

Matplotlib for beginners

Matplotlib is a library for making 2D plots in Python. It is designed with the philosophy that you should be able to create simple plots with just a few commands:

1 Initialize

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

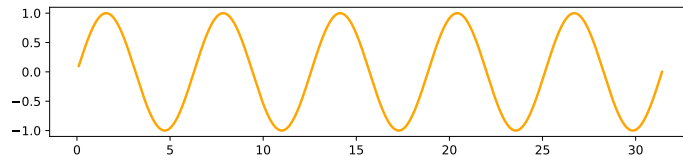
2 Prepare

```
X = np.linspace(0, 4*np.pi, 1000)
Y = np.sin(X)
```

3 Render

```
fig, ax = plt.subplots()
ax.plot(X, Y)
fig.show()
```

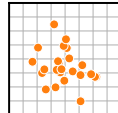
4 Observe



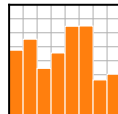
Choose

Matplotlib offers several kind of plots (see Gallery):

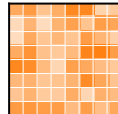
```
X = np.random.uniform(0, 1, 100)
Y = np.random.uniform(0, 1, 100)
ax.scatter(X, Y)
```



```
X = np.arange(10)
Y = np.random.uniform(1, 10, 10)
ax.bar(X, Y)
```



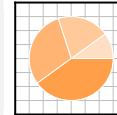
```
Z = np.random.uniform(0, 1, (8,8))
ax.imshow(Z)
```



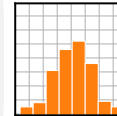
```
Z = np.random.uniform(0, 1, (8,8))
ax.contourf(Z)
```



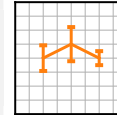
```
Z = np.random.uniform(0, 1, 4)
ax.pie(Z)
```



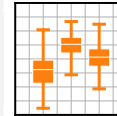
```
Z = np.random.normal(0, 1, 100)
ax.hist(Z)
```



```
X = np.arange(5)
Y = np.random.uniform(0, 1, 5)
ax.errorbar(X, Y, Y/4)
```



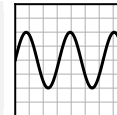
```
Z = np.random.normal(0, 1, (100,3))
ax.boxplot(Z)
```



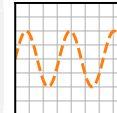
Tweak

You can modify pretty much anything in a plot, including limits, colors, markers, line width and styles, ticks and ticks labels, titles, etc.

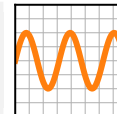
```
X = np.linspace(0, 10, 100)
Y = np.sin(X)
ax.plot(X, Y, color="black")
```



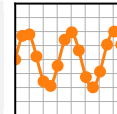
```
X = np.linspace(0, 10, 100)
Y = np.sin(X)
ax.plot(X, Y, linestyle="--")
```



```
X = np.linspace(0, 10, 100)
Y = np.sin(X)
ax.plot(X, Y, linewidth=5)
```



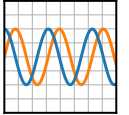
```
X = np.linspace(0, 10, 100)
Y = np.sin(X)
ax.plot(X, Y, marker="o")
```



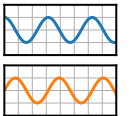
Organize

You can plot several data on the the same figure, but you can also split a figure in several subplots (named Axes):

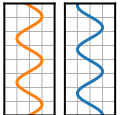
```
X = np.linspace(0, 10, 100)
Y1, Y2 = np.sin(X), np.cos(X)
ax.plot(X, Y1, X, Y2)
```



```
fig, (ax1, ax2) = plt.subplots((2,1))
ax1.plot(X, Y1, color="C1")
ax2.plot(X, Y2, color="C0")
```

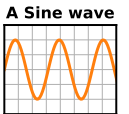


```
fig, (ax1, ax2) = plt.subplots((1,2))
ax1.plot(Y1, X, color="C1")
ax2.plot(Y2, X, color="C0")
```

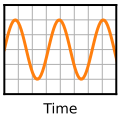


Label (everything)

```
ax.plot(X, Y)
fig.suptitle(None)
ax.set_title("A Sine wave")
```



```
ax.plot(X, Y)
ax.set_ylabel(None)
ax.set_xlabel("Time")
```



Explore

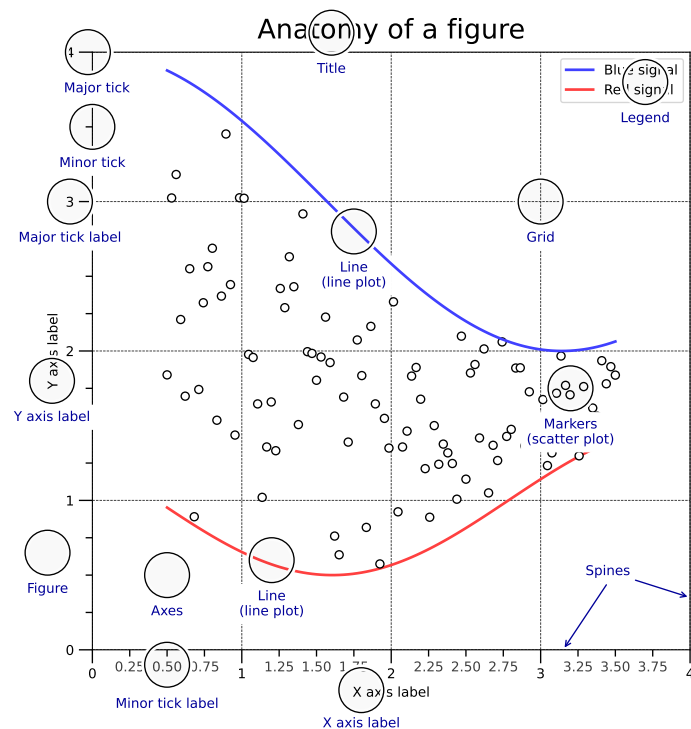
Figures are shown with a graphical user interface that allows to zoom and pan the figure, to navigate between the different views and to show the value under the mouse.

Save (bitmap or vector format)

```
fig.savefig("my-first-figure.png", dpi=300)
fig.savefig("my-first-figure.pdf")
```

Matplotlib for intermediate users

A matplotlib figure is composed of a hierarchy of elements that forms the actual figure. Each element can be modified.

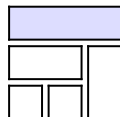


Figure, axes & spines

```
fig, axs = plt.subplots(3,3)
axs[0,0].set_facecolor("#dddfdf")
axs[2,2].set_facecolor("#fffdd")
```



```
gs = fig.add_gridspec(3, 3)
ax = fig.add_subplot(gs[0, :])
ax.set_facecolor("#dddfdf")
```

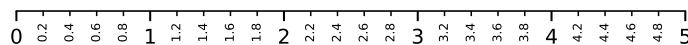


```
fig, ax = plt.subplots()
ax.spines["top"].set_color("None")
ax.spines["right"].set_color("None")
```



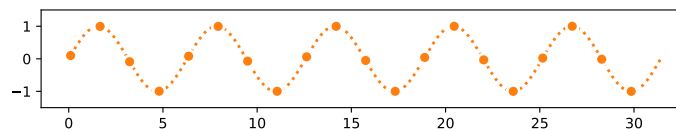
Ticks & labels

```
from mpl.ticker import MultipleLocator as ML
from mpl.ticker import ScalarFormatter as SF
ax.xaxis.set_minor_locator(ML(0.2))
ax.xaxis.set_minor_formatter(SF())
ax.tick_params(axis='x', which='minor', rotation=90)
```



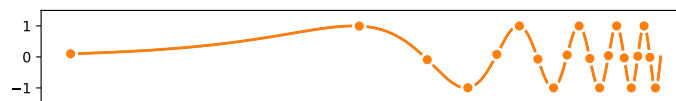
Lines & markers

```
X = np.linspace(0.1, 10*np.pi, 1000)
Y = np.sin(X)
ax.plot(X, Y, "C1o:", markevery=25, mec="1.0")
```



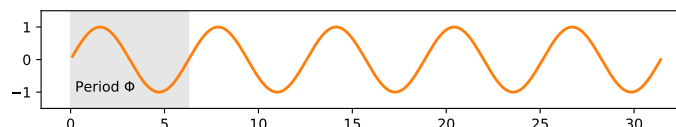
Scales & projections

```
fig, ax = plt.subplots()
ax.set_xscale("log")
ax.plot(X, Y, "C1o-", markevery=25, mec="1.0")
```



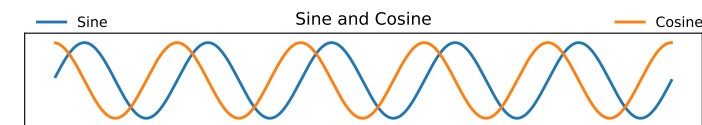
Text & ornaments

```
ax.fill_betweenx([-1,1],[0],[2*np.pi])
ax.text(0, -1, r"Period $\Phi$")
```



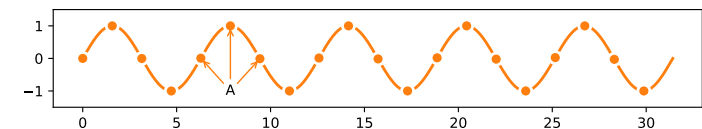
Legend

```
ax.plot(X, np.sin(X), "C0", label="Sine")
ax.plot(X, np.cos(X), "C1", label="Cosine")
ax.legend(bbox_to_anchor=(0,1,1,.1), ncol=2,
         mode="expand", loc="lower left")
```



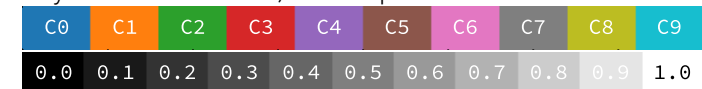
Annotation

```
ax.annotate("A", (X[250],Y[250]),(X[250],-1),
          ha="center", va="center",arrowprops =
          {"arrowstyle": "->", "color": "C1"})
```



Colors

Any color can be used, but Matplotlib offers sets of colors:



Size & DPI

Consider a square figure to be included in a two-columns A4 paper with 2cm margins on each side and a column separation of 1cm. The width of a figure is (21 - 2*2 - 1)/2 = 8cm. One inch being 2.54cm, figure size should be 3.15×3.15 in.

```
fig = plt.figure(figsize=(3.15,3.15), dpi=50)
plt.savefig("figure.pdf", dpi=600)
```

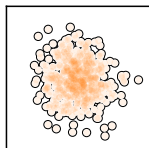
Matplotlib 3.5.0 handout for intermediate users. Copyright (c) 2021 Matplotlib Development Team. Released under a CC-BY 4.0 International License. Supported by NumFOCUS.

Matplotlib tips & tricks

Transparency

Scatter plots can be enhanced by using transparency (alpha) in order to show area with higher density. Multiple scatter plots can be used to delineate a frontier.

```
X = np.random.normal(-1, 1, 500)
Y = np.random.normal(-1, 1, 500)
ax.scatter(X, Y, 50, "0.0", lw=2) # optional
ax.scatter(X, Y, 50, "1.0", lw=0) # optional
ax.scatter(X, Y, 40, "C1", lw=0, alpha=0.1)
```



Rasterization

If your figure has many graphical elements, such as a huge scatter, you can rasterize them to save memory and keep other elements in vector format.

```
X = np.random.normal(-1, 1, 10_000)
Y = np.random.normal(-1, 1, 10_000)
ax.scatter(X, Y, rasterized=True)
fig.savefig("rasterized-figure.pdf", dpi=600)
```

Offline rendering

Use the Agg backend to render a figure directly in an array.

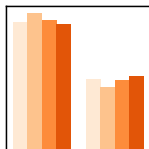
```
from matplotlib.backends.backend_agg import FigureCanvas
canvas = FigureCanvas(Figure())
... # draw some stuff
canvas.draw()
Z = np.array(canvas.renderer.buffer_rgba())
```

Range of continuous colors

You can use colormap to pick from a range of continuous colors.

```
X = np.random.randn(1000, 4)
cmap = plt.get_cmap("Oranges")
colors = cmap([0.2, 0.4, 0.6, 0.8])
```

```
ax.hist(X, 2, histtype='bar', color=colors)
```



Text outline

Use text outline to make text more visible.

```
import matplotlib.patheffects as fx
text = ax.text(0.5, 0.1, "Label")
text.set_path_effects([
    fx.Stroke(linewidth=3, foreground='1.0'),
    fx.Normal()])
```



Multiline plot

You can plot several lines at once using None as separator.

```
X, Y = [], []
for x in np.linspace(0, 10*np.pi, 100):
    X.extend([x, x, None]), Y.extend([0, sin(x), None])
ax.plot(X, Y, "black")
```



Dotted lines

To have rounded dotted lines, use a custom linestyle and modify dash_capstyle.

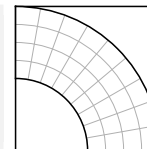
```
ax.plot([0,1], [0,0], "C1",
        linestyle = (0, (0.01, 1)), dash_capstyle="round")
ax.plot([0,1], [1,1], "C1",
        linestyle = (0, (0.01, 2)), dash_capstyle="round")
```



Combining axes

You can use overlaid axes with different projections.

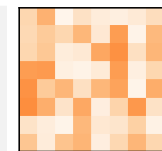
```
ax1 = fig.add_axes([0,0,1,1],
                    label="cartesian")
ax2 = fig.add_axes([0,0,1,1],
                    label="polar",
                    projection="polar")
```



Colorbar adjustment

You can adjust a colorbar's size when adding it.

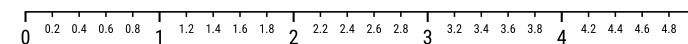
```
im = ax.imshow(Z)
cb = plt.colorbar(im,
                  fraction=0.046, pad=0.04)
cb.set_ticks([])
```



Taking advantage of typography

You can use a condensed font such as Roboto Condensed to save space on tick labels.

```
for tick in ax.get_xticklabels(which='both'):
    tick.set_fontname("Roboto Condensed")
```



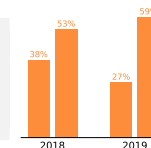
Getting rid of margins

Once your figure is finished, you can call `tight_layout()` to remove white margins. If there are remaining margins, you can use the `pdfcrop` utility (comes with TeX live).

Hatching

You can achieve a nice visual effect with thick hatch patterns.

```
cmap = plt.get_cmap("Oranges")
plt.rcParams['hatch.color'] = cmap(0.2)
plt.rcParams['hatch.linewidth'] = 8
ax.bar(X, Y, color=cmap(0.6), hatch="/" )
```



Read the documentation

Matplotlib comes with an extensive documentation explaining the details of each command and is generally accompanied by examples. Together with the huge online gallery, this documentation is a gold-mine.

Matplotlib 3.5.0 handout for tips & tricks. Copyright (c) 2021 Matplotlib Development Team. Released under a CC-BY 4.0 International License. Supported by NumFOCUS.

Quick start

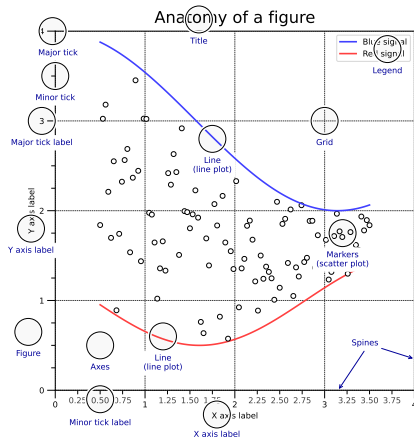
```
import numpy as np
import matplotlib as mpl
import matplotlib.pyplot as plt
```

```
X = np.linspace(0, 2*np.pi, 100)
Y = np.cos(X)
```

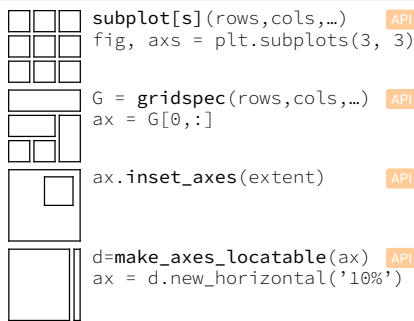
```
fig, ax = plt.subplots()
ax.plot(X, Y, color='green')
```

```
fig.savefig("figure.pdf")
fig.show()
```

Anatomy of a figure



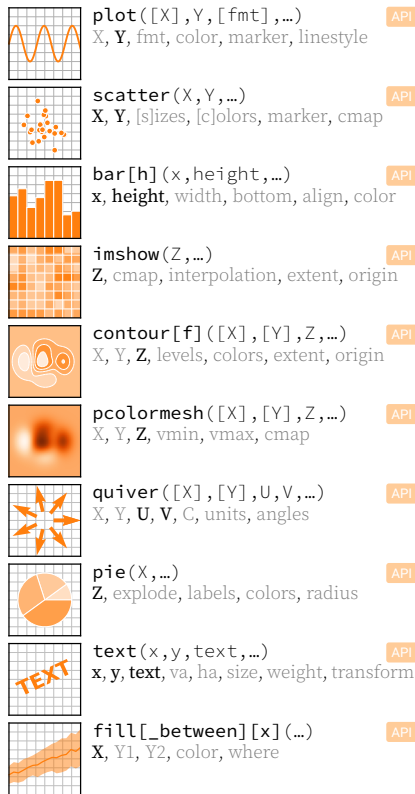
Subplots layout



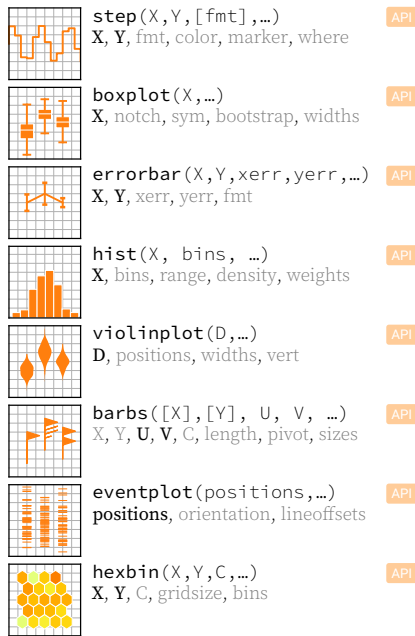
Getting help

- matplotlib.org
- github.com/matplotlib/matplotlib/issues
- discourse.matplotlib.org
- stackoverflow.com/questions/tagged/matplotlib
- gitter.im/matplotlib
- twitter.com/matplotlib
- Matplotlib users mailing list

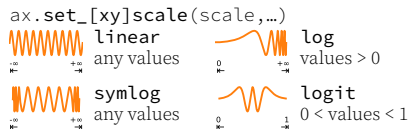
Basic plots



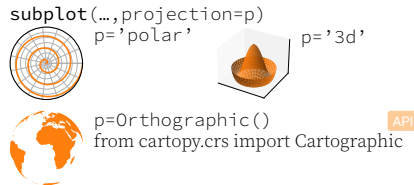
Advanced plots



Scales



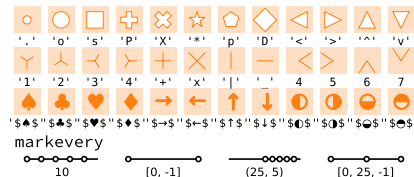
Projections



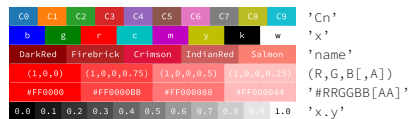
Lines



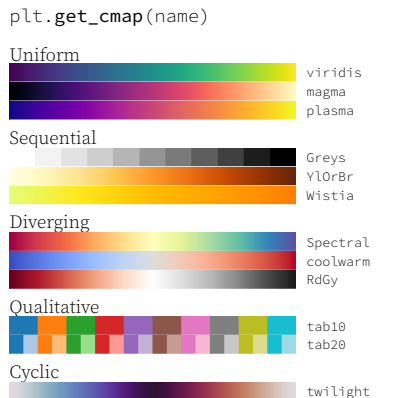
Markers



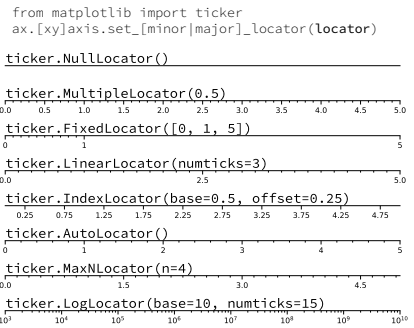
Colors



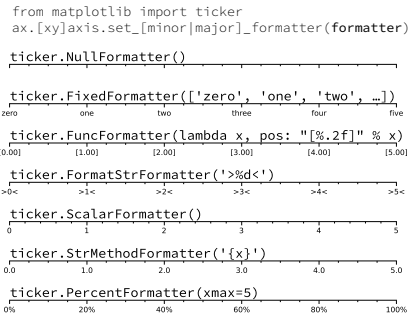
Colormaps



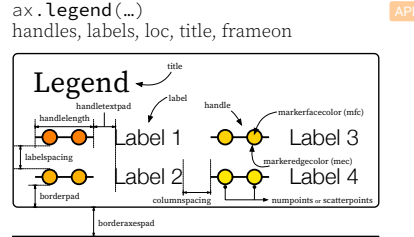
Tick locators



Tick formatters



Ornaments



ax.colorbar(...)



ax.annotate(...)



Event handling

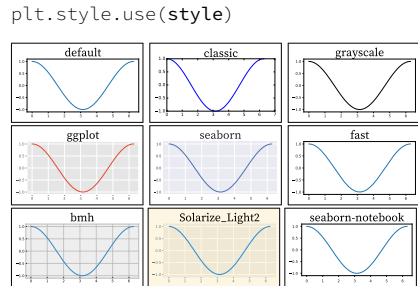
```
fig, ax = plt.subplots()
def on_click(event):
    print(event)
fig.canvas.mpl_connect(
    'button_press_event', on_click)
```

Animation

```
import matplotlib.animation as mpla

T = np.linspace(0, 2*np.pi, 100)
S = np.sin(T)
line, = plt.plot(T, S)
def animate(i):
    line.set_ydata(np.sin(T+i/50))
anim = mpla.FuncAnimation(
    plt.gcf(), animate, interval=5)
plt.show()
```

Styles



Quick reminder

```
ax.grid()
ax.set_xlabel(vmin, vmax)
ax.set_ylabel(label)
ax.set_xticks(ticks, [labels])
ax.set_yticklabels(labels)
ax.set_title(title)
ax.tick_params(width=10, ...)
ax.set_axis_on/off()
```

```
fig.suptitle(title)
fig.tight_layout()
plt.gcf(), plt.gca()
mpl.rc('axes', linewidth=1, ...)
[fig|ax].patch.set_alpha(0)
text=r'$\frac{-e^{i\pi}}{2\pi}$'
```

Keyboard shortcuts

- | | |
|---------------------|---------------------|
| ctrl + s Save | ctrl + w Close plot |
| r Reset view | f Fullscreen 0/1 |
| f View forward | b View back |
| p Pan view | o Zoom to rect |
| x X pan/zoom | y Y pan/zoom |
| g Minor grid 0/1 | m Major grid 0/1 |
| l X axis log/linear | L Y axis log/linear |

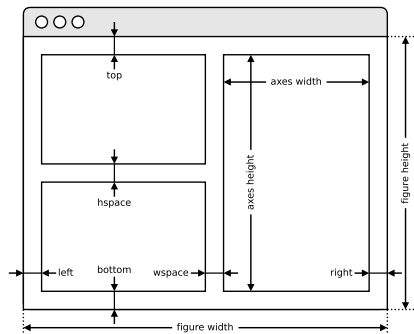
Ten simple rules

1. Know Your Audience
2. Identify Your Message
3. Adapt the Figure
4. Captions Are Not Optional
5. Do Not Trust the Defaults
6. Use Color Effectively
7. Do Not Mislead the Reader
8. Avoid "Chartjunk"
9. Message Trumps Beauty
10. Get the Right Tool

Axes adjustments

API

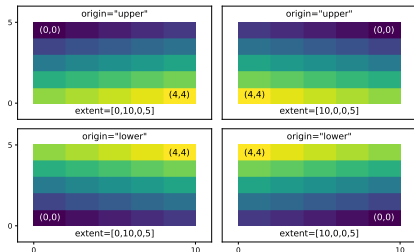
plt.subplots_adjust(...)



Extent & origin

API

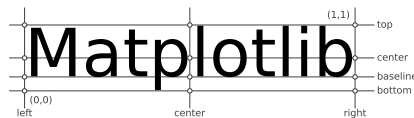
ax.imshow(extent=..., origin=...)



Text alignments

API

ax.text(..., ha=..., va=..., ...)



Text parameters

API

ax.text(..., family=..., size=..., weight=...)

ax.text(..., fontproperties=...)

The quick brown fox
The quick brown fox
The quick brown fox
The quick brown fox
The quick brown fox
The quick brown fox
The quick brown fox

xx-large (1.73)
x-large (1.44)
large (1.20)
medium (1.00)
small (0.83)
x-small (0.69)
xx-small (0.58)

The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog

black (900)
bold (700)
semibold (600)
normal (400)
ultralight (100)

The quick brown fox jumps over the lazy dog
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The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog

monospace
serif
sans
cursive

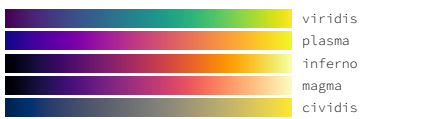
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog
The quick brown fox jumps over the lazy dog

italic
normal

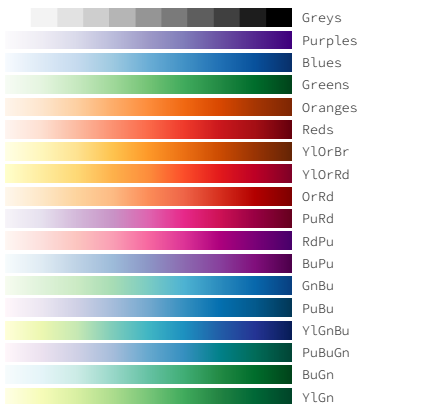
THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG
The quick brown fox jumps over the lazy dog

small-caps
normal

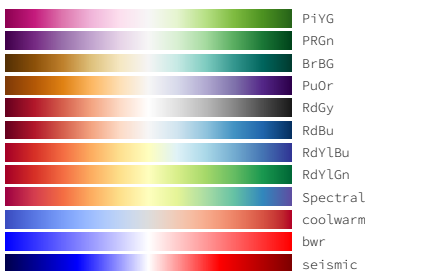
Uniform colormaps



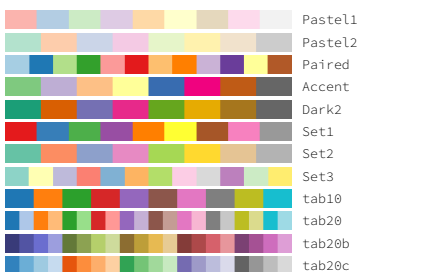
Sequential colormaps



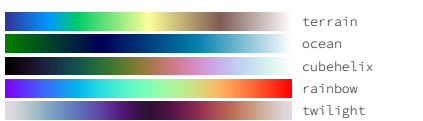
Diverging colormaps



Qualitative colormaps



Miscellaneous colormaps



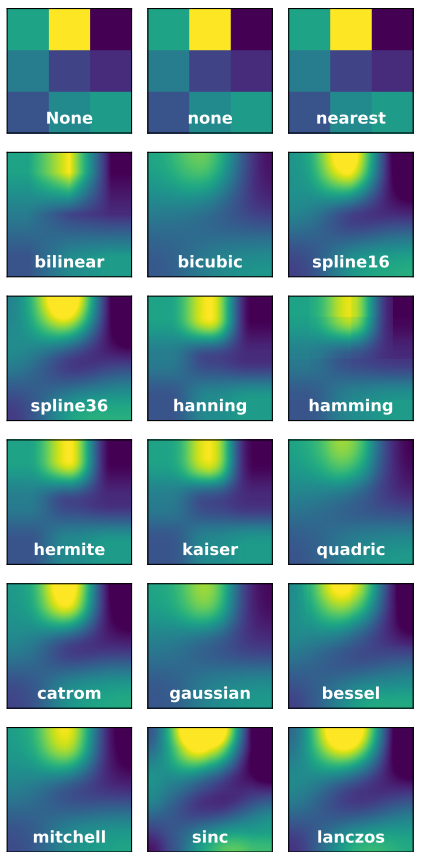
Color names

API

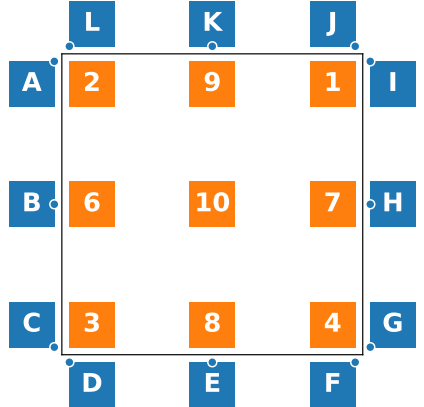


Image interpolation

API



Legend placement

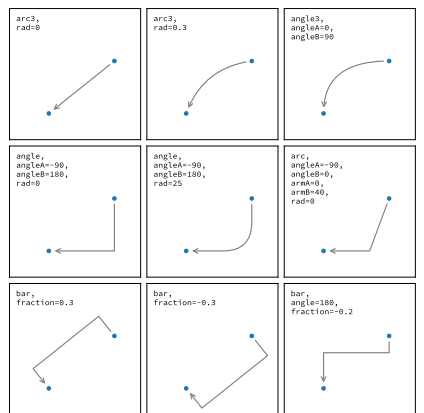


ax.legend(loc="string", bbox_to_anchor=(x,y))

2: upper left 9: upper center 1: upper right
6: center left 10: center 7: center right
3: lower left 8: lower center 4: lower right
A: upper right / (-0.1, 0.9) B: center right / (-0.1, 0.5)
C: lower right / (-0.1, 0.1) D: upper left / (0.1, -0.1)
E: upper center / (0.5, -0.1) F: upper right / (0.9, -0.1)
G: lower left / (1.1, 0.1) H: center left / (1.1, 0.5)
I: upper left / (1.1, 0.9) J: lower right / (0.9, 1.1)
K: lower center / (0.5, 1.1) L: lower left / (0.1, 1.1)

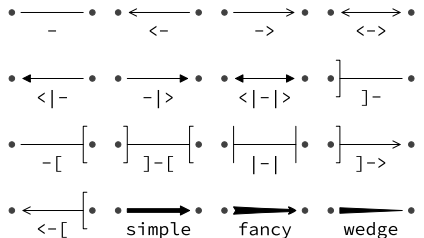
Annotation connection styles

API



Annotation arrow styles

API



How do I ...

... resize a figure?
→ `fig.set_size_inches(w, h)`
... save a figure?
→ `fig.savefig("figure.pdf")`
... save a transparent figure?
→ `fig.savefig("figure.pdf", transparent=True)`
... clear a figure/an axes?
→ `fig.clear()` → `ax.clear()`
... close all figures?
→ `plt.close("all")`
... remove ticks?
→ `ax.set_[xy]ticks([])`
... remove tick labels?
→ `ax.set_[xy]ticklabels([])`
... rotate tick labels?
→ `ax.set_[xy]ticks(rotation=90)`
... hide top spine?
→ `ax.spines['top'].set_visible(False)`
... hide legend border?
→ `ax.legend(frameon=False)`
... show error as shaded region?
→ `ax.fill_between(X, Y+error, Y-error)`
... draw a rectangle?
→ `ax.add_patch(plt.Rectangle((0, 0), 1, 1))`
... draw a vertical line?
→ `ax.axvline(x=0.5)`
... draw outside frame?
→ `ax.plot(..., clip_on=False)`
... use transparency?
→ `ax.plot(..., alpha=0.25)`
... convert an RGB image into a gray image?
→ `gray = 0.2989*R + 0.5870*G + 0.1140*B`
... set figure background color?
→ `fig.patch.set_facecolor("grey")`
... get a reversed colormap?
→ `plt.get_cmap("viridis_r")`
... get a discrete colormap?
→ `plt.get_cmap("viridis", 10)`
... show a figure for one second?
→ `fig.show(block=False, time.sleep(1))`

Performance tips

`scatter(X, Y, marker="o", ls="")` slow
`plot(X, Y, marker="o", ls="")` fast
for i in range(n): `plot(X[i])` slow
`plot(sum([x+[None] for x in X], []))` fast
`cla(), imshow(...), canvas.draw()` slow
`im.set_data(...), canvas.draw()` fast

Beyond Matplotlib

Seaborn: Statistical Data Visualization
Cartopy: Geospatial Data Processing
yt: Volumetric data Visualization
mpld3: Bringing Matplotlib to the browser
Datashader: Large data processing pipeline
plotnine: A Grammar of Graphics for Python

Matplotlib Cheatsheets
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