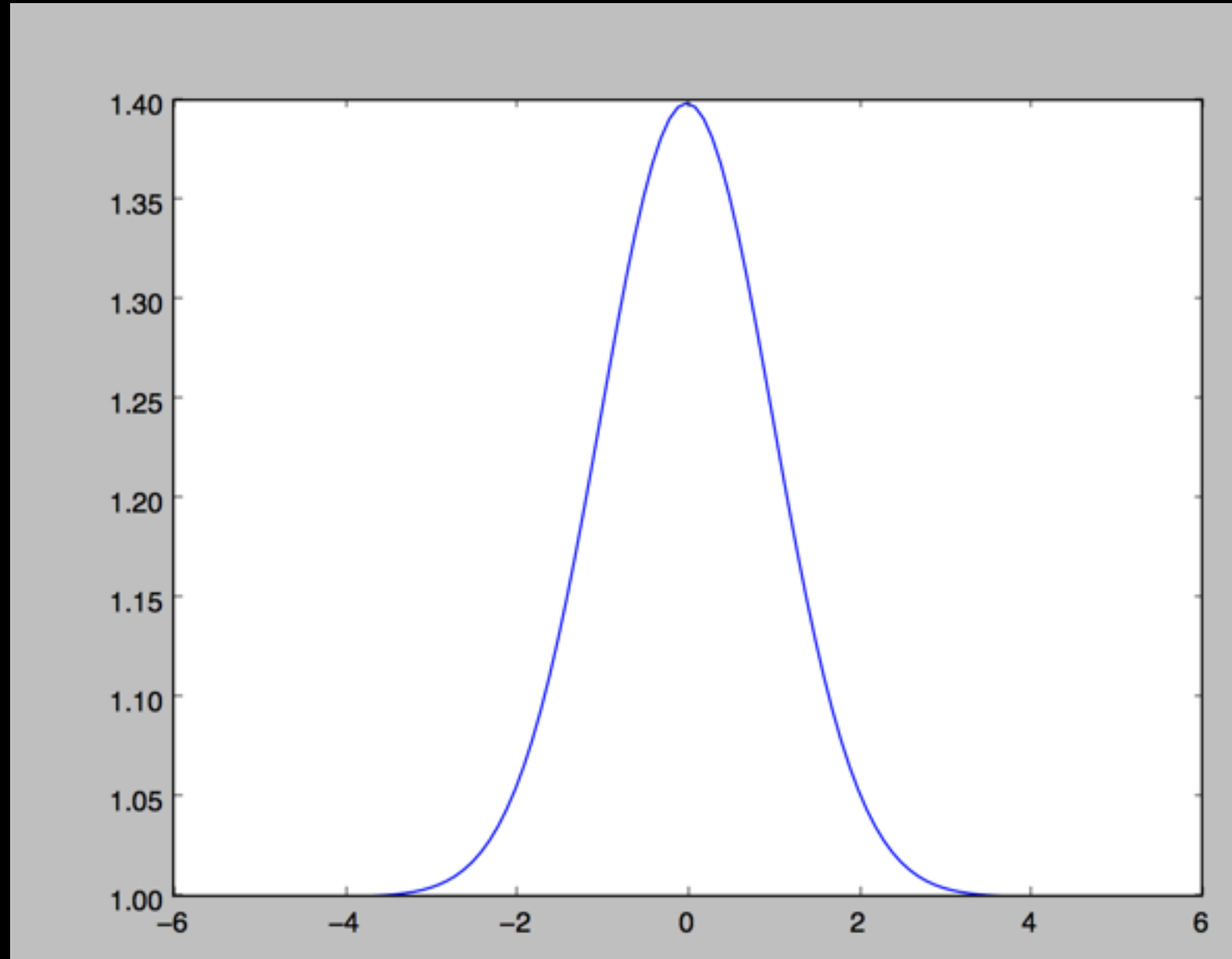
```
Jonathans-MacBook-Pro:lecture3 sievers$ python matplotlib_example.py
```

# Functions in Python

```
import numpy
from matplotlib import pyplot as plt
#functions defined with def
#arguments can be given default values
def mygauss(x,cent=0,sig=0.1):
    y=numpy.exp(-0.5*(x-cent)**2/sig**2)
    #pick this normalization so area under
    #gaussian is one.
    y=1+y/numpy.sqrt(2*numpy.pi*sig**2)
    return y

#only run this part if script is executed
if __name__ == "__main__":
    dx=0.1
    x=numpy.arange(-5,5,dx)
    y=mygauss(x,0,1)
    y2=mygauss(x,sig=1)
    print 'y total is ' +repr(y.sum()*dx)

    plt.plot(x,y)
    plt.show()
```

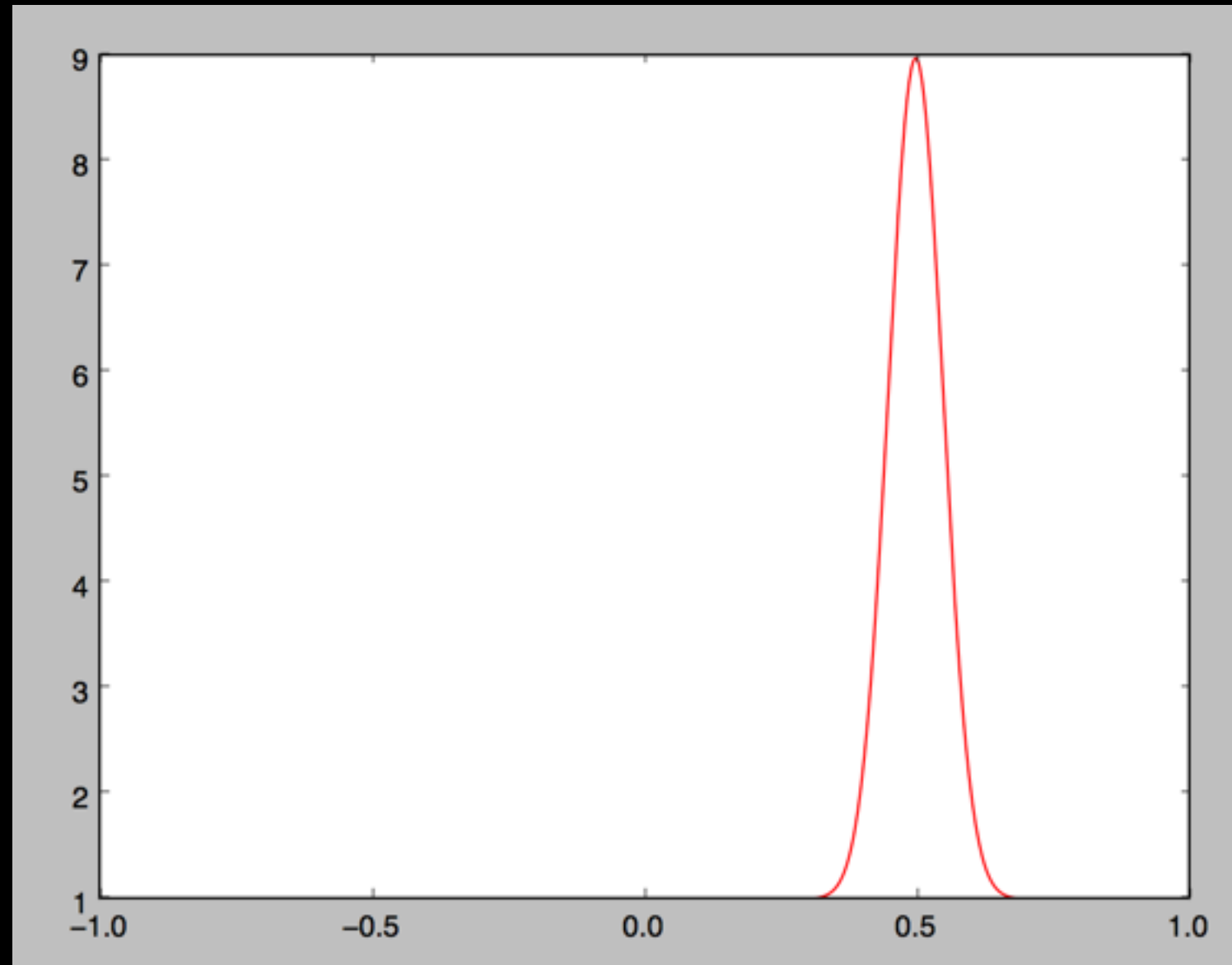


numpy arrays know how to do a lot of things. Can sum all elements with e.g. `y.sum()`. arrays also know their dimensions (`shape`), `min`, `max`, etc.

# Functions Ctd.

```
import numpy
from matplotlib import pyplot as plt
#we can import functions we just wrote!
import func_example

x=numpy.arange(-1,1,0.002)
#functions are referenced by the file they're in
y=func_example.mygauss(x,cent=0.5,sig=0.05)
#we can assign the function to a variable
gg=func_example.mygauss
y2=gg(x,cent=0.5,sig=0.05)
delt=numpy.abs(y2-y)
print 'error is ' + repr(delt.sum())
#will output:
#error is 0.0
plt.plot(x,y,'r')
plt.show()
```





# Integration

- We know have the tools to do some simple definite integrals
- Recall fundamental definition -  $\sum (f(x_i) * dx)$  as  $dx \rightarrow 0$
- How would we approximate integral of sin from 0 to pi?
- Before we do that, what *\*should\** the answer be?

# Example

- Here's some code that does the numerical integral of sin while varying the step size. How well does it work?
- you might also want to play with `numpy.linspace...`

```
import numpy

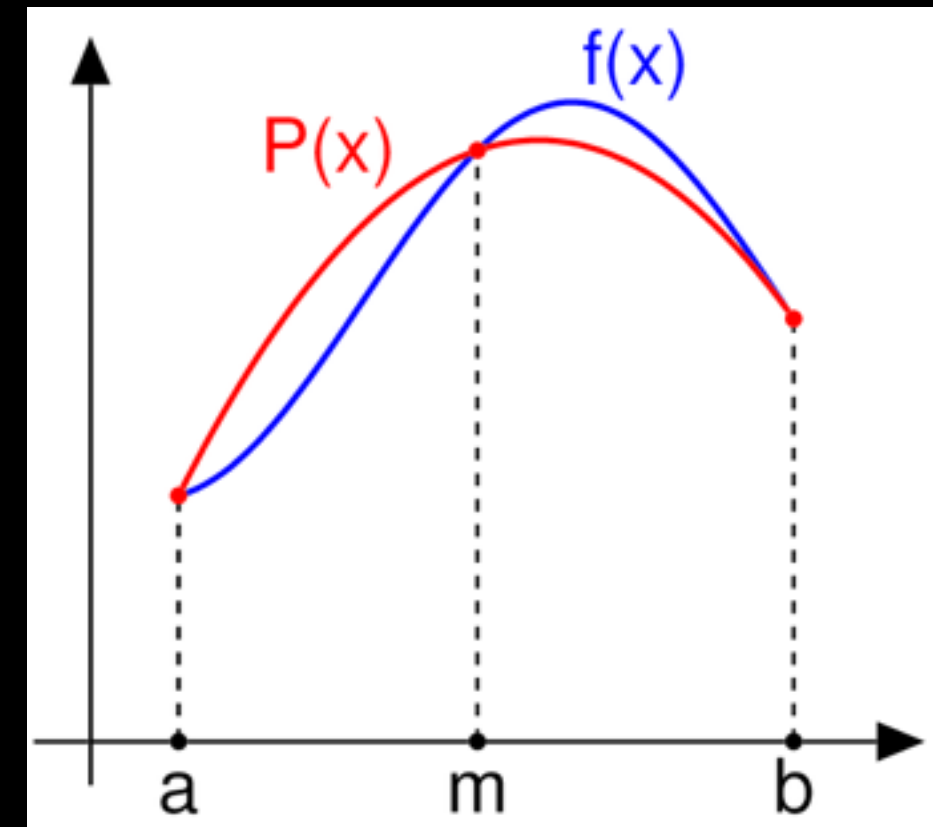
x0=0
x1=numpy.pi

mydelts=[0.5,0.1,0.03,0.01,0.003,0.001]
for dx in mydelts:
    x=numpy.arange(x0,x1,dx)
    y=numpy.sin(x)
    tot=y.sum()*dx
    print 'integral is ' + repr(tot) + ' with dx=' + repr(dx)
```

```
Jonathans-MacBook-Pro:lecture3 sievers$ python sin_integral.py
integral is 1.9836405445028298 with dx=0.5
integral is 1.999547959712598 with dx=0.1
integral is 1.9999407675824561 with dx=0.03
integral is 1.9999900283082466 with dx=0.01
integral is 1.9999992133611066 with dx=0.003
integral is 1.9999999540409921 with dx=0.001
Jonathans-MacBook-Pro:lecture3 sievers$
```

# Simpson's Rule

- Let's integrate a quadratic over three points.
- Draw a straight line between the left and right points. The middle point is now off the straight line by  $y_{\text{mid}} - 0.5 \cdot (y_{\text{left}} + y_{\text{right}})$
- What is the average value of  $(1-x^2)$  between  $-1$  and  $1$ ?
- Area is now  $1/2 \cdot (y_{\text{left}} + y_{\text{right}}) + 2/3 \cdot (y_{\text{mid}} - 0.5 \cdot (y_{\text{left}} + y_{\text{right}}))$
- simplify:  $\text{area} = 1/6 \cdot y_{\text{left}} + 2/3 \cdot y_{\text{mid}} + 1/6 \cdot y_{\text{right}}$ .
- for a bunch of points, string together segments,  $y_{\text{right}}$  become  $y_{\text{left}}$  of the next segment.
- Simpson's rule:  $\text{integral} = dx \cdot (1/6 y_0 + 2/3 y_{\text{odd}} + 1/3 y_{\text{even}} + 1/6 y_{\text{last}})$



# Tutorial

- Write a python script to make a vector of  $n$  evenly spaced numbers between 0 and  $\pi/2$ . i.e.  $x[0]=0$ ,  $x[-1]=\pi/2$  (5)
- Use this vector to integrate  $\cos(x)$  from 0 to  $\pi/2$  for a range # of points using the simple method. include 10,30,100,300,1000 points between 0 and  $\pi/2$ . How does error scale with # of points? (5)
- Python supports array slicing -  $x[5:10:2]$  will take points 5,7,9 from  $x$ .  $x[5::2]$  will take points 5,7,9... from  $x$ . How can I take all odd points from an array? How can I take all even points from an array, but skipping the first and last points? (5)
- Write a python function to integrate this vector using Simpson's rule. How does error scale with # of points? How many points did we need to use in part 2 to get same accuracy as 11 points with Simpson's rule? (10)
- Plot the errors as a function of # of points using Simpson's rule and standard sum. You will want to use a log scale here - look at logplot.py in the github distribution (5)

# Bonus Points

- the `scipy` module has built in integration functions in `scipy.integrate`. The `quad` routine will do numerical integrals. `quad` will try to put its effort where the function changes quickly.
- Look at `scipy_quad_example.py`, which uses `scipy` to integrate our Gaussian function over two different ranges. The integrals should be (almost) identical - yet they are not. Can you figure out why? (5)
- Can you write another function that will always give the correct answer to this integral? (5) Hint - you may want to do two integrals instead of one.