Matplotlib tutorial

Nicolas P. Rougier - Euroscipy 2012 - Prace 2013

This tutorial is based on Mike Müller's tutorial available from the scipy lecture notes.

Sources are available here. Figures are in the figures directory and all scripts are located in the scripts directory. Github repository is here

Many thanks to Bill Wing and Christoph Deil for review and corrections.

Introductory slides on scientific visualization are here

Introduction

matplotlib is probably the single most used Python package for 2D-graphics. It provides both a very quick way to visualize data from Python and publication-quality figures in many formats. We are going to explore matplotlib in interactive mode covering most common cases.

IPython and the pylab mode

IPython is an enhanced interactive Python shell that has lots of interesting features including named inputs and outputs, access to shell commands, improved debugging and many more. When we start it with the command line argument -pylab (--pylab since IPython version 0.12), it allows interactive matplotlib sessions that have Matlab/Mathematica-like functionality.

pylab

pylab provides a procedural interface to the matplotlib object-oriented plotting library. It is modeled closely after Matlab(TM). Therefore, the majority of plotting commands in pylab have Matlab(TM) analogs with similar arguments. Important commands are explained with interactive examples.

Simple plot

In this section, we want to draw the cosine and sine functions on the same plot. Starting from the default settings, we'll enrich the figure step by step to make it nicer.

First step is to get the data for the sine and cosine functions:

```
from pylab import *

X = np.linspace(-np.pi, np.pi, 256,endpoint=True)
C,S = np.cos(X), np.sin(X)
```

X is now a numpy array with 256 values ranging from $-\pi$ to $+\pi$ (included). C is the cosine (256 values) and S is the sine (256 values).

To run the example, you can type them in an IPython interactive session

$ ipython --pylab
This brings us to the IPython prompt:

```
IPython 0.13 -- An enhanced Interactive Python.
?         -> Introduction to IPython's features.
%magic    -> Information about IPython's 'magic' % functions.
help      -> Python's own help system.
object?   -> Details about 'object'. ?object also works, ?? prints
more.

Welcome to pylab, a matplotlib-based Python environment.
For more information, type 'help(pylab)'.
```

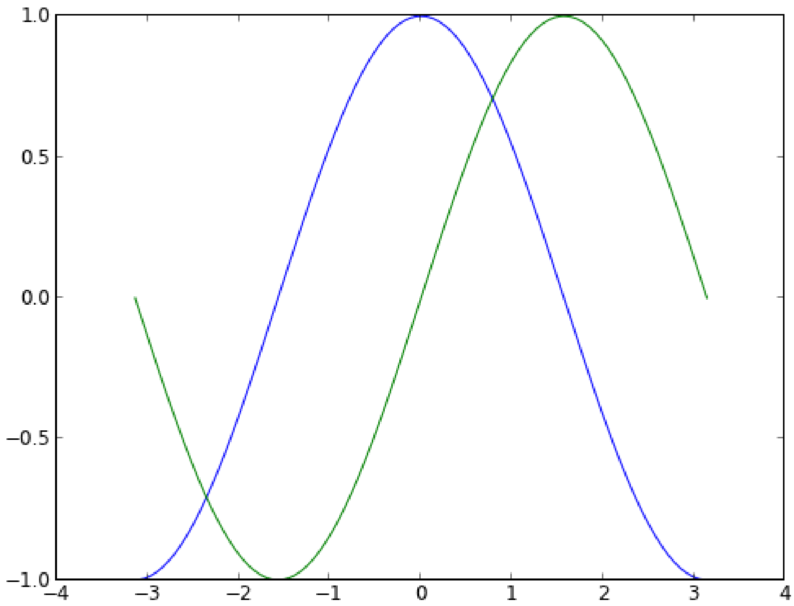
or you can download each of the examples and run it using regular python:

```
$ python exercice_1.py
```

You can get source for each step by clicking on the corresponding figure.

Using defaults

Documentation
plot tutorial
plot() command



Matplotlib comes with a set of default settings that allow customizing all kinds of properties. You can control the defaults of almost every property in matplotlib: figure size and dpi, line width, color and style, axes, axis and grid properties, text and font properties and so on. While matplotlib defaults are rather good in most cases, you may want to modify some properties for specific cases.

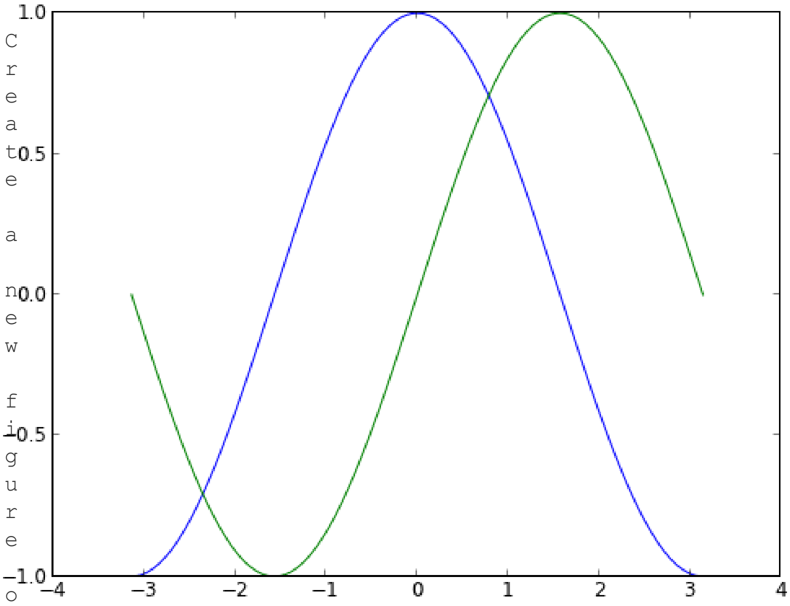
```
from pylab import *

X = np.linspace(-np.pi, np.pi, 256,endpoint=True)
C,S = np.cos(X), np.sin(X)

plot(X,C)
plot(X,S)

show()
```

Instantiating defaults

Documentation
Customizing matplotlib

In the script below, we've instantiated (and commented) all the figure settings that influence the appearance of the plot. The settings have been explicitly set to their default values, but now you can interactively play with the values to explore their affect (see Line properties and Line styles below).

```
# Import everything from matplotlib (numpy is accessible via 'np'
 alias)
from pylab import *
```

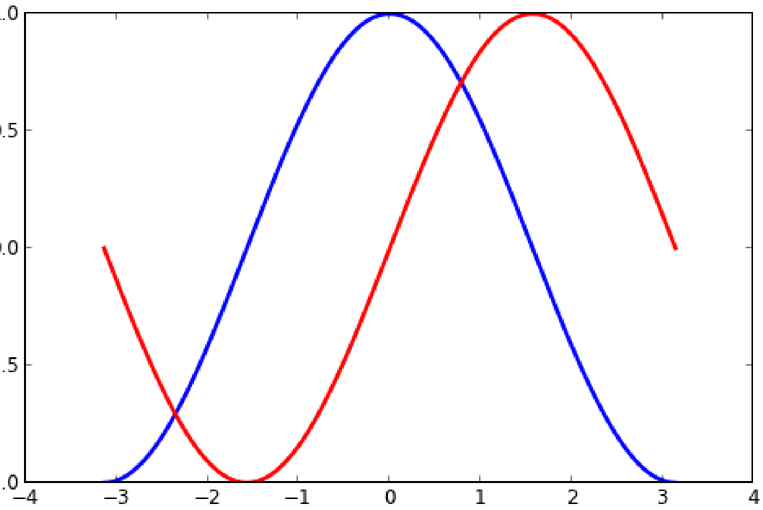



```
# Create a new figure of size 8x6 points, using 80 dots per inch
figure(figsize=(8,6), dpi=80)

# Create a new subplot from a grid of 1x1
subplot(1,1,1)

X = np.linspace(-np.pi, np.pi, 256,endpoint=True)
C,S = np.cos(X), np.sin(X)

# Plot cosine using blue color with a continuous line of width 1
(pixels)
plot(X, C, color="blue", linewidth=1.0, linestyle="-")

# Plot sine using green color with a continuous line of width 1 (
pixels)
plot(X, S, color="green", linewidth=1.0, linestyle="-")

# Set x limits
xlim(-4.0,4.0)

# Set x ticks
xticks(np.linspace(-4,4,9,endpoint=True))

# Set y limits
ylim(-1.0,1.0)

# Set y ticks
yticks(np.linspace(-1,1,5,endpoint=True))

# Save figure using 72 dots per inch
# savefig("exercice_2.png",dpi=72)

# Show result on screen
show()
```

Changing colors and line widths

Documentation
Controlling line properties
Line API

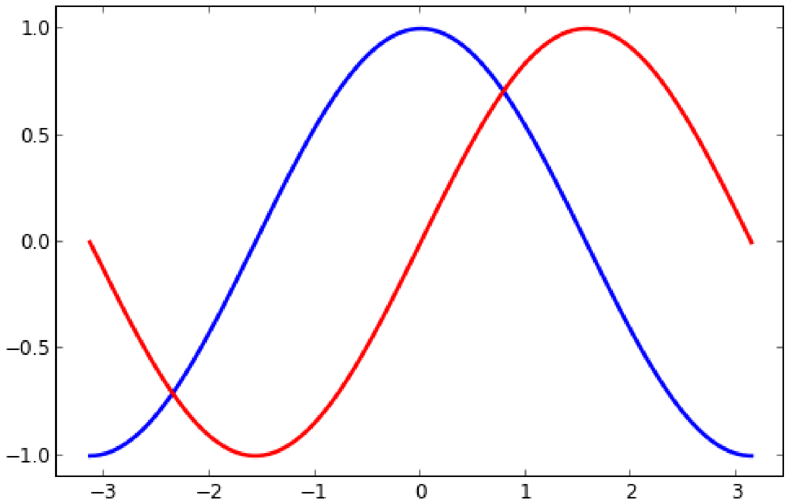
First step, we want to have the cosine in blue and the sine in red and a slighty thicker line for both of them. We'll also slightly alter the figure size to make it more horizontal.




```
...
figure(figsize=(10,6), dpi=80)
plot(X, C, color="blue", linewidth=2.5, linestyle="-")
plot(X, S, color="red",  linewidth=2.5, linestyle="-")
...
```

Setting limits

Documentation
xlim() command
ylim() command

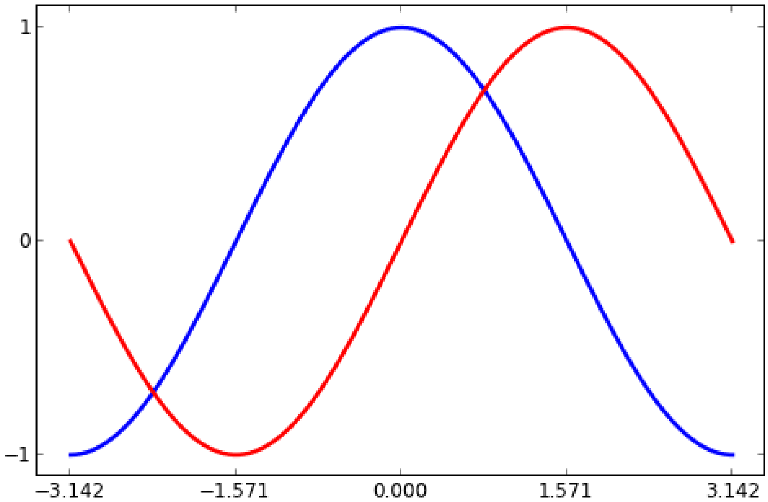


Current limits of the figure are a bit too tight and we want to make some space in order to clearly see all data points.

```
...
xlim(X.min()*1.1, X.max()*1.1)
ylim(C.min()*1.1, C.max()*1.1)
...
```

Setting ticks

Documentation
xticks() command
yticks() command
Tick container
Tick locating and formattir

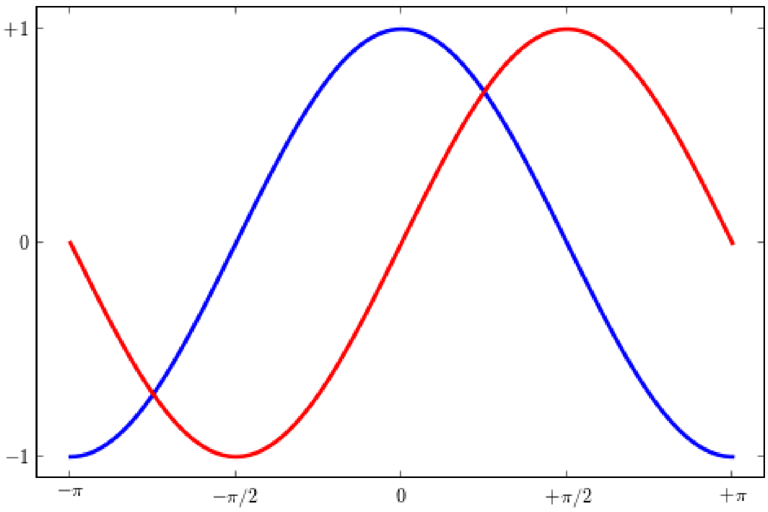


Current ticks are not ideal because they do not show the interesting values (+/−π,+/−π/2) for sine and cosine. We'll change them such that they show only these values.

```
...
xticks( [-np.pi, -np.pi/2, 0, np.pi/2, np.pi])
yticks([-1, 0, +1])
...
```

Setting tick labels

Documentation
Working with text
xticks() command
yticks() command
set_xticklabels()
set_yticklabels()



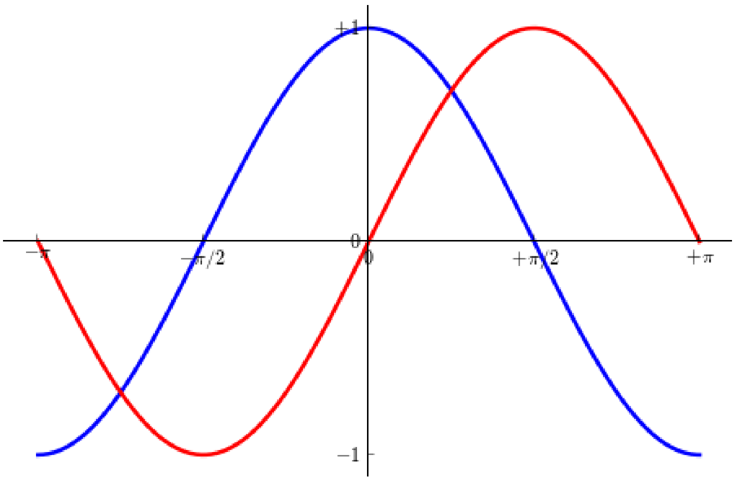
Ticks are now properly placed but their label is not very explicit. We could guess that 3.142 is π but it would be better to make it explicit. When we set tick values, we can also provide a corresponding label in the second argument list. Note that we'll use latex to allow for nice rendering of the label.

```
...
```

```
xticks([-np.pi, -np.pi/2, 0, np.pi/2, np.pi],
       [r'$-\pi$', r'$-\pi/2$', r'$0$', r'$+\pi/2$', r'$+\pi$'])

yticks([-1, 0, +1],
       [r'$-1$', r'$0$', r'$+1$'])
...
```

Moving spines

Documentation
Spines
Axis container
Transformations tutorial



Spines are the lines connecting the axis tick marks and noting the boundaries of the data area. They can be placed at arbitrary positions and until now, they were on the border of the axis. We'll change that since we want to have them in the middle. Since there are four of them (top/bottom/left/right), we'll discard the top and right by setting their color to none and we'll move the bottom and left ones to coordinate 0 in data space coordinates.

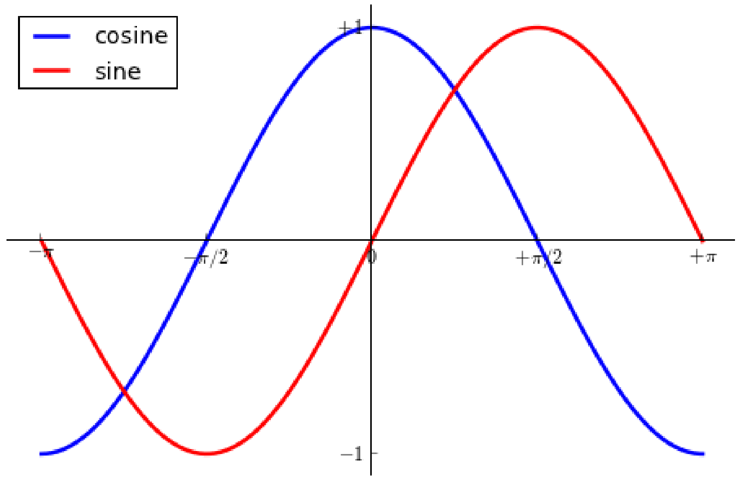
```
...
ax = gca()
ax.spines['right'].set_color('none')
ax.spines['top'].set_color('none')
ax.xaxis.set_ticks_position('bottom')
ax.spines['bottom'].set_position(('data',0))
ax.yaxis.set_ticks_position('left')
ax.spines['left'].set_position(('data',0))
...
```

Adding a legend

Documentation
Legend guide
legend() command

Let's add a legend in the upper left corner. This only requires adding the keyword argument label (that will be used in the legend box) to the plot commands.

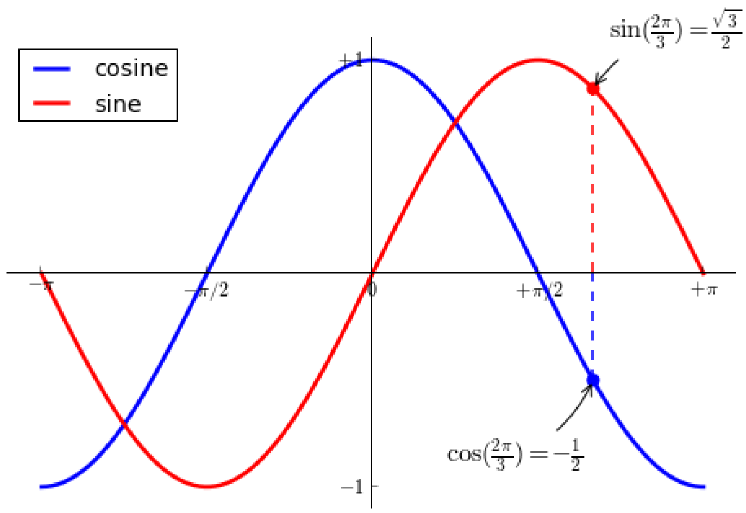
Legend API




```
...
plot(X, C, color="blue", linewidth=2.5, linestyle="-", label="cosine")
plot(X, S, color="red",  linewidth=2.5, linestyle="-", label="sine")

legend(loc='upper left')
...
```

Annotate some points

Documentation
Annotating axis
annotate() command



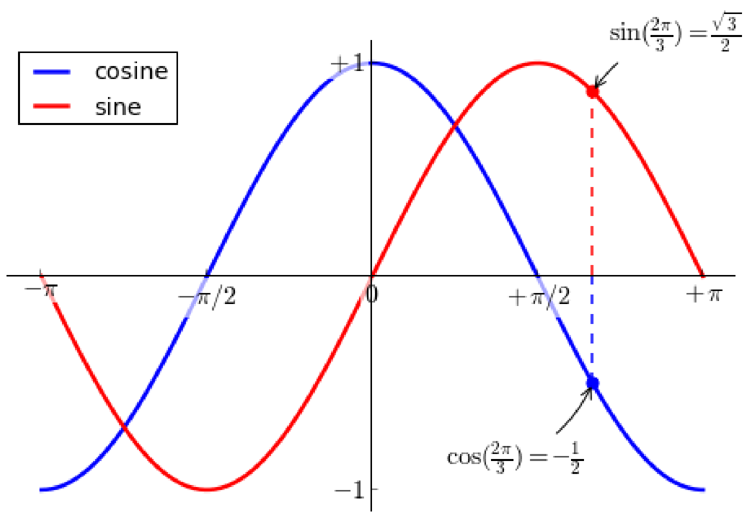
Let's annotate some interesting points using the annotate command. We chose the 2π/3 value and we want to annotate both the sine and the cosine. We'll first draw a marker on the curve as well as a straight dotted line. Then, we'll use the annotate command to display some text with an arrow.

```
...

t = 2*np.pi/3
plot([t,t],[0,np.cos(t)], color ='blue', linewidth=2.5, linestyle="--")
scatter([t,],[np.cos(t),], 50, color ='blue')
```

```
annotate(r'$\sin(\frac{2\pi}{3})=\frac{\sqrt{3}}{2}$',
         xy=(t, np.sin(t)), xycoords='data',
         xytext=(+10, +30), textcoords='offset points', fontsize=
16,
         arrowprops=dict(arrowstyle="->", connectionstyle="arc3,r
ad=.2"))

plot([t,t],[0,np.sin(t)], color ='red', linewidth=2.5, linestyle=
"--")
scatter([t,],[np.sin(t),], 50, color ='red')

annotate(r'$\cos(\frac{2\pi}{3})=-\frac{1}{2}$',
         xy=(t, np.cos(t)), xycoords='data',
         xytext=(-90, -50), textcoords='offset points', fontsize=
16,
         arrowprops=dict(arrowstyle="->", connectionstyle="arc3,r
ad=.2"))
...
```

Devil is in the details

Documentation
Artists
BBox



The tick labels are now hardly visible because of the blue and red lines. We can make them bigger and we can also adjust their properties such that they'll be rendered on a semi-transparent white background. This will allow us to see both the data and the labels.

```
...
for label in ax.get_xticklabels() + ax.get_yticklabels():
    label.set_fontsize(16)
    label.set_bbox(dict(facecolor='white', edgecolor='None', alph
a=0.65 ))
...
```

Figures, Subplots, Axes and

Ticks

So far we have used implicit figure and axes creation. This is handy for fast plots. We can have more control over the display using figure, subplot, and axes explicitly. A figure in matplotlib means the whole window in the user interface. Within this figure there can be subplots. While subplot positions the plots in a regular grid, axes allows free placement within the figure. Both can be useful depending on your intention. We've already worked with figures and subplots without explicitly calling them. When we call plot, matplotlib calls gca() to get the current axes and gca in turn calls gcf() to get the current figure. If there is none it calls figure() to make one, strictly speaking, to make a subplot(111). Let's look at the details.

Figures

A figure is the windows in the GUI that has "Figure #" as title. Figures are numbered starting from 1 as opposed to the normal Python way starting from 0. This is clearly MATLAB-style. There are several parameters that determine what the figure looks like:

Argument	Default	Description
num	1	number of figure
figsize	figure.figsize	figure size in in inches (width, height)
dpi	figure.dpi	resolution in dots per inch
facecolor	figure.facecolor	color of the drawing background
edgecolor	figure.edgecolor	color of edge around the drawing background
frameon	True	draw figure frame or not

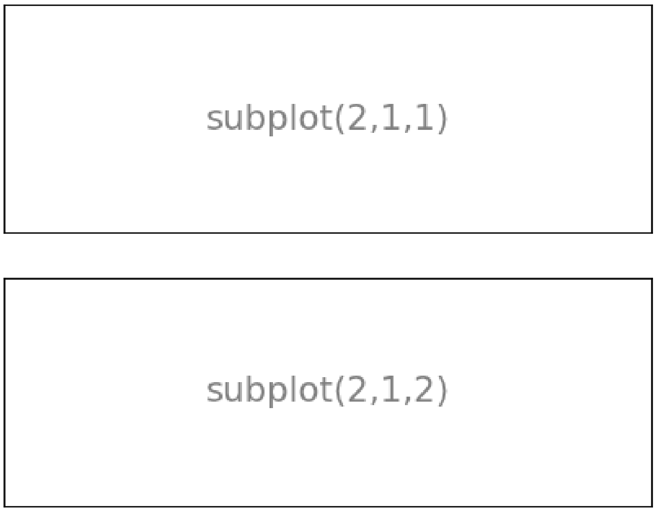
The defaults can be specified in the resource file and will be used most of the time. Only the number of the figure is frequently changed.

When you work with the GUI you can close a figure by clicking on the x in the upper right corner. But you can close a figure programmatically by calling close. Depending on the argument it closes (1) the current figure (no argument), (2) a specific figure (figure number or figure instance as argument), or (3) all figures (all as argument).

As with other objects, you can set figure properties also setp or with the set_something methods.

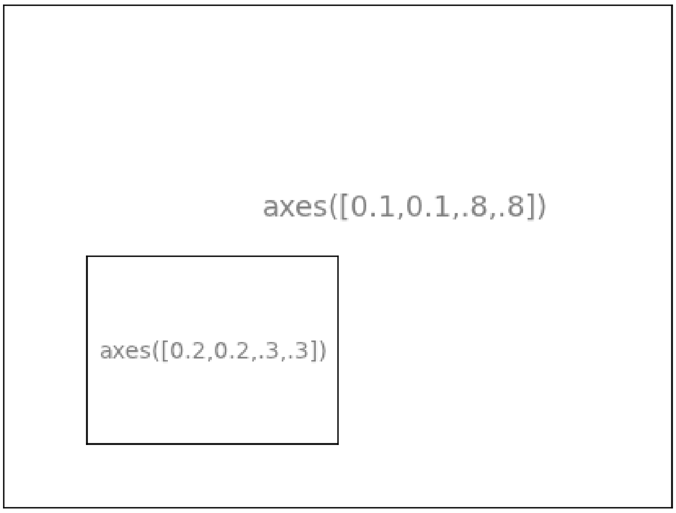
Subplots

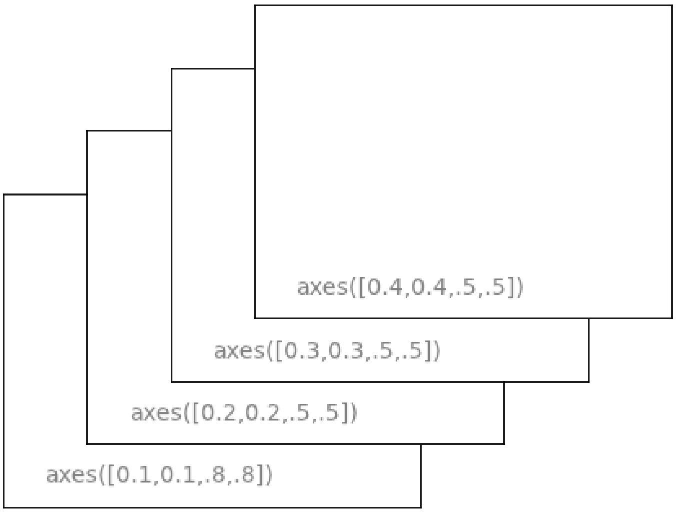
With subplot you can arrange plots in a regular grid. You need to specify the number of rows and columns and the number of the plot. Note that the gridspec command is a more powerful alternative.



Axes

Axes are very similar to subplots but allow placement of plots at any location in the figure. So if we want to put a smaller plot inside a bigger one we do so with axes.





Ticks

Well formatted ticks are an important part of publishing-ready figures. Matplotlib provides a totally configurable system for ticks. There are tick locators to specify where ticks should appear and tick formatters to give ticks the appearance you want. Major and minor ticks can be located and formatted independently from each other. Per default minor ticks are not shown, i.e. there is only an empty list for them because it is as NullLocator (see below).

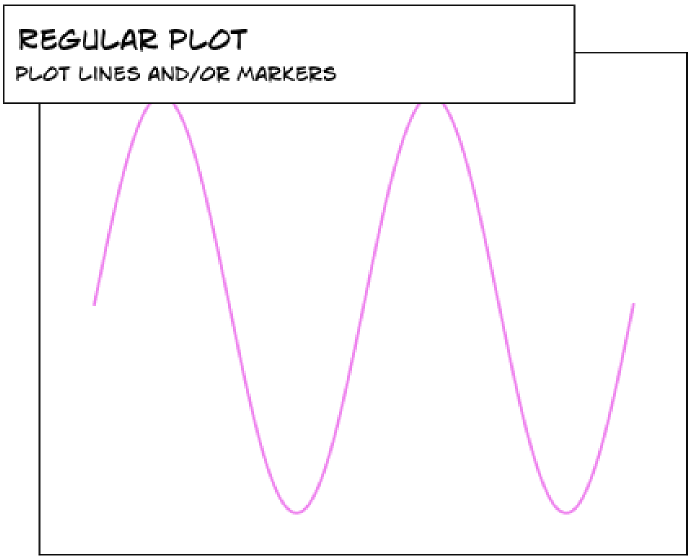
Tick Locators

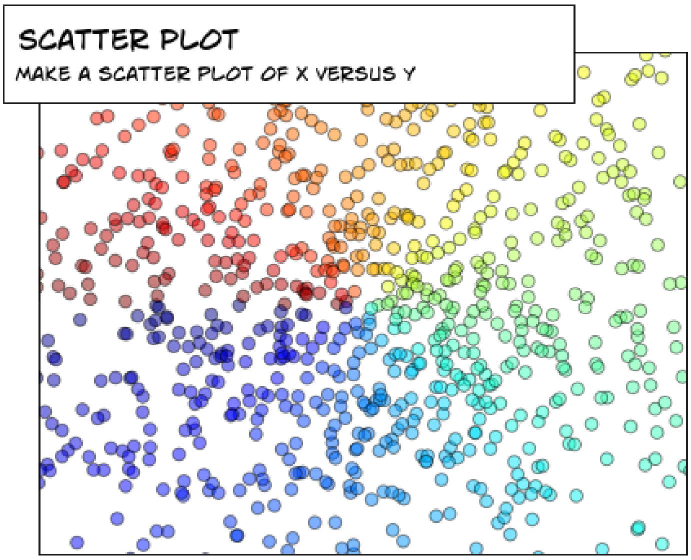
There are several locators for different kind of requirements:

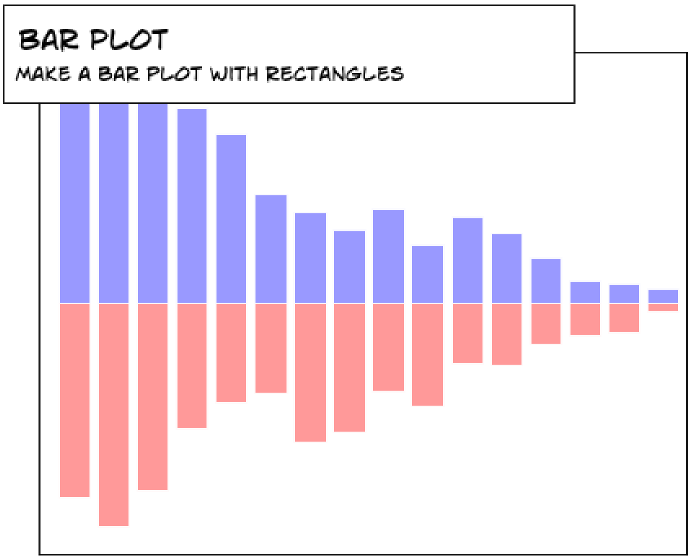
Class	Description
`NullLocator`	No ticks.
`IndexLocator`	Place a tick on every multiple of some base number of points plotted. 
`FixedLocator`	Tick locations are fixed. 
`LinearLocator`	Determine the tick locations. 
`MultipleLocator`	Set a tick on every integer that is multiple of some base. 
`AutoLocator`	Select no more than n intervals at nice locations. 
`LogLocator`	Determine the tick locations for log axes. 

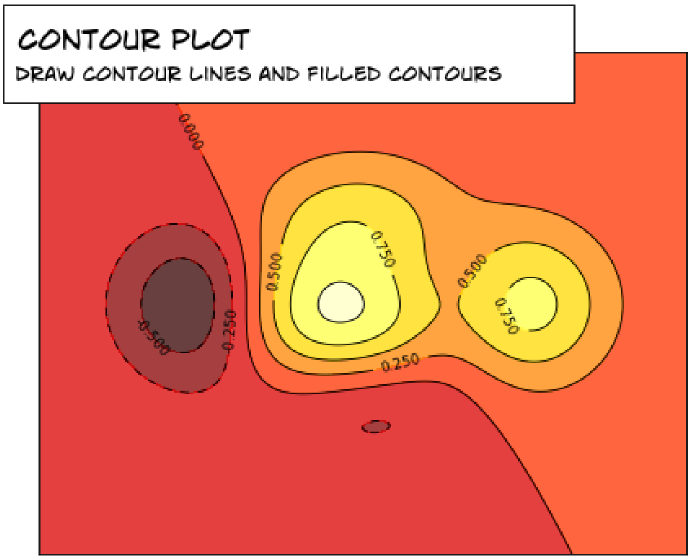
All of these locators derive from the base class matplotlib.ticker.Locator. You can make your own locator deriving from it. Handling dates as ticks can be especially tricky. Therefore, matplotlib provides special locators in matplotlib.dates.

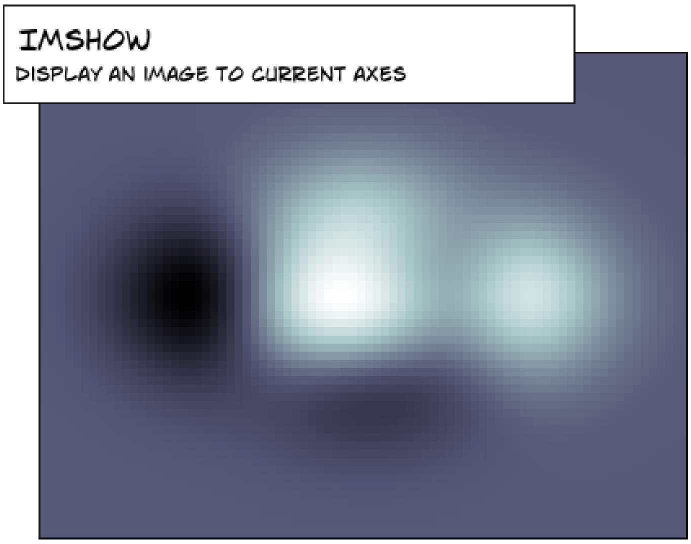
Other Types of Plots

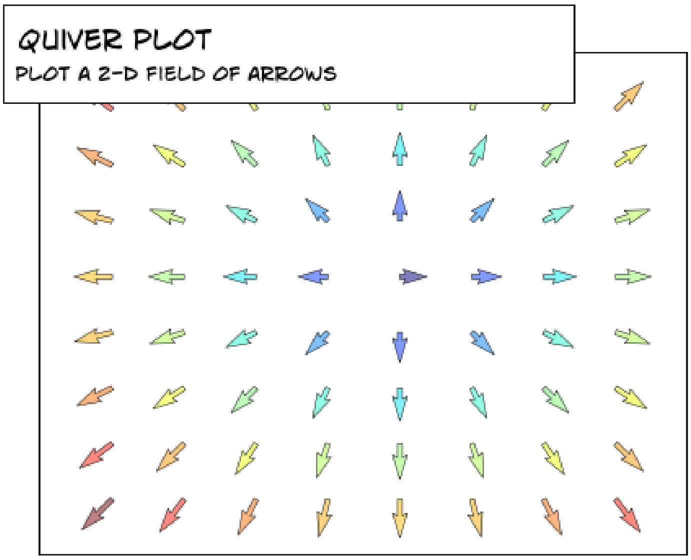

REGULAR PLOT
PLOT LINES AND/OR MARKERS


SCATTER PLOT
MAKE A SCATTER PLOT OF X VERSUS Y


BAR PLOT
MAKE A BAR PLOT WITH RECTANGLES

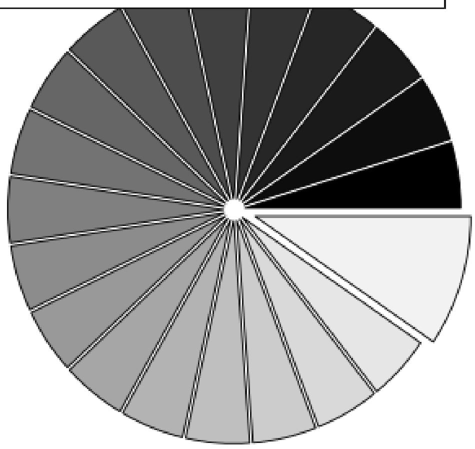

CONTOUR PLOT
DRAW CONTOUR LINES AND FILLED CONTOURS
0.000
0.500
0.750
0.500
0.750
-0.500
0.250
0.250


IMSHOW
DISPLAY AN IMAGE TO CURRENT AXES


QUIVER PLOT
PLOT A 2-D FIELD OF ARROWS

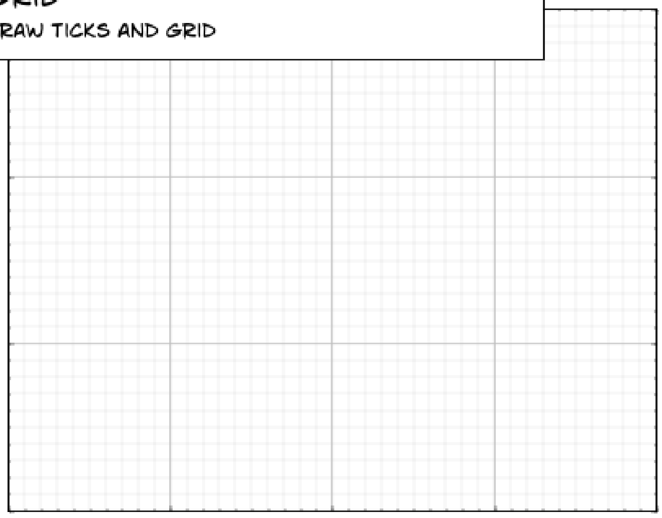
PIE CHART

MAKE A PIE CHART OF AN ARRAY



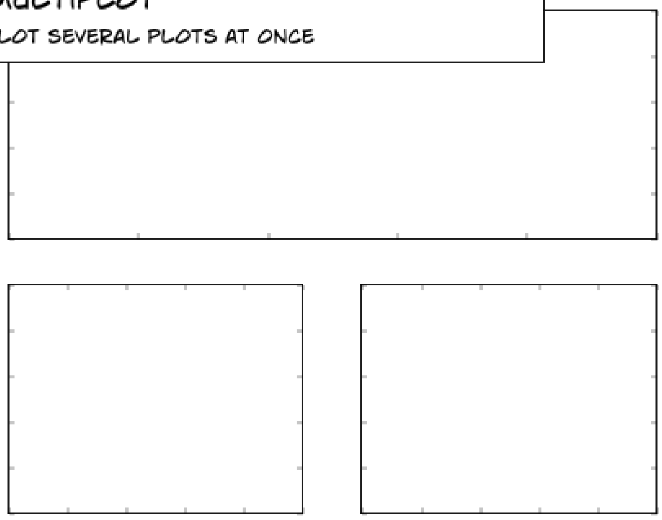
GRID

DRAW TICKS AND GRID



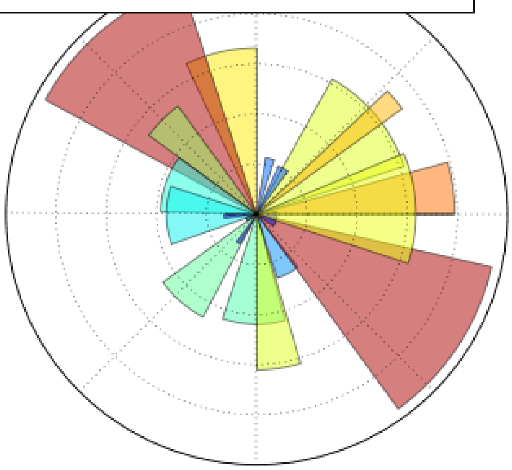
MULTIPLOT

PLOT SEVERAL PLOTS AT ONCE



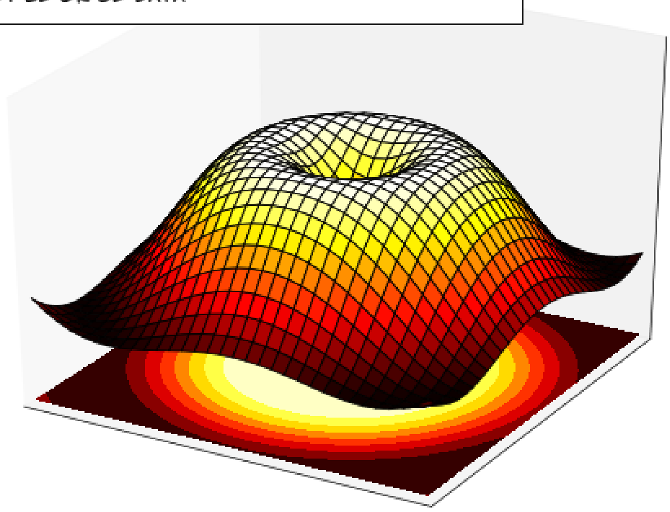
POLAR AXIS

PLOT ANYTHING USING POLAR AXIS



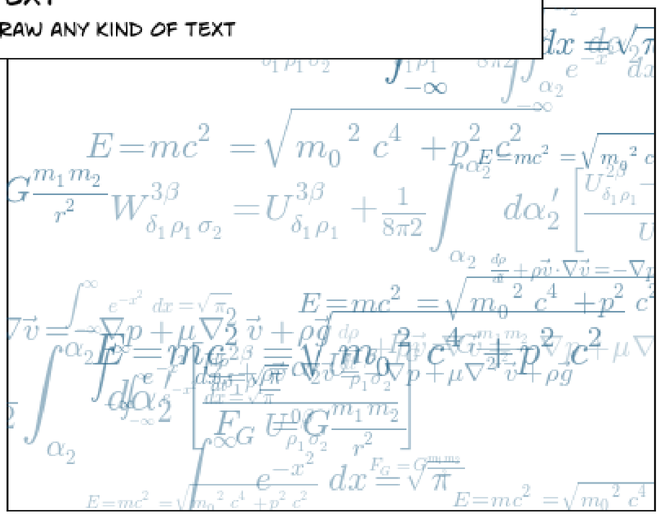
3D PLOTS

PLOT 2D OR 3D DATA



TEXT

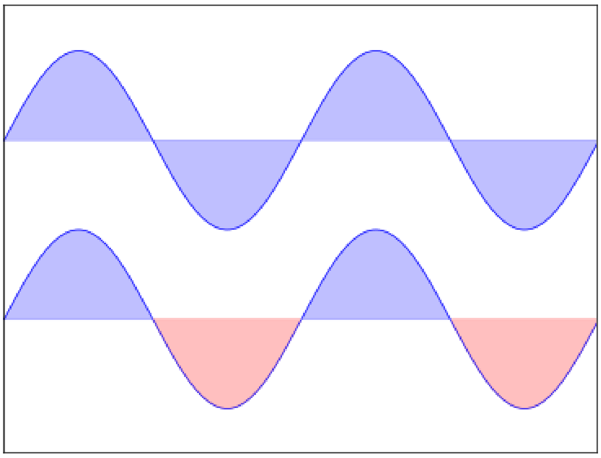
DRAW ANY KIND OF TEXT



Regular Plots

Hints
You need to use the fill_between command.

Starting from the code below, try to reproduce the graphic on the right taking care of filled areas:



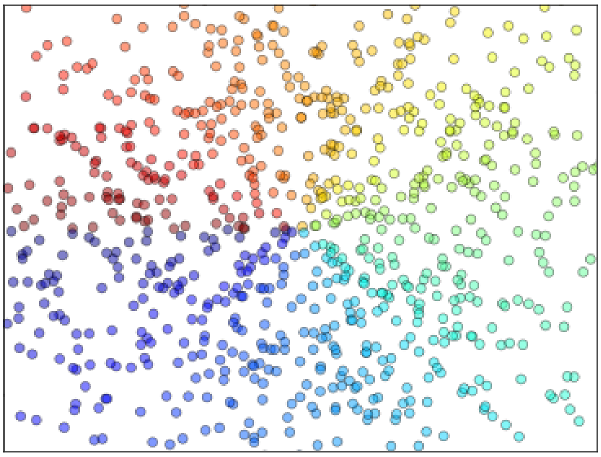
```
from pylab import *

n = 256
X = np.linspace(-np.pi,np.pi,n,endpoint=True)
Y = np.sin(2*X)

plot (X, Y+1, color='blue', alpha=1.00)
plot (X, Y-1, color='blue', alpha=1.00)
show()
```

Click on figure for solution.

Scatter Plots

Hints
Color is given by angle of (X,Y).

Starting from the code below, try to reproduce the graphic on the right taking care of marker size, color and transparency.



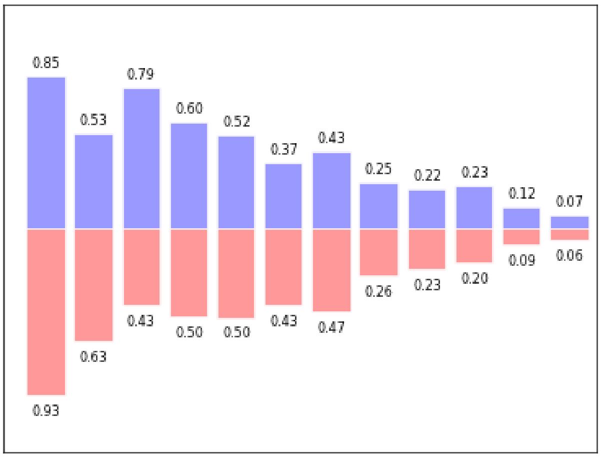
```
from pylab import *

n = 1024
X = np.random.normal(0,1,n)
Y = np.random.normal(0,1,n)

scatter(X,Y)
show()
```

Click on figure for solution.

Bar Plots

Hints
You need to take care of text alignment.

Starting from the code below, try to reproduce the graphic on the right by adding labels for red bars.



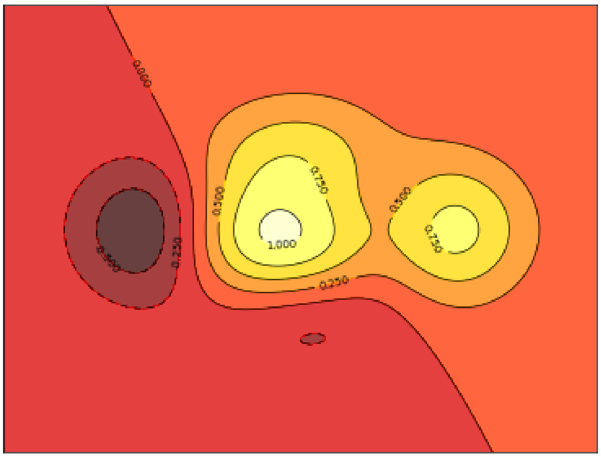

```
from pylab import *

n = 12
X = np.arange(n)
Y1 = (1-X/float(n)) * np.random.uniform(0.5,1.0,n)
Y2 = (1-X/float(n)) * np.random.uniform(0.5,1.0,n)

bar(X, +Y1, facecolor='#9999ff', edgecolor='white')
bar(X, -Y2, facecolor='#ff9999', edgecolor='white')

for x,y in zip(X,Y1):
    text(x+0.4, y+0.05, '%.2f' % y, ha='center', va= 'bottom')

ylim(-1.25,+1.25)
show()
```

Click on figure for solution.

Contour Plots

Hints
You need to use the clabel command.

Starting from the code below, try to reproduce the graphic on the right taking care of the colormap (see Colormaps below).



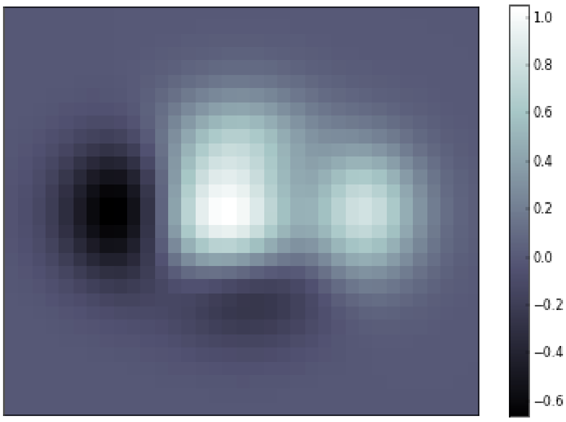
```
from pylab import *

def f(x,y): return (1-x/2+x**5+y**3)*np.exp(-x**2-y**2)

n = 256
x = np.linspace(-3,3,n)
y = np.linspace(-3,3,n)
X,Y = np.meshgrid(x,y)

contourf(X, Y, f(X,Y), 8, alpha=.75, cmap='jet')
C = contour(X, Y, f(X,Y), 8, colors='black', linewidth=.5)
show()
```

Click on figure for solution.

Imshow

Hints
You need to take care of the `origin` of the image in the imshow command and use a colorbar

Starting from the code below, try to reproduce the graphic on the right taking care of colormap, image interpolation and origin.



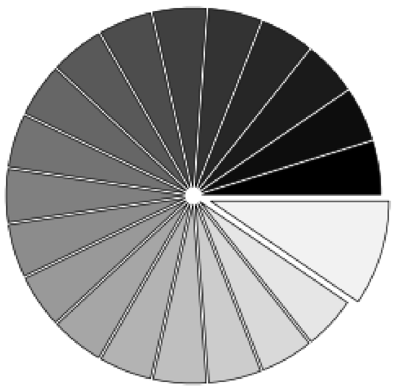

```
from pylab import *

def f(x,y): return (1-x/2+x**5+y**3)*np.exp(-x**2-y**2)

n = 10
x = np.linspace(-3,3,4*n)
y = np.linspace(-3,3,3*n)
X,Y = np.meshgrid(x,y)
imshow(f(X,Y)), show()
```

Click on figure for solution.

Pie Charts

Hints
You need to modify Z.

Starting from the code below, try to reproduce the graphic on the right taking care of colors and slices size.



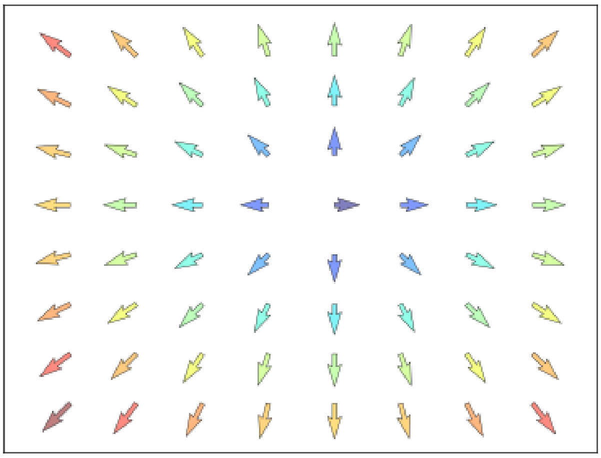
```
from pylab import *

n = 20
Z = np.random.uniform(0,1,n)
pie(Z), show()
```

Click on figure for solution.

Quiver Plots

Hints
You need to draw arrows twice.

Starting from the code above, try to reproduce the graphic on the right taking care of colors and orientations.

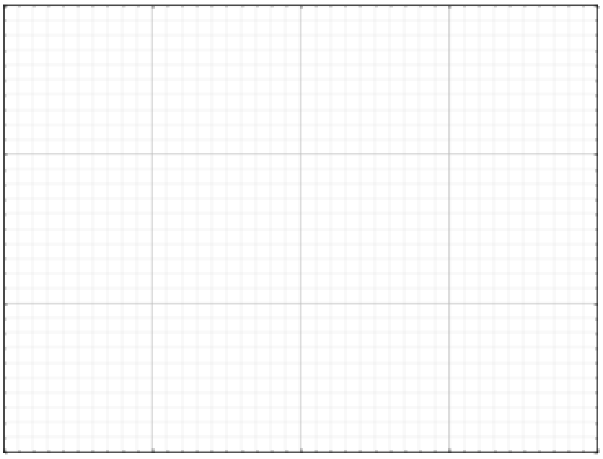


```
from pylab import *

n = 8
X,Y = np.mgrid[0:n,0:n]
quiver(X,Y), show()
```

Click on figure for solution.

Grids

Starting from the code below, try to reproduce the graphic on the right taking care of line styles.



```
from pylab import *

axes = gca()
axes.set_xlim(0,4)
axes.set_ylim(0,3)
axes.set_xticklabels([])
axes.set_yticklabels([])

show()
```

Click on figure for solution.

Multi Plots

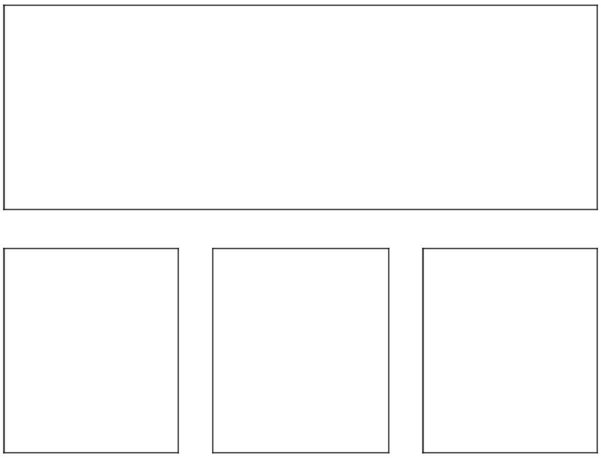
Starting from the code below, try to reproduce the graphic on the right.

```
from pylab import *

subplot(2,2,1)
subplot(2,2,3)
```

Hints
You can use several subplots with different partition.

```
subplot(2,2,4)

show()
```

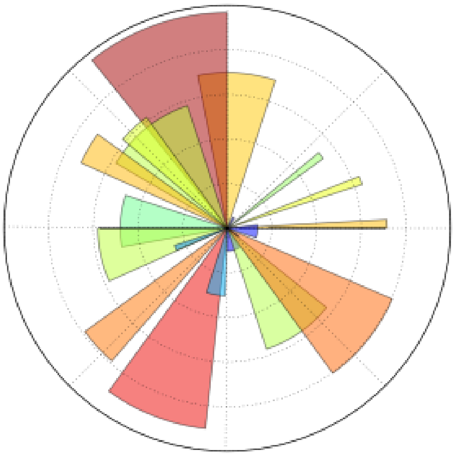
Click on figure for solution.



Polar Axis

Hints
You only need to modify the `axes` line

Starting from the code below, try to reproduce the graphic on the right.



```
from pylab import
*

axes([0,0,1,1])

N = 20
theta = np.arange(
0.0, 2*np.pi, 2*np
.pi/N)
radii = 10*np.random.rand(N)
width = np.pi/4*np.random.rand(N)
bars = bar(theta, radii, width=width, bottom=0.0)

for r,bar in zip(radii, bars):
    bar.set_facecolor( cm.jet(r/10.))
    bar.set_alpha(0.5)

show()
```

Click on figure for solution.

3D Plots

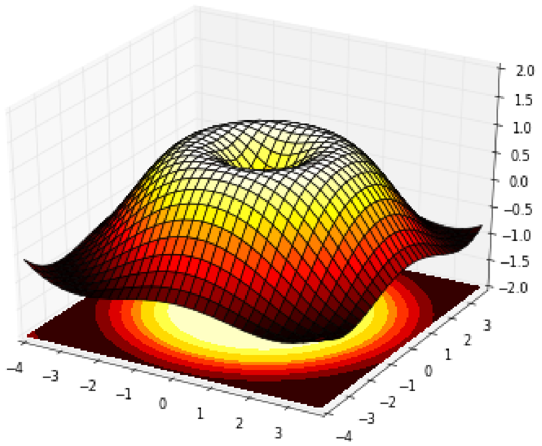
Starting from the code below, try to reproduce the graphic on the right.

```
from pylab import *
from mpl_toolkits.mplot3d import Axes3D

fig = figure()
ax = Axes3D(fig)
X = np.arange(-4, 4, 0.25)
Y = np.arange(-4, 4, 0.25)
```

Hints
You need to use contourf

```
X, Y = np.meshgrid
(X, Y)
R = np.sqrt(X**2 +
 Y**2)
Z = np.sin(R)

ax.plot_surface(X,
 Y, Z, rstride=1,
cstride=1, cmap='h
ot')

show()
```

Click on figure for solution.

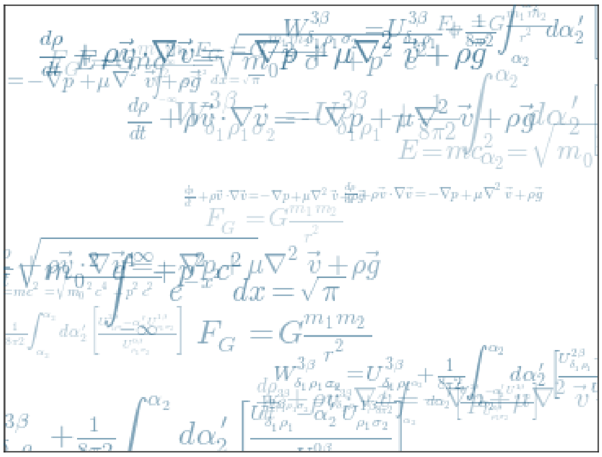


Text

Hints
Have a look at the matplotlib logo.

Try to do the same from scratch !

Click on figure for solution.



Beyond this tutorial

Matplotlib benefits from extensive documentation as well as a large community of users and developpers. Here are some links of interest:

Tutorials

Pyplot tutorial
- Introduction
- Controlling line properties
- Working with multiple figures and axes
- Working with text

Image tutorial

Matplotlib documentation

Code documentation

The code is fairly well documented and you can quickly access a specific command from within a python session:

```
>>> from pylab import *
>>> help(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 marker
s
       plot(y)            # plot y using x as index array 0..N-1
       plot(y, 'r+')      # ditto, but with red plusses

   If *x* and/or *y* is 2-dimensional, then the corresponding col
umns
   will be plotted.
   ...
```

Galleries

The matplotlib gallery is also incredibly useful when you search how to render a given graphic. Each example comes with its source.

A smaller gallery is also available here.

Mailing lists

Finally, there is a user mailing list where you can ask for help and a developers mailing list that is more technical.

Quick references

Here is a set of tables that show main properties and styles.

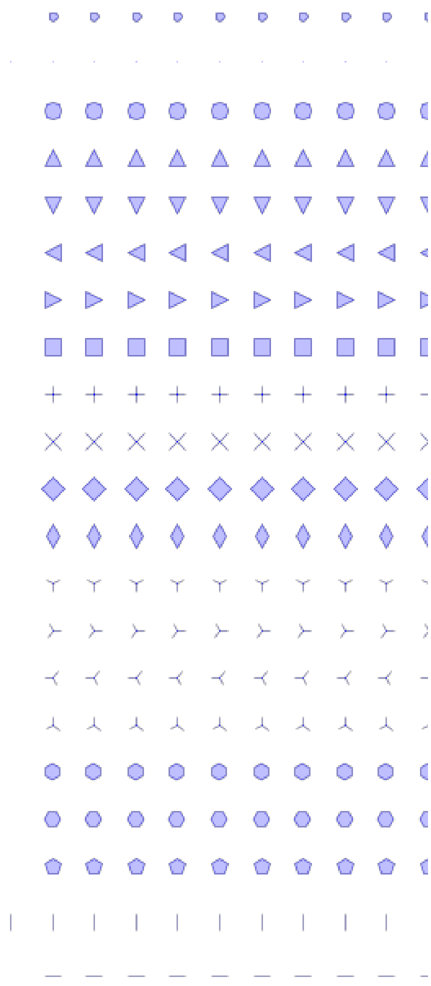
Line properties

Property	Description	Appearance
alpha (or a)	alpha transparency on 0-1 scale	
antialiased	True or False - use antialised rendering	Aliased Anti-aliased
color (or c)	matplotlib color arg	
linestyle (or ls)	see Line properties	
linewidth (or lw)	float, the line width in points	
solid_capstyle	Cap style for solid lines	
solid_joinstyle	Join style for solid lines	
dash_capstyle	Cap style for dashes	
dash_joinstyle	Join style for dashes	
marker	see Markers	
markeredgewidth (mew)	line width around the marker symbol	
markeredgecolor (mec)	edge color if a marker is used	
markerfacecolor (mfc)	face color if a marker is used	
markersize (ms)	size of the marker in points	

Line styles

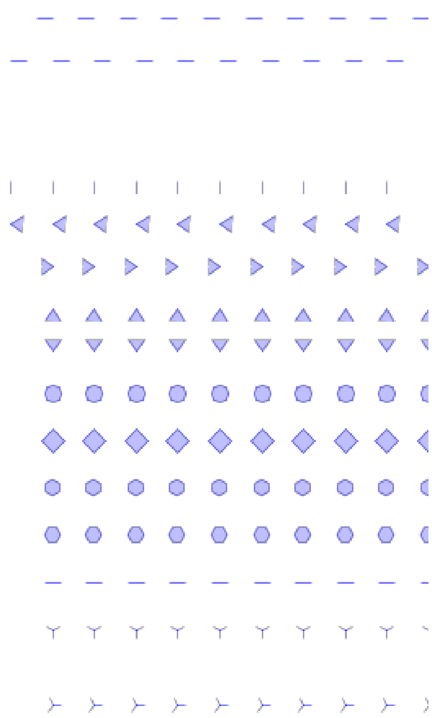
Symbol	Description	Appearance
-	solid line	
--	dashed line	
-.	dash-dot line	
:	dotted line	

.	points	
,	pixels	
o	circle	
^	triangle up	
v	triangle down	
<	triangle left	
>	triangle right	
s	square	
+	plus	
x	cross	
D	diamond	
d	thin diamond	
1	tripod down	
2	tripod up	
3	tripod left	
4	tripod right	
h	hexagon	
H	rotated hexagon	
p	pentagon	
|	vertical line	
_	horizontal line	



Markers

Symbol	Description	Appearance
0	tick left	
1	tick right	
2	tick up	
3	tick down	
4	caret left	
5	caret right	
6	caret up	
7	caret down	
o	circle	
D	diamond	
h	hexagon 1	
H	hexagon 2	
_	horizontal line	
1	tripod down	
2	tripod up	



`3`	tripod left
`4`	tripod right
`8`	octagon
`p`	pentagon
`^`	triangle up
`v`	triangle down
`<`	triangle left
`>`	triangle right
`d`	thin diamond
`,`	pixel
`+`	plus
`.`	point
`s`	square
`*`	star
`|`	vertical line
`x`	cross
`r'$\sqrt{2}$'`	any latex expression

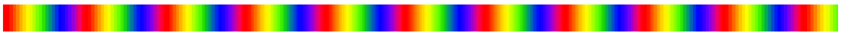
Colormaps

All colormaps can be reversed by appending `_r`. For instance, `gray_r` is the reverse of `gray`.

If you want to know more about colormaps, checks Documenting the matplotlib colormaps.

Base

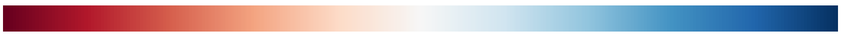
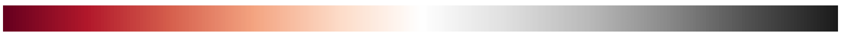
Name	Appearance
autumn	
bone	
cool	
copper	
flag	
gray	
hot	

hsv	
jet	
pink	
prism	
spectral	
spring	
summer	
winter	

GIST

Name	Appearance
gist_earth	
gist_gray	
gist_heat	
gist_ncar	
gist_rainbow	
gist_stern	
gist_yarg	

Sequential

Name	Appearance
BrBG	
PiYG	
PRGn	
PuOr	
RdBu	
RdGy	
RdYlBu	
RdYlGn	
Spectral	

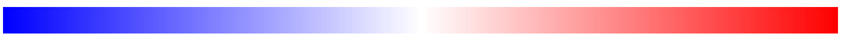
Diverging

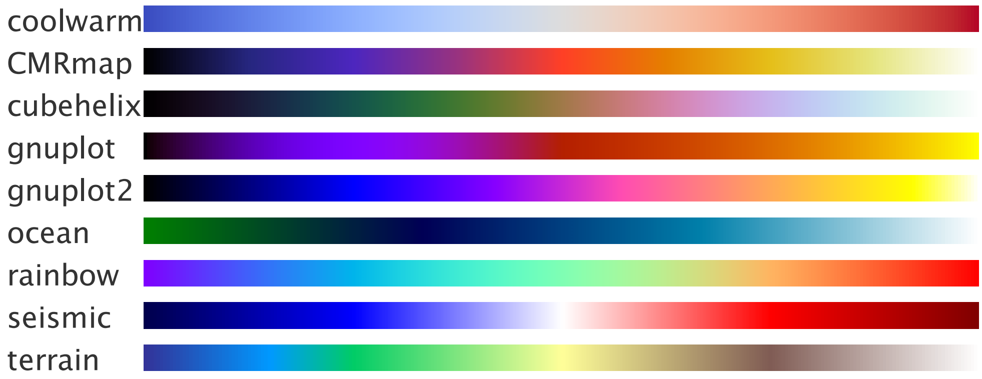
Name	Appearance
Blues	
BuGn	
BuPu	
GnBu	
Greens	
Greys	
Oranges	
OrRd	
PuBu	
PuBuGn	
PuRd	
Purples	
RdPu	
Reds	
YlGn	
YlGnBu	
YlOrBr	
YlOrRd	

Qualitative

Name	Appearance
Accent	
Dark2	
Paired	
Pastel1	
Pastel2	
Set1	
Set2	
Set3	

Miscellaneous

Name	Appearance
afmhot	
binary	
brg	
bwr	


coolwarm
CMRmap
cubehelix
gnuplot
gnuplot2
ocean
rainbow
seismic
terrain