Using Python for Scientific Computing

Session 3 - NumPy, SciPy, Matplotlib

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Inhalt

Overview

What is NumPy?

- Fundamental package for scientific computing in Python
- Provides multidimensional arrays, matrices and polynom objects
- Fast operations on arrays through vectorized functions
- Differences to Python sequences:
  - Fixed size at creation
  - All elements of the same data type
  - greater variety on numerical datatypes
    (e.g. int8, int32, uint32, float64)
  - highly efficient (implemented in C)
- base for many other scientific related packages

Python is slow(er) ...

Simple test: Multiply two arrays of length 10.000.000

pure Python

```
import time

l = 10000000
start = time.time()
a, b = range(l), range(l)
c = []
for i in a:
   c.append(a[i] * b[i])
t = time.time() - start
print("Duration: %s" % t)
```

Duration: 4.67 s

Using numpy

```
import numpy as np
import time

l = 10000000
start = time.time()
a = np.arange(l)
b = np.arange(l)
c = a * b
t = time.time() - start
print("Duration: %s" % t)
```

Duration: 0.73 s

Creating NumPy arrays

NumPy arrays can be created from Python structures or by using specific array creation functions.

Python Interpreter

```
>>> import numpy as np
>>> a = np.array([1.5, 2.2, 3.0, 0.9])
>>> a
array([ 1.5,  2.2,  3. ,  0.9])
>>> zeros = np.zeros(6)
>>> zeros
array([ 0.,  0.,  0.,  0.,  0.,  0.])
>>> ones = np.ones(6)
>>> ones
array([ 1.,  1.,  1.,  1.,  1.,  1.])
>>> a = np.arange(12)
>>> print a
[ 0  1  2  3  4  5  6  7  8  9 10 11]
>>> print a.size, a.ndim, a.shape
12 1 (12,)
>>> m = a.reshape(3, 4)
>>> print m
[[ 0  1  2  3]
 [ 4  5  6  7]
 [ 8  9 10 11]]
```

```
>>> print m.size, m.ndim, m.shape
12 2 (3, 4)
>>> Z = zeros((2,3))
>>> print Z
[[ 0.  0.  0.]
 [ 0.  0.  0.]]
>>> v = np.linspace(0, 1.0, 5)
>>> v
array([ 0.  , 0.25, 0.5 , 0.75, 1.  ])
```

Array Creation Functions

- `np.array(seq, dtype)`:
  Creates an array from `seq` having data type `dtype` (optional)
- `np.ones(shape, dtype)`, `np.zeros(shape, dtype)`:
  Creates an array of given shape and type, filled with ones/zeros.
  Default type is `float64`.
- `np.arange([start,] stop[, step], dtype)`:
  Like the normal `range` function but works also with floats.
  Returns evenly spaced values *within* a given interval.
- `np.linspace(start, stop[, num])`:
  Returns evenly spaced numbers *over* a specified interval.
- `arange` vs. `linspace`:
  `np.arange(0.0, 1.0, 0.25)` ⇒ [0.0, 0.25, 0.5 0.75]
  `np.linspace(0.0, 1.0, 5)` ⇒ [0.0, 0.25, 0.5, 0.75, 1.0]

Indexing Arrays

Python Interpreter

```
>>> import numpy as np
>>> a = np.arange(20)
>>> a = a.reshape(5,4)
>>> a[3,2]
14
```

5×4matrix

$$\begin{pmatrix} 0 & 1 & 2 & 3 \\ 4 & 5 & 6 & 7 \\ 8 & 9 & 10 & 11 \\ 12 & 13 & \boxed{14} & 15 \\ 16 & 17 & 18 & 19 \end{pmatrix}$$

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>>> a[1]                # second row
array([4, 5, 6, 7])
```

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>>> a[1]             # second row
array([4, 5, 6, 7])
>>> a[-2]            # second last row
array([12, 13, 14, 15])
```

5 × 4matrix

$$\begin{pmatrix} 0 & 1 & 2 & 3 \\ 4 & 5 & 6 & 7 \\ 8 & 9 & 10 & 11 \\ \boxed{12 \quad 13 \quad 14 \quad 15} \\ 16 & 17 & 18 & 19 \end{pmatrix}$$

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>>> a[1]                # second row
array([4, 5, 6, 7])
>>> a[-2]               # second last row
array([12, 13, 14, 15])
>>> a[:,0]              # first column
array([ 0,  4,  8, 12, 16])
```

5×4matrix

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>>> a = np.arange(20)
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>>> a[3,2]
14
>>> a[1]                    # second row
array([4, 5, 6, 7])
>>> a[-2]                   # second last row
array([12, 13, 14, 15])
>>> a[:,0]                  # first column
array([ 0,  4,  8, 12, 16])
>>> a[1:4, 0:3]             # sub-array
array([[ 4,  5,  6],
       [ 8,  9, 10],
       [12, 13, 14]])
```

5×4matrix

$$\begin{pmatrix} 0 & 1 & 2 & 3 \\ 4 & 5 & 6 & 7 \\ 8 & 9 & 10 & 11 \\ 12 & 13 & 14 & 15 \\ 16 & 17 & 18 & 19 \end{pmatrix}$$

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>>> a = np.arange(20)
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>>> a[-2]               # second last row
array([12, 13, 14, 15])
>>> a[:,0]              # first column
array([ 0,  4,  8, 12, 16])
>>> a[1:4, 0:3]         # sub-array
array([[ 4,  5,  6],
       [ 8,  9, 10],
       [12, 13, 14]])
>>> a[::2, ::3]         # skipping indices
array([[ 0,  3],
       [ 8, 11],
       [16, 19]])
```

5×4matrix

$$\begin{pmatrix} \boxed{0} & 1 & 2 & \boxed{3} \\ 4 & 5 & 6 & 7 \\ \boxed{8} & 9 & 10 & \boxed{11} \\ 12 & 13 & 14 & 15 \\ \boxed{16} & 17 & 18 & \boxed{19} \end{pmatrix}$$

Functions on numpy arrays

- The worst thing you can do is iterating with a `for`-loop over a numpy array.
- That's why numpy supports several standard functions on arrays.

Python Interpreter

```
>>> import numpy as np
>>> a = np.arange(1, 21)
>>> a
[1, 2, 3, 4, ..., 20]
>>> print a.min(), a.max(), a.mean()      # minimum, maximum, arithmetic mean
1 20 10.5
>>> print a.std(), a.var()                # standard deviation, variance
5.76 33.25
>>> print a.sum(), a.prod()               # sum, product
210 2432902008176640000
>>> print a.any(), a.all()                # any True?, all True?
True True
>>> b = np.array([0,0,1])
>>> print b.any(), b.all()
True False
```

Arithmetic operations on arrays

- NumPy supports arithmetic operations between arrays
- Advantage: No `for`-loops necessary (looping occurs in C)
- Element-wise operation for arrays of the same shape

Python Interpreter

```
>>> import numpy as np
>>> a, b = np.arange(1, 11), np.arange(1,11)
>>> a
array([ 1,  2,  3,  4,  5,  6,  7,  8,  9, 10])
>>> a + 1
array([ 2,  3,  4,  5,  6,  7,  8,  9, 10, 11])
>>> a * 2
array([ 2,  4,  6,  8, 10, 12, 14, 16, 18, 20])
>>> a + b
array([ 2,  4,  6,  8, 10, 12, 14, 16, 18, 20])
>>> a * b
array([  1,   4,   9,  16,  25,  36,  49,  64,  81, 100])
```

Things get little more complicated when arrays have different shapes. (see Broadcasting)

Operations on arrays of different shapes

- *broadcasting* describes how numpy treats arrays of different shapes during arithmetic operations
- Two dimensions are compatible when they are equal or one of the dimensions is 1

Python Interpreter

```
>>> import numpy as np
>>> a = np.arange(9.0)
>>> a = a.reshape((3,3))
>>> a
array([[ 0.,  1.,  2.],
       [ 3.,  4.,  5.],
       [ 6.,  7.,  8.]])
>>> b = np.array([1.0, 2.0, 3.0])
>>> a * b
array([[  0.,   2.,   6.],
       [  3.,   8.,  15.],
       [  6.,  14.,  24.]])
```

```
a (2d array):  3 x 3
b (1d array):    x 3
Result      :  3 x 3
```

The smaller array gets broadcasted to the larger array. Thus, result is computed by element-wise multiplication of

$$\begin{pmatrix} 0 & 1 & 2 \\ 3 & 4 & 5 \\ 6 & 7 & 8 \end{pmatrix} \cdot \begin{pmatrix} 1 & 2 & 3 \\ 1 & 2 & 3 \\ 1 & 2 & 3 \end{pmatrix}$$

Matrices

- Matrices are special array objects
- Always 2-dimensional
- Matrix multiplication
- special properties of matrices:
  - matrix.I (Inverse)
  - matrix.T (Transposed)
  - matrix.H (Conjugate)
  - matrix.A (Array conversion)

Python Interpreter

```
>>> import numpy as np
>>> m = np.matrix([[1, 2], [3,4]])
>>> m
matrix([[1, 2],
        [3, 4]])
>>> m.I
matrix([[-2. ,  1. ],
        [ 1.5, -0.5]])
>>> m.T
matrix([[1, 3],
        [2, 4]])
>>> b = np.array([2, 3])
>>> b.shape = (2, 1)
>>> b
array([[2],
       [3]])
>>> m * b
matrix([[ 8],                #[1 2][2]
        [18]])               #[3 4][3]
```

Linear Algebra

The `numpy.linalg` submodule provides core linear algebra tools

Python Interpreter

```
>>> import numpy as np
>>> import numpy.linalg as linalg
>>> A = np.matrix([[2, 3, -1],
    [1,3,1],[-2,-2,4]])
>>> A
matrix([[ 2,  3, -1],
        [ 1,  3,  1],
        [-2, -2,  4]])
>>> b = np.array([1, 2, 4])
>>> linalg.solve(A, b)
array([ 3., -1.,  2.])
```

$$
\begin{aligned}
2x + 3y - z &= 1 \\
x + 3y + z &= 2 \\
-2x - 2y + 4z &= 4
\end{aligned}
$$

Polynoms

- NumPy defines a polynom datatype that allows symbolic computations
- value evaluation and polynomial arithmetic
- Derivation, Integration

e.g. $f(x) = 3x^2 - 2x + 1$

- `p = np.poly1d(coefs)`: Constructs a polynom `p` from the given coefficient sequence ordered in decreasing power.
- `p.deriv(m), p.integ(m)`: Compute the derivative or anti-derivative of `p`. Parameter `m` determines the order of derivation.

Python Interpreter

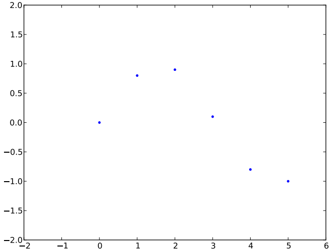
```
>>> import numpy as np
>>> f = np.poly1d([3, -2, 1])
>>> print(f)
   2
3 x - 2 x + 1
>>> f(2.5)
14.75
>>> f_1, F = f.deriv(), f.integ()
>>> print f_1
6 x - 2
>>> print F
   3     2
1 x - 1 x + 1 x
```

Curve fitting

- polynomial regression
- `np.polyfit(x, y, deg)`:
  Least squares polynomial fit of degree `deg` for coordinate sequences `x` and `y`. Returns array with polynomial coefficients.

Python Interpreter

```
from numpy import array, poly1d, polyfit
>>> x = array([0.0, 1.0, 2.0, 3.0, 4.0, 5.0])
>>> y = array([0.0, 0.8, 0.9, 0.1, -0.8, -1.0])
```



Curve fitting

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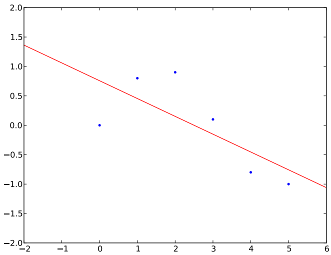
```
from numpy import array, poly1d, polyfit
>>> x = array([0.0, 1.0, 2.0, 3.0, 4.0, 5.0])
>>> y = array([0.0, 0.8, 0.9, 0.1, -0.8, -1.0])
# linear fit
>>> coefs = polyfit(x, y, 1)
>>> p1 = poly1d(coefs)
>>> print p1
-0.3029 x + 0.7571
```



Curve fitting

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  Least squares polynomial fit of degree `deg` for coordinate sequences `x` and `y`.
  Returns array with polynomial coefficients.

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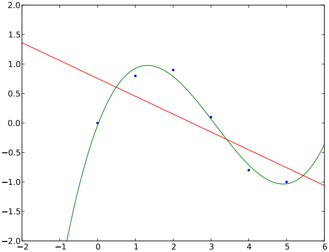
```
from numpy import array, poly1d, polyfit
>>> x = array([0.0, 1.0, 2.0, 3.0, 4.0, 5.0])
>>> y = array([0.0, 0.8, 0.9, 0.1, -0.8, -1.0])
# linear fit
>>> coefs = polyfit(x, y, 1)
>>> p1 = poly1d(coefs)
>>> print p1
-0.3029 x + 0.7571
# cubical fit
>>> coefs = polyfit(x, y, 3)
>>> p3 = poly1d(coefs)
>>> print p3
         3          2
0.08704 x - 0.8135 x + 1.693 x - 0.03968
```



SciPy package

- Collection of mathematical algorithms and convenience functions
- Built on NumPy
- Organized into sub-packages

Some of the interesting modules:

Sub-Module	Description
`cluster`	Clustering algorithms
`constants`	Physical Constants
`fftpack`	Fast Fourier Transformation
`integrate`	Integration and ODE solvers
`interpolate`	Interpolation (e.g. Splines)
`special`	Special functions (e.g. Bessel functions, Gamma-Function)
`stats`	Statistical Functions and Distributions

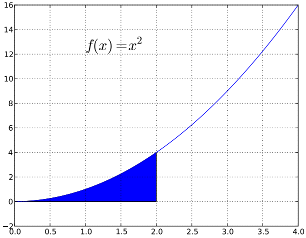
See SciPy-Documentation: http://www.scipy.org

SciPy-Safari: Integration

```
import scipy.integrate as spint

def f(x):
  return x**2

spint.quad(f, 0, 2)
output: (2.66..., 2.96e-14)
```



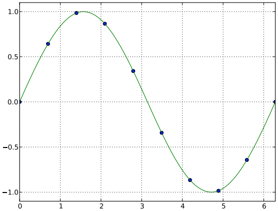
SciPy also supports infinite integration limits. See documentation.

SciPy-Safari: Spline Interpolation

```
import numpy as np
import scipy.interpolate as spintp

x = np.linspace(0, 2 * np.pi, 10)
y = np.sin(x)
x_spline = np.linspace(0, 2 * np.pi, 100)
y_spline = spintp.spline(x, y, x_spline)
y_spline

# output:
array([  3.851e-16, 6.465e-02,   1.286e-01,
         1.917e-01, 2.538e-01,   3.146e-01,
         3.739e-01, 4.317e-01,   4.876e-01,
         5.416e-01, 5.934e-01,   6.427e-01,
         6.896e-01, 7.337e-01,   7.749e-01,
         8.132e-01, 8.483e-01,   8.801e-01,
         9.085e-01, 9.333e-01,   9.544e-01,
         ...])
```



Random Number Generation

`numpy.random` sub module (= `scipy.random`) provides many different functions for random number generation.

- `sp.rand(d0, d1, ...)`:
  Create array of given shape filled with uniform random numbers over $[0, 1]$.
- `sp.randn(d0, d1, ...)`:
  The same as `sp.rand()` but generates zero-mean unit-variance Gaussian random numbers.
- `sp.random.randint(low, high=None, size=None)`:
  Return random integers x such that $low \leq x < high$. If high is `None`, then $0 \leq x < low$.
- `sp.random.binomial(n, p, shape=None)`:
  Draw `n` samples from binomial distr. with success probability `p`. Returns array of given shape containing the number of successes.

Random Number Generation - Examples

Python Interpreter

```
>>> from scipy.random import *    # import all random functions
>>> rand(2,3)                     # 2x3 array
array([[ 0.49010722,  0.73308678,  0.5209828 ],
       [ 0.54217486,  0.75698016,  0.10697513]])
>>> rnd = randn(100)              # 100 norm. distr. numbers
>>> rnd.mean()                    # mean should be close to 0
0.0789
>>> randint(1, 50, 6)             # lottery numbers 6 of 49
array([ 2, 28, 15, 49, 22, 35])
>>> binomial(5, 0.4)              # unfair coin flipping
2
>>> binomial(5, 0.4, 10)          # 10 games with 5 flips
array([4, 3, 0, 1, 3, 2, 3, 2, 1, 3])
```

Data Visualization with matplotlib

- `matplotlib` provides 2D data visualization as in MATLAB.
  - Publication quality plots
  - Export to different file formats
  - Embeddable in graphical user interfaces
  - Making plots should be easy!
- Heavy use of NumPy and SciPy
- `pylab`: provides a matlab-like environment
  (roughly: combines NumPy, SciPy and matplotlib)

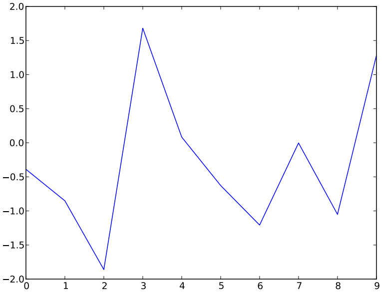
`pylab (matplotlib.pylab)` (Provides plot functions similar to MATLAB)
matplotlib API (Basic libraries for creating and managing figures, text, lines, ...)
Backend (device dependent renderers)

A simple plot

Plots are generated successively. Each plotting function makes changes to the figure.

Python Interpreter

```
>>> from pylab import *
# Turn on interactive mode
>>> ion()
# 10 norm. distr. rnd numbers
>>> x = randn(10)
>>> plot(x)
```



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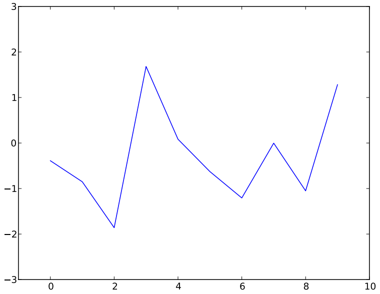
Python Interpreter

```
>>> from pylab import *
# Turn on interactive mode
>>> ion()
# 10 norm. distr. rnd numbers
>>> x = randn(10)
>>> plot(x)
# setting axis limits
>>> axis([0, 10, -3, 3])
```



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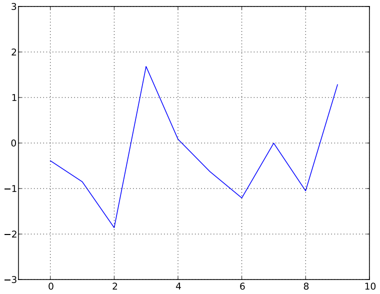
>>> plot(x)
# setting axis limits
>>> axis([0, 10, -3, 3])
# toggle grid
>>> grid()
```



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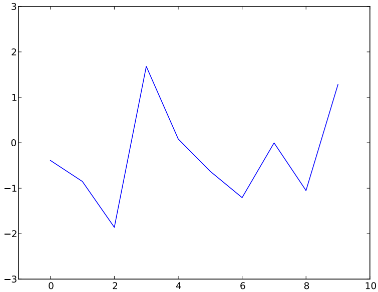
```



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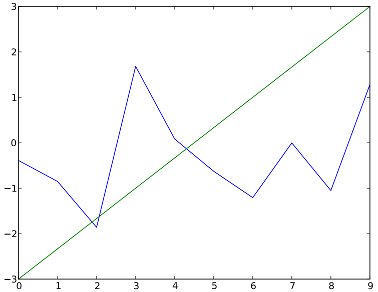
>>> x = randn(10)
>>> plot(x)
# setting axis limits
>>> axis([0, 10, -3, 3])
# toggle grid
>>> grid()
>>> grid()
# add another plot
>>> y = linspace(-3, 3, 10)
>>> plot(y)
```



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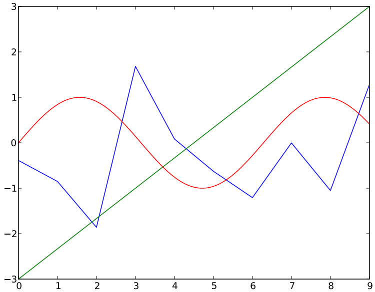
>>> x = randn(10)
>>> plot(x)
# setting axis limits
>>> axis([0, 10, -3, 3])
# toggle grid
>>> grid()
>>> grid()
# add another plot
>>> y = linspace(-3, 3, 10)
>>> plot(y)
# plot with x and y axis values
>>> x = linspace(0, 9, 100)
>>> plot(x, sin(x))
```



Basic Plotting Functions

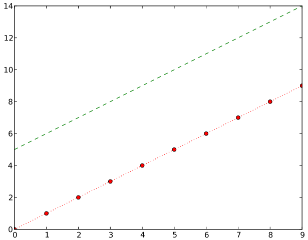
- `plot([x,] y)`:
  Generates simple line plot for x and y values. If `x`-values are not specified the array index values (0, 1, 2, ...) will be used.
- `axis(v)`:
  Sets the axis limits to the values `v = [xmin, xmax, ymin, ymax]`. `v` can also be a string (e.g. 'off', 'equal', 'auto')
- `xlabel(s), ylabel(s)`:
  Set labels for `x` or `y` axis to `s`.
- `title(s), suptitle(s)`:
  Set title for current plot or for the whole figure.
- `show()`:
  Shows the current figure. Usually the last function to be called in a script after generating a plot.
- `clf()`: **cl**ear the **f**igure

Plot style

- The plot function accepts a pattern string specifying the line and symbol style in the format: "<color><line><symbol>"

example

```
# initialize some values
>>> values = arange(10)
# plot red dotted line with circles
>>> plot(x, "r:o")
# plot green dashed line
>>> plot(x + 5, "g--")
```



Line Colors			
r	red	c	cyan
g	green	m	magenta
b	blue	y	yellow
w	white	k	black

Line Styles	
-	solid line
--	dashed line
-.	dash-dot line
:	dotted line

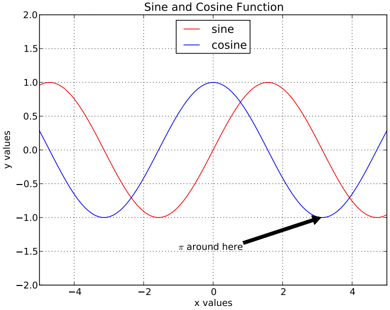
Marker Symbols			
.	points	o	circles
s	squares	+	plus'es
x	crosses	*	stars
D	diamonds	d	thin diamonds

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
```



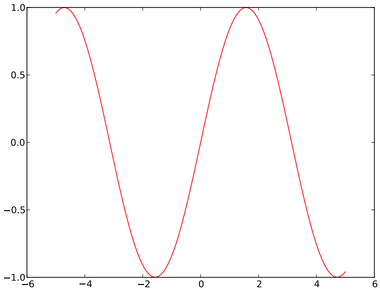
This is the plot we want to create.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
```



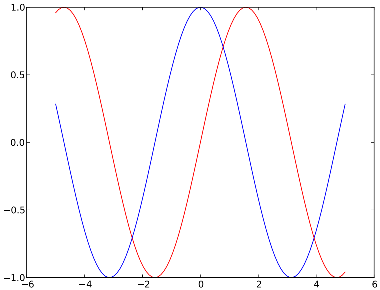
Adding the sine curve.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
>>> plot(x, y_cos, "b", label="cosine")
```



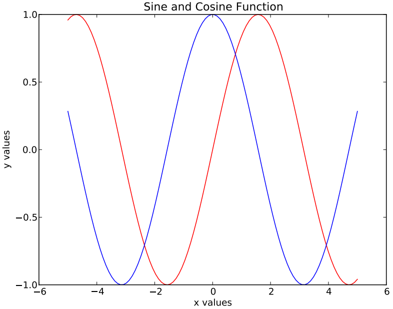
Adding the cosine curve.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
>>> plot(x, y_cos, "b", label="cosine")
>>> xlabel("x-value")
>>> ylabel("y-value")
>>> title("Sine and Cosine function")
```



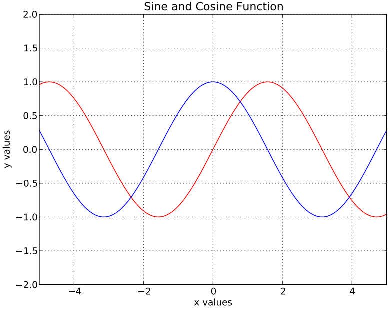
Adding labels and title.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
>>> plot(x, y_cos, "b", label="cosine")
>>> xlabel("x-value")
>>> ylabel("y-value")
>>> title("Sine and Cosine function")
>>> axis([-5, 5, -2, 2])
>>> grid()
```



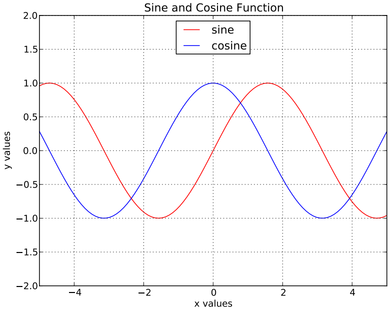
Changing axis and adding grid.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
>>> plot(x, y_cos, "b", label="cosine")
>>> xlabel("x-value")
>>> ylabel("y-value")
>>> title("Sine and Cosine function")
>>> axis([-5, 5, -2, 2])
>>> grid()
>>> legend(loc="upper center")
```



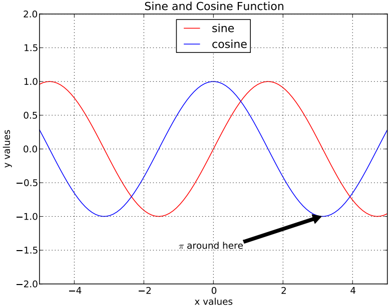
Add the legend.

Adding Labels and Legends

Let's make a plot having labels, title and a legend.

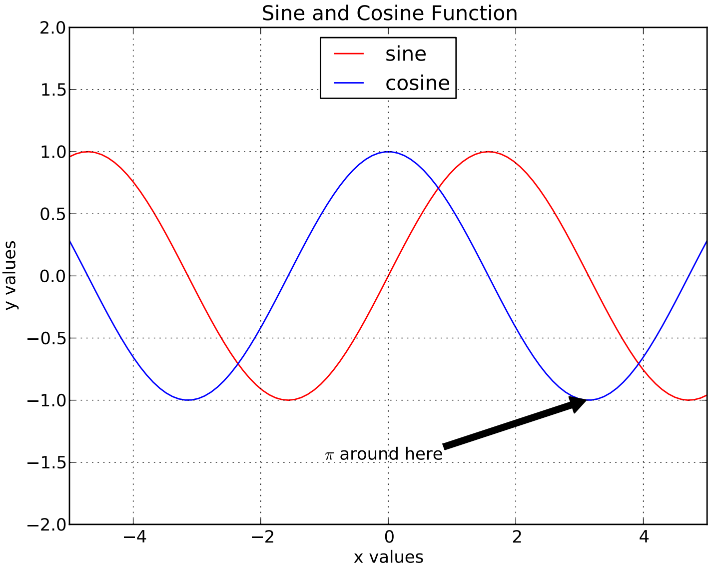
Python Interpreter

```
>>> x = linspace(-5, 5, 100)
>>> y_sin, y_cos = sin(x), cos(x)
>>> plot(x, y_sin, "r", label="sine")
>>> plot(x, y_cos, "b", label="cosine")
>>> xlabel("x-value")
>>> ylabel("y-value")
>>> title("Sine and Cosine function")
>>> axis([-5, 5, -2, 2])
>>> grid()
>>> legend(loc="upper center")
>>> annotate(r"$\pi$ around here",
   xy=(3.1, 1.0), xytext=(-1.0, -1.5),
   arrowprops=dict(color='black'))
```



Add the annotation.

The complete plot

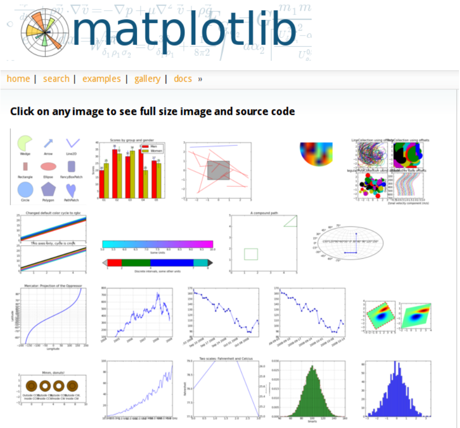


Annotations and Text functions

- `legend()`:
  Adds a legend to the current plot. Use keyword parameter `loc` to set the location either by string (e.g. `'upper center'`) or by 2-tuple (e.g. `(2,3)`)
- `annotate(text, xy=(ax, ay), xytext=(tx, ty))`:
  Annotate special location `(ax,ay)` and put `text` at location `(tx,ty)`.
  - Optional parameter `arrowprops` is a dictionary of arrow properties. If properties are set, an arrow is drawn in the figure.
- `text(x, y, text)`: Add `text` at location `(x, y)`.
- Wherever text can be added (labels, titles, annotations), you can use TEXformulas (e.g. `r"$\sum_i^n i$"`). `r" "` is a raw string in which backslashes are kept unchanged.

Plot Safari

- `matplotlib` provides a lot of plot types
- Lineplots, Scatterplots, Histograms, Timeseries plots, ...



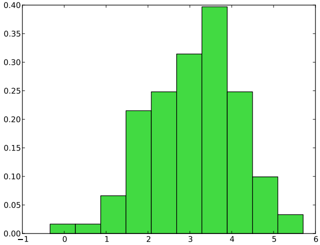
`http://matplotlib.sourceforge.net/gallery.html`

Histograms

- `hist(x, bins=10)`
  Computes and draws the histogram of `x`. Additional keyword options:
  - `normed=[False | True]`: normalize to probability density
  - `orientation=["horizontal"|"vertical"]`

Python Interpreter

```
# create some data
>>> mu, sigma = 3, 1.2
>>> values = mu + sigma * randn(100)
# plot histogram
>>> hist(values, normed=True,
   color="#42da42", ec="black")
```



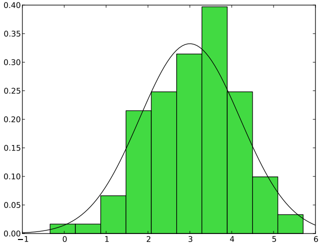
Histograms

- `hist(x, bins=10)`
  Computes and draws the histogram of `x`. Additional keyword options:
  - `normed=[False | True]`: normalize to probability density
  - `orientation=["horizontal"|"vertical"]`

Python Interpreter

```
# create some data
>>> mu, sigma = 3, 1.2
>>> values = mu + sigma * randn(100)
# plot histogram
>>> hist(values, normed=True,
   color="#42da42", ec="black")

# add Norm PDF
>>> p = gca()
>>> x_min, x_max = p.get_xlim()
>>> x = linspace(x_min, x_max, 100)
>>> plot(x, normpdf(x, mu, sigma))
```



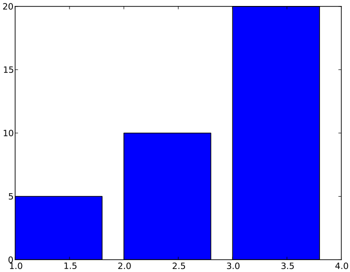
`gca()`: **g**et **c**urrent **a**xes

Bar Plots

- `bar(left, height)`: Make a bar plot with rectangles.
- `xticks(pos, labels)`: Set locations and labels of the xticks

Python Interpreter

```
>>> left = [1, 2, 3]
>>> height = [5, 10, 20]
>>> bar(left, height)
```

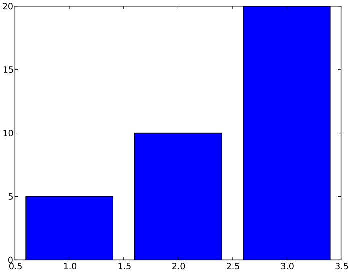


Bar Plots

- `bar(left, height)`: Make a bar plot with rectangles.
- `xticks(pos, labels)`: Set locations and labels of the xticks

Python Interpreter

```
>>> left = [1, 2, 3]
>>> height = [5, 10, 20]
>>> bar(left, height)
>>> clf()
>>> bar(left, height, align="center")
```

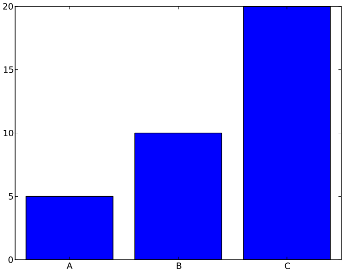


Bar Plots

- `bar(left, height)`: Make a bar plot with rectangles.
- `xticks(pos, labels)`: Set locations and labels of the xticks

Python Interpreter

```
>>> left = [1, 2, 3]
>>> height = [5, 10, 20]
>>> bar(left, height)
>>> clf()
>>> bar(left, height, align="center")
>>> xticks(left, ("A", "B", "C"))
```

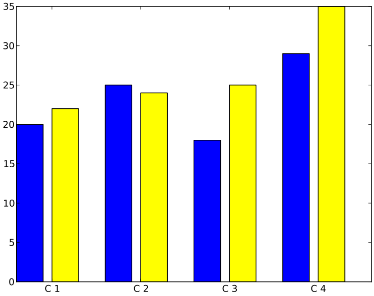


Bar Plots cntd.

Bar Plots for different groups require the separate plotting of each group.

Python Interpreter

```
>>> bar_width = .5
>>> group1 = [20, 25, 18, 29]
>>> group2 = [22, 24, 25, 35]
```



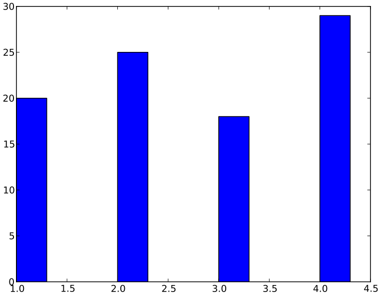
Bar Plots cntd.

Bar Plots for different groups require the separate plotting of each group.

Python Interpreter

```
>>> bar_width = .5
>>> group1 = [20, 25, 18, 29]
>>> group2 = [22, 24, 25, 35]

>>> pos1 = arange(4) + 1
>>> bar(pos1, group1, color="blue")
```



Bar Plots cntd.

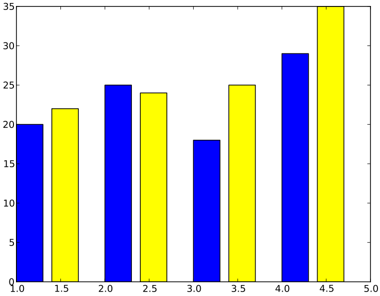
Bar Plots for different groups require the separate plotting of each group.

Python Interpreter

```
>>> bar_width = .5
>>> group1 = [20, 25, 18, 29]
>>> group2 = [22, 24, 25, 35]

>>> pos1 = arange(4) + 1
>>> bar(pos1, group1, color="blue")

>>> pos2 = pos1 + bar_width + .1
>>> bar(pos2, group2, color="yellow")
```



Bar Plots for different groups require the separate plotting of each group.

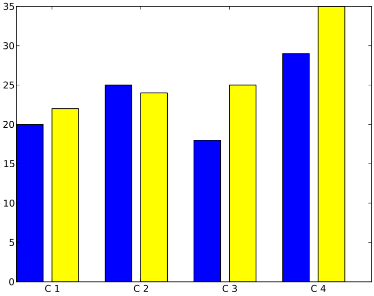
Python Interpreter

```
>>> bar_width = .5
>>> group1 = [20, 25, 18, 29]
>>> group2 = [22, 24, 25, 35]

>>> pos1 = arange(4) + 1
>>> bar(pos1, group1, color="blue")

>>> pos2 = pos1 + bar_width + .1
>>> bar(pos2, group2, color="yellow")

>>> cond = ('C 1', 'C 2', 'C 3', 'C 4')
>>> xticks(pos2, cond)
```



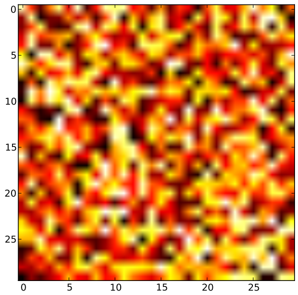
Plotting 2D Arrays (as Images)

- `imshow(X[, cmap])`:
  Display the image or float array in `X`. The parameter `cmap` lets you specify a colormap (e.g. `cmap=cm.gray`)
- `colorbar()`: adds a colorbar to the current plot

Python Interpreter

```
>>> img_dat = rand(30,30)
>>> imshow(img_dat)
```

(see help(colormaps) for more themes)



Plotting 2D Arrays (as Images)

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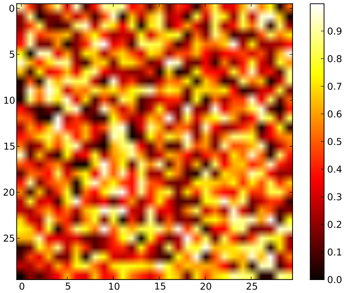
Python Interpreter

```
>>> img_dat = rand(30,30)
>>> imshow(img_dat)
>>> colorbar()
```

(see help(colormaps) for more themes)



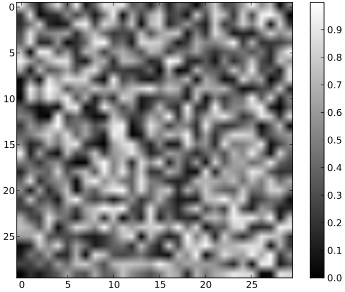
Plotting 2D Arrays (as Images)

- `imshow(X[, cmap])`:
  Display the image or float array in `X`. The parameter `cmap` lets you specify a colormap (e.g. `cmap=cm.gray`)
- `colorbar()`: adds a colorbar to the current plot

Python Interpreter

```
>>> img_dat = rand(30,30)
>>> imshow(img_dat)
>>> colorbar()
>>> gray()
```

(see help(colormaps) for more themes)



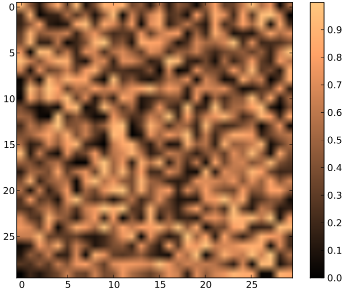
Plotting 2D Arrays (as Images)

- `imshow(X[, cmap])`:
  Display the image or float array in `X`. The parameter `cmap` lets you specify a colormap (e.g. `cmap=cm.gray`)
- `colorbar()`: adds a colorbar to the current plot

Python Interpreter

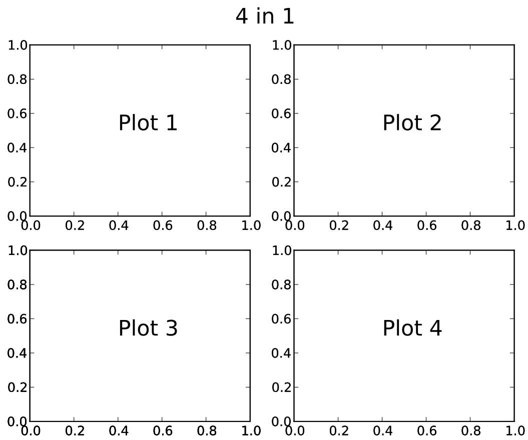
```
>>> img_dat = rand(30,30)
>>> imshow(img_dat)
>>> colorbar()
>>> gray()
>>> copper()
```

(see help(colormaps) for more themes)



Multiple figures and subplots

- `matplotlib` uses concept of current figures and current plots.
- plot command changes current subplot in current figure.
- arbitrary number of figures and subplots possible
- Plots are arranged in a matrix grid.

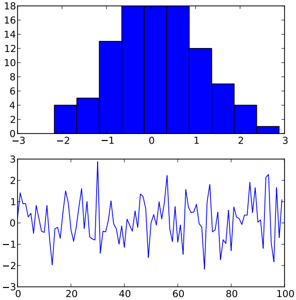


Multiple figures and subplots cntd.

- Let's create two figures, with two plots in each.
- One aligned horizontally, the other vertically

Python Interpreter

```
#get some data
>>> x = randn(100)
# create 1st figure
>>> figure(1)
>>> subplot(2,1,1)
>>> hist(x)
>>> subplot(2,1,2)
>>> plot(x)
```



`subplot(rows, cols, n)` creates or switches to `n`-th plot in a `rows`×`cols` arrangement

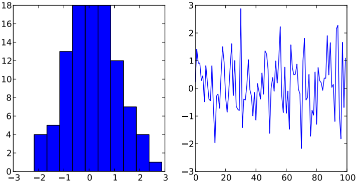
Multiple figures and subplots cntd.

- Let's create two figures, with two plots in each.
- One aligned horizontally, the other vertically

Python Interpreter

```
#get some data
>>> x = randn(100)
# create 1st figure
>>> figure(1)
>>> subplot(2,1,1)
>>> hist(x)
>>> subplot(2,1,2)
>>> plot(x)

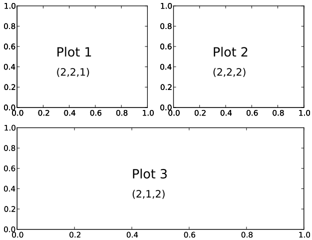
# create 2nd figure
>>> figure(2)
>>> subplot(1,2,1)
>>> hist(x)
>>> subplot(1,2,2)
>>> plot(x)
```



More complex layouts

- `subplot` command allows creation of more complex plot arrangements
- limited to matrix arrangement, no spanning over several cols/rows

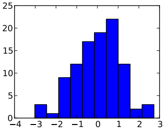
- Plot 1 is first plot in 2×2 layout
- Plot 2 is second plot in 2×2 layout
- Plot 3 is second plot in 2×1 layout



Example

Python Interpreter

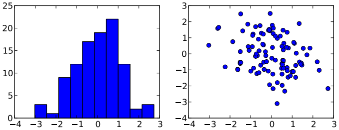
```
# generate some data
>>> x, y = randn(100), randn(100)
# generate 1st subplot
>>> subplot(2,2,1)
>>> hist(x)
```



Example

Python Interpreter

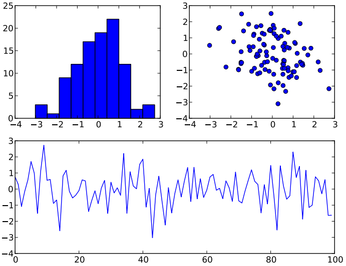
```
# generate some data
>>> x, y = randn(100), randn(100)
# generate 1st subplot
>>> subplot(2,2,1)
>>> hist(x)
# generate 2nd subplot
>>> subplot(2,2,2)
>>> plot(x, y, "bo")
```



Example

Python Interpreter

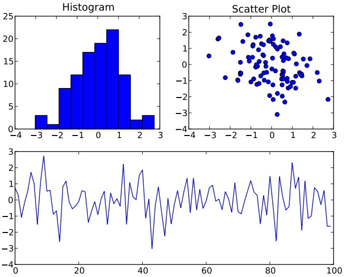
```
# generate some data
>>> x, y = randn(100), randn(100)
# generate 1st subplot
>>> subplot(2,2,1)
>>> hist(x)
# generate 2nd subplot
>>> subplot(2,2,2)
>>> plot(x, y, "bo")
# generate 3rd subplot
>>> subplot(2,1,2)
>>> plot(x)
```



Example

Python Interpreter

```
# generate some data
>>> x, y = randn(100), randn(100)
# generate 1st subplot
>>> subplot(2,2,1)
>>> hist(x)
# generate 2nd subplot
>>> subplot(2,2,2)
>>> plot(x, y, "bo")
# generate 3rd subplot
>>> subplot(2,1,2)
>>> plot(x)
# switch back to plots
>>> subplot(2,2,1)
>>> title("Histogram")
>>> subplot(2,2,2)
>>> title("Scatter Plot")
```



Saving figures

- Figures can be saved from interactive window or with function `savefig`.
- `savefig(filename)`:
  Saves the current figure as PNG to `filename`.
  Optional keyword parameters:
  - format: 'png', 'pdf', 'ps', 'eps', 'svg'
  - transparent: If `True` makes the figure transparent

saveplot.py

```
from pylab import *
x = linspace(-3, 3, 100)
y = sin(x)
plot(x, y)
savefig("sineplot", format="pdf")
```