Matplotlib for Storytellers

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Find more material on this book's GitHub page and on YouTube.
github.com/alexanderthclark/Matplotlib-for-Storytellers
youtube.com/@alexanderthclark

Contents

Code

All code and data files are (not yet) available on the book's GitHub repository. Note I exclude imports from the Python files in the main text. The imports below should cover the entire text. All of these should be included if you installed Anaconda, except for the ternary library, which I comment out below. When saving figures, I also sometimes run `fig.tight_layout()`, which is not always included in the Python files. See `Figure-Dev.ipynb` which contains the complete code for every figure.

```
import numpy as np
import pandas as pd
import math
from itertools import combinations
from itertools import product
from sklearn.datasets import load_iris

# matplotlib specific
import matplotlib as mpl
import matplotlib.pyplot as plt

# For Special Topics
# import ternary # requires install
# from ternary.helpers import simplex_iterator
from sklearn.manifold import MDS
from sklearn.decomposition import PCA
from scipy import stats

# Made redundant in the text
from matplotlib import colors
from matplotlib.patches import ConnectionPatch
from matplotlib.patches import Rectangle
import matplotlib.gridspec as gridspec
from matplotlib.ticker import MultipleLocator
from matplotlib.colors import colorConverter
from mpl_toolkits.mplot3d import Axes3D
```

```
27 from mpl_toolkits.mplot3d.art3d import Poly3DCollection
28 import matplotlib.dates as mdates
29 from matplotlib import font_manager
```

imports.py

Preface

Technical Notes and Prerequisites

I use Python 3.9 and matplotlib 3.5.1. I assume familiarity with basic Python programming, NumPy, pandas, and even matplotlib. In Part I, the premise is that you can make a plot, but now you want to polish it. Other parts assume less background knowledge. For those needing to review some Python before approaching this text, I recommend *A Whirlwind Tour of Python* and *Python Data Science Handbook*, both by Jake VanderPlas.

Why Matplotlib?

Though a bit aged, matplotlib is the standard in Python. matplotlib is integrated with pandas and Seaborn is based off matplotlib. You might prefer Plotnine if you already know R's ggplot2. You might prefer to leave Python and use D3 if you know javascript. You might prefer Microsoft Excel if you want consultants in your audience to feel at home.

I recommend matplotlib to anyone who is already committed to working in Python (and with the Python community) and values reproducibility and customizability. By the time we get to Part **??**, we'll be drawing more than plotting. This allows for more creativity than Excel allows and we'll maintain a reproducible Python-only workflow.

Good Visualization is Like Good Writing

This book isn't a guide to visualization design, but we must consider, at least briefly, what makes for good visualization and then

why you might find matplotlib useful in that pursuit.

Data visualization is a form of communication not much different than writing. Cole Nussbaumer Knaflic's *Storytelling with Data* parallels writing style guides like Sir Ernest Gowers' *The Complete Plain Words*. They both emphasize clarity and stripping out what is not essential. Matplotlib doesn't offer any unique advantage in pursuing clarity. Instead, the advantage is a tactical one. Matplotlib will expand your options. Sometimes straightforward prose is appropriate and sometimes only poetry will be stirring enough to capture your audience's attention. There exist prosaic visualizations and poetic visualizations with all the same tradeoffs.

Prose is precise and direct. Poetry has a certain beauty that invites interest and mediates higher truths. The familiar bar chart is prose, plainly reporting the numbers that need to be reported. Your boss will appreciate prose in a routine meeting. But imagine the king must wrestle with a difficult truth. Prose won't do. Only a jester or a Shakespearean fool can deliver the message and only by rhyme and riddle. So it may be with your C-level audience. The small truths of your bar charts don't matter to a busy CEO. Easier said than done, but capture your CEO's attention with a poetic visualization that might sacrifice some precision for its larger message.

A hurdle to crafting good visualizations is being limited to a short menu of cookie cutter graphics, whatever is available in Excel, a dashboard tool, or from a limited knowledge of matplotlib. Ahead of us is the chance to break free from those cookie cutter, ready-made visuals. In writing, George Orwell made good note of the "invasion of one's mind by ready-made phrases," in his worthwhile essay *Politics and the English Language*:

> [Ready-made phrases] will construct your sentences for you—even think your thoughts for you, to a certain extent—and at need they will perform the important service of partially concealing your meaning even from yourself.

The important point here is that the unimaginative application of ready-made visualizations, just like phrases, can conceal your meaning from yourself, not to mention your audience, and create a monotonous presentation of bar chart after bar chart.

The parallels between writing and making visuals go one level further. If you want to *become* a good writer, you will learn grammar, read good writers who came before you, write a lot, and skirt

the rules a bit as you find your voice. In other words, you will do many things. Data visualization is no different. In what follows, you will begin to master just one thing, the technical grammar of matplotlib.

Resources and Inspiration

Before you dive in, you ought to get excited about data visualization. While there is a glaring lack of major museum space devoted to data visualization (I just recall a disappointing exhibit at the Cooper Hewitt), you will find many wonderful displays if you only keep your eyes peeled.

If you like to listen to people talk about data visualization, I recommend the Data Stories podcast.

If you'd like to start by reading one of the pioneers, check out Edward Tufte, who continues to write new material. For more explicit or domain-specific guidance than Tufte might provide, see Storytelling with Data by Cole Nussbaumer Knaflic or Better Data Visualization by Jonathan Schwabish. Many of Schwabish's main themes are also communicated more briefly in Schwabish 2014. I have limited patience for how-to guides when they edge toward being overly prescriptive (I've never read any books on how to write well either), but I've profited from these titles. They are useful for their treatment of fundamentals like preattentive processing and surfacing more variety in visualizations, helping to inspire a richer repertoire. Knaflic's book is oriented toward business professionals and Schwabish adds his own public policy background. As a result, Knaflic concentrates on what I call prosaic visuals and Schwabish pushes further into the realm of poetry. Schwabish discusses the tradeoffs between standard and nonstandard graphs, noting that novelty can encourage more active processing, providing further justification for using a less accurate graph in select, exploratory cases.

Media outlets like the New York Times and Wall Street Journal make usually good use of data visualization. Take appropriate inspiration these sources and from the r/DataIsBeautiful and r/DataIsUgly subreddits.

There is also a good Data Visualization section in *Coding for Economists* by Arthur Turrell. For a more advanced treatment of matplotlib, check out Scientific Visualization: Python + Matplotlib.

Text Organization

Continuing the parallel to writing, I have built this text around two main parts: Prose and Poetry, though the distinction between prose and poetry is surely less exact than the division I've created. Prose, or Part I, focuses on the fundamentals of customizing plots through the object-oriented interface. This section attempts to be reasonably thorough in breadth while providing only a minimal effective dose in depth. Then, after a mathematical interlude in Part **??**, we reach poetry in Part **??**. There can be no comprehensiveness to this section. I provide a guide to drawing in matplotlib, mostly with various artist objects. The mathematical interlude is there for those who would like to review some trigonometry I use. Then, I introduce two special (for fun) topics in Part **??**, multi-dimensional scaling and ternary plots.

Part I

Prose

Still Life with Apples and Grapes by Claude Monet (Public Domain)

Chapter 1

The Object-oriented Interface

Matplotlib offers two interfaces: a MATLAB-style interface and the more cumbersome object-oriented interface. If you count yourself among the matplotlib-averse, you likely never had the stomach for object-oriented headaches. Still, we are using the object oriented interface because we can do more with this.

The MATLAB-style interface looks like the following.

```
import matplotlib.pyplot as plt
x = 1,0
y = 0,1

plt.plot(x,y)
plt.title("My Plot")
```

matlab-plot.py

The object-oriented interface looks like this.

```
fig, ax = plt.figure(), plt.axes()
ax.plot(x,y)
ax.set_title("My Plot")
```

oop-plot.py

There is no such thing as a free lunch, so you will observe this interface requires more code to do the same exact thing. Its virtues will be more apparent later. Object-oriented programming (OOP) also requires some new vocabulary. OOP might be contrasted with procedural programming as another common method of programming. In procedural programming, the MATLAB-style interface

being an example, the data and code are separate and the programmer creates procedures that operate on the program's data. OOP instead focuses on the creation of *objects* which encapsulate both data and procedures.

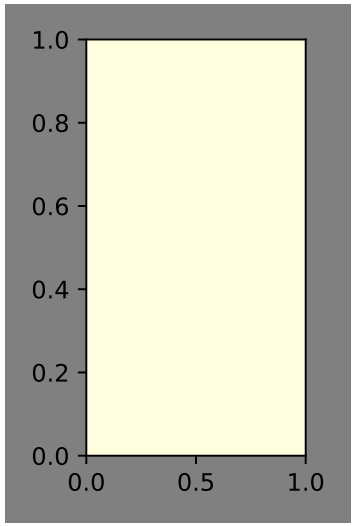
An object's data are called its *attributes* and the procedures or functions are called *methods*. In the previous code, we have figure and axes objects, making use of axes methods `plot()` and `set_title()`, both of which add data to the axes object in some sense, as we could extract the lines and title from `ax` with more code. Objects themselves are instances of a *class*. So `ax` is an object and an instance of the Axes class. Classes can also branch into subclasses, meaning a particular kind of object might also belong to a more general class. A deeper knowledge is beyond our scope, but this establishes enough vocabulary for us to continue building an applied knowledge of matplotlib. Because `ax` contains its data, you can think of `set_title()` as changing `ax` and this helps make sense of the `get_title()` method, which simply returns the title belonging to `ax`. Having some understanding that these objects contain both procedures and data will be helpful in starting to make sense of intimidating programs or inscrutable documentation you might come across.

1.1 Figure, Axes

A plot requires a figure object and an axes object, typically defined as `fig` and `ax`. The figure object is the top level container. In many cases like in the above, you'll define it at the beginning of your code and never need to reference it again, as plotting is usually done with axes methods. A commonly used figure parameter is `figsize`, to which you can pass a sequence to alter the size of the figure. Both the figure and axes objects have a `facecolor` parameter which might help to illustrate the difference between the axes and figure.

```
fig = plt.figure(figsize = (2,3),
                 facecolor = 'gray')
ax = plt.axes(facecolor = 'lightyellow')
```

figparams.py



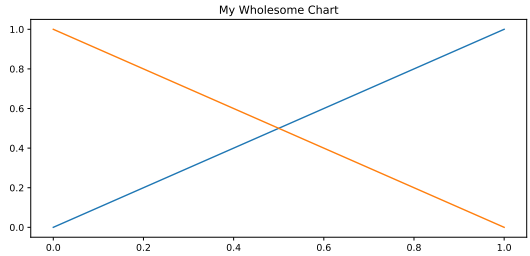
The axes object, named `ax` by convention, gets more use in most programs. In place of `plt.plot()`, you'll use `ax.plot()`. Similary, `plt.hist()` is replaced with `ax.hist()` to create a histogram. If you have experience with the MATLAB interface, you might get reasonably far with the object-oriented style just replacing the `plt` prefix on your pyplot functions with `ax` to see if you have an equivalent axes method.

This wishful coding won't take you everywhere though. For example, `plt.xlim()` is replaced by `ax.set_xlim()` to set the x-axis view limits. To modfiy the title, `plt.title()` is replaced with `ax.set_title()` and there is `ax.get_title()` simply to get the title. The axes object also happens to have a `title` attribute, which is only used to access the title, similar to the `get_title()` method. Many matplotlib methods can be classified as *getters* or *setters* like for these title methods. The plot method and its logic is different. Later calls of `ax.plot()` don't overwrite earlier calls and there is not the same getter and setter form. There's a `plot()` method but no single `plot` attribute being mutated. Whatever has been plotted can be retrieved, or gotten (getter'd?), but it's more complicated and rarely necessary. Use the code below to see what happens with two calls of `plot()` and two calls of `set_title()`. The second print statement demonstrates that the second call of `set_title()` overwrites the title attribute, but a second plot does not nullify the first.

```
x = np.linspace(0,1,2)
```

```
fig, ax = plt.figure(figsize = (8,4)), plt.axes()
ax.plot(x, x)
ax.plot(x, 1 - x)
ax.set_title("My Chart")
print(ax.title)
print(ax.get_title())  # Similar to above line
ax.set_title("My Wholesome Chart")
print(ax.get_title())  # long
```

gettersetter.py



Axes methods `set_xlim()` and `get_xlim()` behave just like `set_title()` and `get_title()`, but note there is no attribute simply accessible with `ax.xlim`, so the existence of getters and setters is the more fundamental pattern.[1]

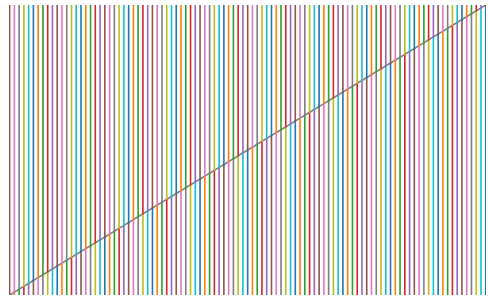
1.2 Mixing the Interfaces

You can also mix the interfaces. Use `plt.gca()` to *g*et the *c*urrent *a*xis. Use `plt.gcf()` to *g*et the *c*urrent *f*igure.

```
x = np.linspace(0,1,2)
plt.plot(x,x)
plt.title("My Chart")

ax = plt.gca()
print(ax.title)

ax.plot(x, 1 - x)
ax.set_title('My Wholesome Chart')
print(ax.title)
```

chart.py

[1] Getters and setters are thought of as old-fashioned. It's more Pythonic to access attributes directly, but matplotlib doesn't yet support this.



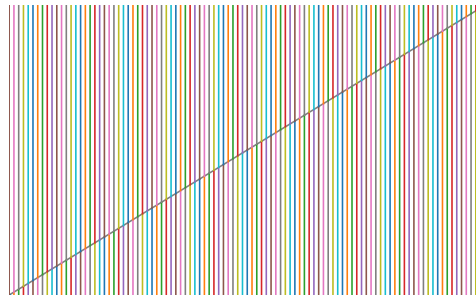
In the above, we started with MATLAB and then converted to object-oriented. We can also go in the opposite direction, though it's not always ideal, especially when working with subplots. Below, we start with our figure and axes objects, and then revert back to the MATLAB style with the `axvline()` functions (producing vertical lines across the axes), toggling off the axis lines and labels, and then saving the figure. This graph would appear unchanged if you replaced `plt.axvline()` with `ax.axvline()`, `plt.axis()` with `ax.axis()`, and `fig.savefig()` would do the same as `plt.savefig()`.

```
# OOP Start
fig, ax = plt.figure(figsize = (8,5)), plt.axes()

x = np.linspace(0,100,2)
ax.plot(x, x, color = 'gray')

ax.set_xlim([0,100])
ax.set_ylim([0,100])

# Back to pyplot functions
for i in range(101):
    plt.axvline(i,0, i / 100, color = 'C' + str(i))
    plt.axvline(i, i/100, 1, color = 'C' + str(i+5))

plt.axis('off')
plt.savefig('colorful.pdf')
```

colorful.py

Matplotlib is also integrated into pandas, with a `plot()` method for both Series and DataFrame objects, among other functionalities. There is excellent documentation available.[2] These plots can be mixed with the object-oriented interface. You can use a plot

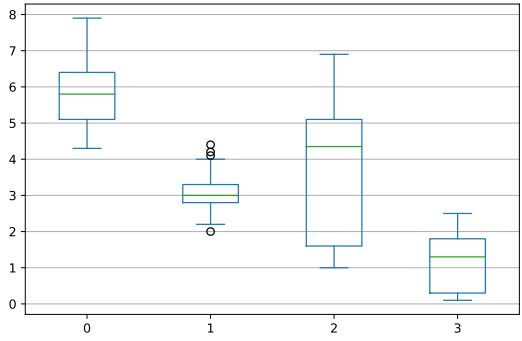
[2] https://pandas.pydata.org/pandas-docs/stable/user_guide/visualization.html



method and specify the appropriate axes object as an argument. Below we import the iris dataset and make a boxplot with a mix of axes methods and then pyplot functions.

```
from sklearn.datasets import load_iris
data = load_iris()['data']
df = pd.DataFrame(data)

fig, ax = plt.figure(), plt.axes()

df.plot.box(ax = ax)
ax.yaxis.grid(True)
ax.xaxis.grid(False)

plt.tight_layout()
plt.savefig('irisbox.pdf')
```

irisbox.py



The above capability is handy, especially with subplots, where every subplot will have its own axes object as we will see later.

Chapter 2

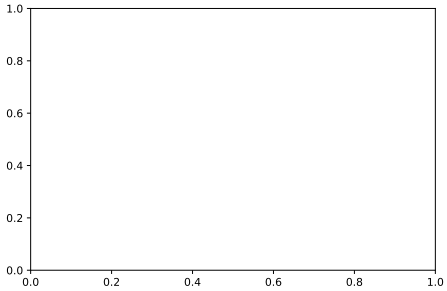
Axes Appearance, Ticks, and Grids

2.1 Axis Aspect and Limits

The most basic plot is the empty plot.

```
1 fig, ax = plt.figure(), plt.axes()
```

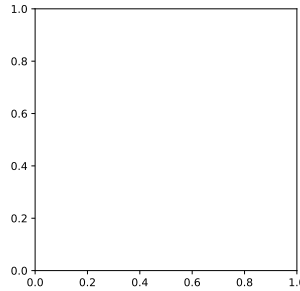
empty.py



You'll notice this defaults to plotting the square region between data points (0,0) and (1,1). However, the plot is not square by default. That is to say the *aspect* is not one, where the aspect is the ratio of height to width. This can be changed with the axes method `set_aspect()`. For equal scaling, use `ax.set_aspect('equal')` or `ax.set_aspect(1)`.

```
fig, ax = plt.figure(), plt.axes()
ax.set_aspect('equal')
```

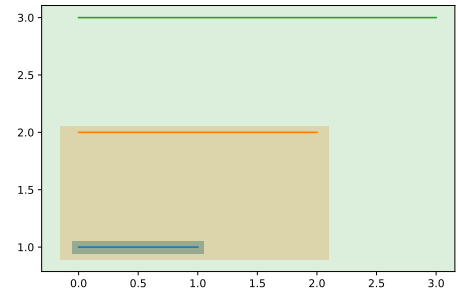
empty-square.py



As we already covered in Chapter 1, the x and y limits can be adjusted with axes methods `set_xlim()` and `set_ylim()`, taking a sequence for the minimum and maximum values. If you don't explicitly set the limits, matplotlib will set the limits automatically based on the data. You can retrieve those limits with the getter methods, `get_xlim()` and `get_ylim()`. The program below makes use of both methods. We plot a few lines, and after each plot call, matplotlib is quietly updating the axes limits. Using the `fill_between()` method, which creates a color fill in the defined region, the expanding limits are shown. The colors are chosen automatically by matplotlib because I haven't explicitly specified a color value.

```
fig, ax = plt.figure(), plt.axes()

for i in range(1,4):
    ax.plot([0,i], [i,i])
    bottom_y, top_y = ax.get_ylim()
    left_x, right_x = ax.get_xlim()
    ax.fill_between(x = [left_x,right_x],
                    y1 = bottom_y,
                    y2 = top_y,
                    alpha = 0.5/i)

# Prevent limits from automatically stretching further
# The last fill_between would stretch limits again
ax.set_ylim(bottom_y, top_y)
ax.set_xlim(left_x, right_x)
```

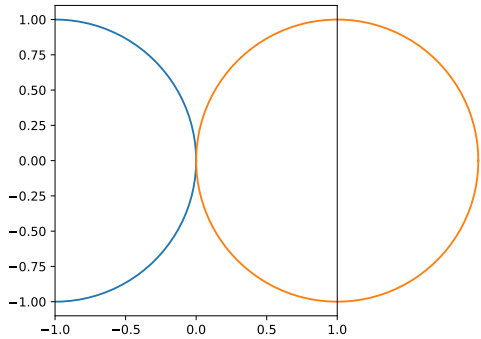
expanding-lims.py



If your axes limits are too restrictive, plot elements will be cut off. If you want your plot element to break past the end of the axes, spilling into the outer figure space, you can change this by setting `clip_on = False` in the appropriate method. Below, we create two circles with `ax.plot()` and set restrictive x-axis limits. The first circle, in blue, would extend further to the left if the limits were more generous. By default, it is clipped so we only see half of a circle. In the next call to `ax.plot()`, we create an orange circle and toggle `clip_on = False`. As a result, the circle extends to the right of the axes limits into the remaining figure space.

```
fig, ax = plt.figure(), plt.axes()
ax.set_aspect(1)

# Create a unit circle
u = np.linspace(0,2*np.pi,100)
x = np.cos(u)
y = np.sin(u)

# Default, clip_on = True
ax.plot(x-1, y)

# Unclipped, extends beyond the axes
ax.plot(x+1, y, clip_on = False)

ax.set_xlim(-1,1)
```

circle-clip.py



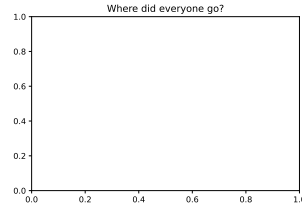
2.2 Axis Lines and Spines

You might be used to plots that aren't surrounded by a box. Those enclosing lines, included by default, are called the *spines*. The default might also be jarring if you're used to the typical x- and y-axis lines at $y = 0$ and $x = 0$, like in most math textbook plots. In this section we'll cover how to modify these.

First, you might just eliminate everything with `ax.axis('off')`. We saw `plt.axis('off)` used similarly in Chapter 1 with a program that alternated between pyplot functions and the object-oriented approach. Below is a simple plot, empty but for a title, that becomes even emptier by eliminating the axis lines and labels. For reference, on the right is the same plot if `ax.axis('off')` were excluded from the program.

```
1 fig, ax = plt.figure(), plt.axes()
2 ax.set_title("Where did everyone go?")
3 ax.axis('off')
```

no-axis.py

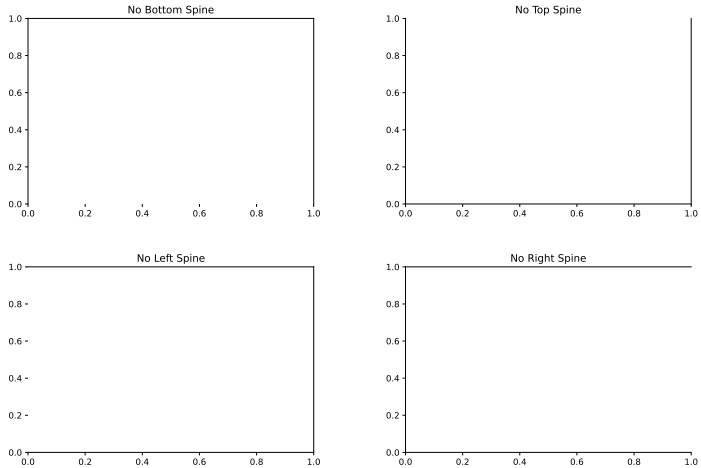


Next, we can access and modify specific spines through `ax.spines`, which returns an `OrderedDict`. Access a specific spine using the

appropriate key: `"left"`, `"right"`, `"top"`, or `"bottom"`. A spine can be toggled on or off by passing the appropriate boolean value to `set_visible()`.

```
for spine in 'bottom', 'top', 'left', 'right':
    fig, ax = plt.figure(), plt.axes()
    ax.set_title("No " + spine.title() + " Spine")
    ax.spines[spine].set_visible(False)
    plt.show()
```

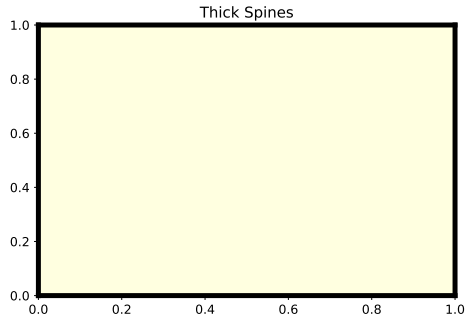
spine-vis.py



Other spine modifications might be their width and color. Again, we access a particular spine and then make use of setter methods, `set_color` and `set_linewidth` in particular.

```
fig, ax = plt.figure(), plt.axes(facecolor = '
    lightyellow')
ax.set_title("Thick Spines")
for spine in 'bottom', 'top', 'left', 'right':
    ax.spines[spine].set_color('black')
    ax.spines[spine].set_linewidth(4)
ax.set_xlim(0,1)
ax.set_ylim(0,1)
```

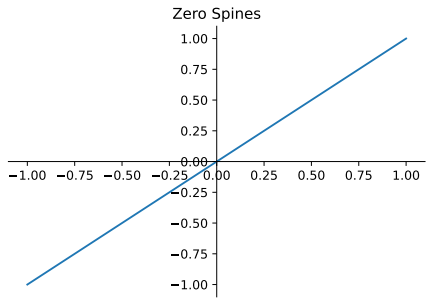
thick-spines.py



It's easy to get this far imagining that spines are simply the pieces of the box enclosing your plot. But they don't have to enclose the plot if we alter them with the `set_position` method. Below, we set the bottom spine to be along the usual x-axis and the left spine to be along the usual y-axis by passing `'zero'` to `set_position`. The right and top spines are removed.

```
fig, ax = plt.figure(), plt.axes()
ax.set_title("Zero Spines")
ax.plot([-1,1], [-1,1])
for spine in 'top', 'right':
    ax.spines[spine].set_visible(False)
for spine in 'bottom', 'left':
    ax.spines[spine].set_position('zero')
```

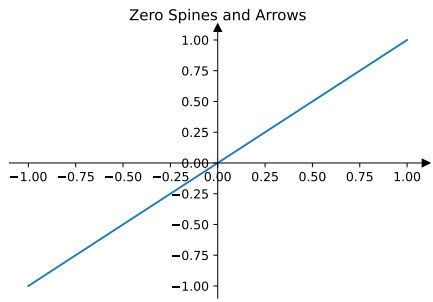
zero-spines.py



We can go a step further and add arrows at the ends of our axis lines with some clever plotting.

```
fig, ax = plt.figure(), plt.axes()
ax.set_title("Zero Spines and Arrows")
ax.plot([-1,1], [-1,1])
for spine in 'top',  'right':
    ax.spines[spine].set_visible(False)
for spine in 'bottom',  'left':
    ax.spines[spine].set_position('zero')

# get current limits
xlims = ax.get_xlim()
ylims = ax.get_ylim()

# Add arrows
ax.plot(xlims[1], 0, ">k", clip_on = False)
ax.plot(0, ylims[1], "^k", clip_on = False)

# revert limits to before the arrows
ax.set_xlim(xlims)
ax.set_ylim(ylims)
```

arrow-axes.py



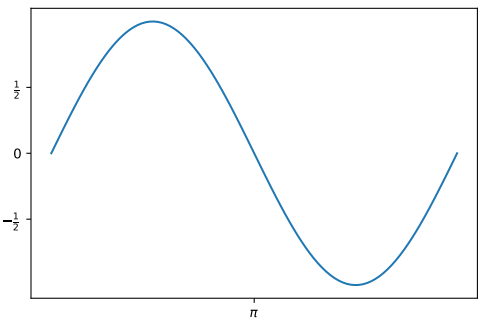
The tick labels do clutter the graph above. This can be solved after we cover Section 2.3. Knaflic 2015 recommends removing the top and right spines as part of the imperative to declutter and remove unnecessary chart border. I think it is arguable. I'm used to default spines enclosing the data. Removing them can seem untidy, like the plot guts might spill out onto the page, or as if the plot is now vulnerable to intruders without any fencing. Arrows on axis lines subtly prod the reader to imagine what happens outside of the plotted region. I don't like that if, for example, I don't want to create the impression that a linear trend in a time series graph will continue into the future.

2.3 Ticks

The important axes methods for ticks are `set_xticks`, `set_xticklabels`, and the natural y-axis counterparts. One may also use the general `set_ticks` and `set_ticklabels` with `ax.xaxis` or `ax.yaxis`—as axis (not axes) methods. These are demonstrated below, taking an array of tick locations and then the corresponding labels. I use LaTeXstrings to label the ticks. Here, that allows for a prettier y-axis, using fractions instead of decimals for tick labels. And on the x-axis, we can give a proper label of π at $x = \pi$.

```
x = np.linspace(0, np.pi * 2, 100)

fig, ax = plt.figure(), plt.axes()
ax.plot(x, np.sin(x))

# Y axis
ax.set_yticks( [-0.5, 0, 0.5] )
ax.set_yticklabels( [r"$-\frac{1}{2}$", 0,  r"$\frac
    {1}{2}$"] )

# X axis
ax.xaxis.set_ticks([np.pi])
ax.xaxis.set_ticklabels([r"$\pi$"])
```

ticks1.py



To remove the ticks entirely, simply pass an empty array to `set_ticks()`. To customize the appearance of your axis ticks and the labels, use the `set_tick_params` axis method. Parameters include `direction`, `width`, `length`, `color`, `pad`, `rotation`, `labelsize`, `labelcolor`

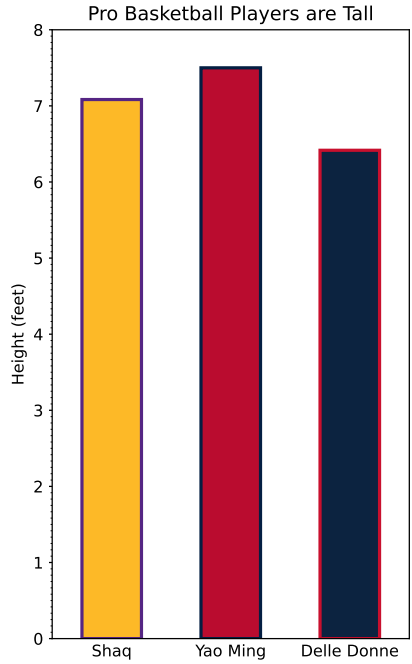
Imagine a measuring ruler, with ticks for every inch and smaller ticks at smaller intervals. So far our ticks have lacked that level of

depth, but in fact we can work with two tick levels in matplotlib, major and minor ticks. Minor ticks are not shown by default.

To start exploring these further customizations, you'll need to import additional formatters and or locators. For the below, you must import `MultipleLocator`, running `from matplotlib.ticker import MultipleLocator`.

```
heights = pd.Series( {'Shaq': 7 + (1/12),
                      'Yao Ming': 7.5,
                      'Delle Donne': 6 + (5/12)})

fig, ax = plt.figure(figsize = (4,7)), plt.axes()

heights.plot.bar(ax = ax,
        color = ['#FDB927', '#BA0C2F', '#0C2340'],
        edgecolor = ['#552583', '#041E42', '#C8102E'],
        linewidth = 2)
# https://teamcolorcodes.com/
# LA Lakers and Houston Rockets and DC Mystics

# Get rid of ticks on x-axis, rotate text
ax.xaxis.set_tick_params(length = 0, which = 'major',
                         rotation = 0)

ylim0, ylim1 = 0,8
ax.set_ylim([ylim0, ylim1])

ax.set_yticks(range(ylim0, ylim1+1))
#ax.yaxis.set_major_locator(MultipleLocator(1))

ax.yaxis.set_minor_locator(MultipleLocator(1/12))
ax.yaxis.set_tick_params(length = 1, which = 'minor')
ax.yaxis.set_tick_params(length = 2, which = 'major')

ax.set_ylabel("Height (feet)")
ax.set_title("Pro Basketball Players are Tall")
```

tall-ballers.py

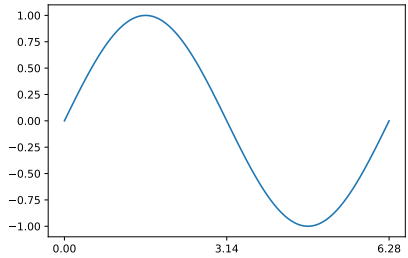


Major ticks can easily be set with `set_ticks` and its variants. Still, `MultipleLocator` and other locators are useful for setting major ticks without fooling with the details of the axes limits.

With a function like $\sin x$, ticks might most naturally be placed at multiples of π. This can be accomplished by the below.

```
x = np.linspace(0, np.pi * 2, 100)

fig, ax = plt.figure(), plt.axes()
ax.plot(x, np.sin(x))

ax.xaxis.set_major_locator(MultipleLocator(np.pi))
```

mult-locator.py

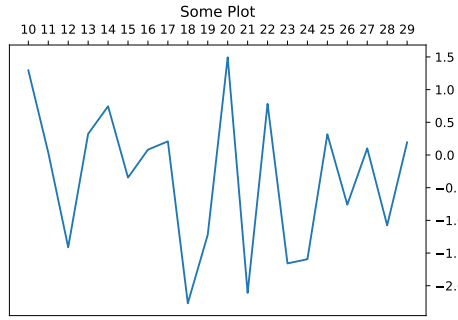


It's true you could avoid the complication of locator classes by just using `ax.set_xticks([0, np.pi, 2*np.pi])`. For a plot this simple, do that. Suppose, you put ticks up to 3π though. Then you've extended the x-axis limit of the plot past your data. So you need to know your data to make the right tick adjustments by hand. If you'll be using the same code with different datasets, it'll be easier to use the details-free `MultipleLocator` and you can still rely on limit defaults or adjust them independently.

Next, you might want to change the positioning of the ticks. By default x-axis ticks are on the bottom and y-axis ticks are on the left. You can modify these positions with axis methods. In time series data, for example, you might prefer to have the y-axis ticks on the right. Time marches on to the right and placing your ticks on the right can help emphasize that movement. This can be done with `set_ticks_position('right')` or the more concise `tick_right()`. The latter also accepts arguments of `'left'`, `'bottom'`, and `'top'`. Each has an abbreviated method like `tick_left()`.

```
fig, ax = plt.figure(), plt.axes()
x = np.arange(10, 30, 1)
y = np.random.normal(size = len(x))
ax.plot(x,y)

# set what ticks are shown
ax.xaxis.set_ticks(x)

# move the ticks
ax.yaxis.tick_right()
ax.xaxis.set_ticks_position('top')

ax.set_title("Some Plot")
```

tick-right.py

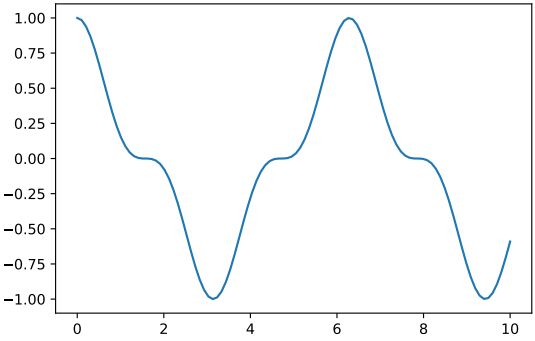


2.4 Grids

Including gridlines in a plot is generally discouraged (Knaflic 2015, Schwabish 2021). It's clutter that won't spark joy. Perhaps we could stop here, with the instruction to run `ax.grid(False)` as in the code below (or rely on a style, like the default, that does this automatically).

```
fig, ax = plt.figure(), plt.axes()
x = np.linspace(0,10,100)
ax.plot(x, np.cos(x)**3)
ax.grid(False)
```

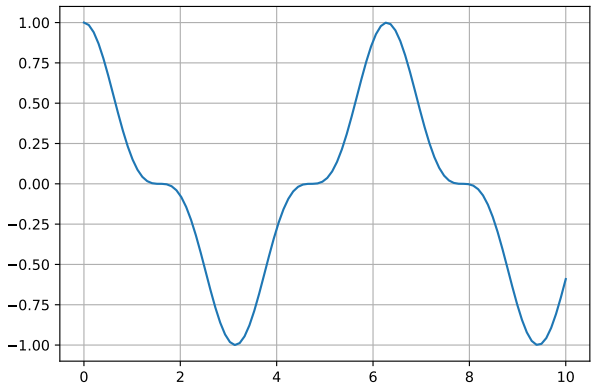
grid-false.py



This does seem preferable to the following, but it's hardly an abomination.

```
fig, ax = plt.figure(), plt.axes()
x = np.linspace(0,10,100)
ax.plot(x, np.cos(x)**3)
ax.grid(True)
```

grid-true.py



As a compromise, you might include gridlines for a single axis. If you want to emphasize that there is a slight trend in the data, then y-axis gridlines can help bring that pattern to the eye. Below we plot plots with and without a line of best fit and gridlines. Axis gridlines can be toggled independently by using `ax.xaxis.grid()` and `ax.yaxis.grid()`.

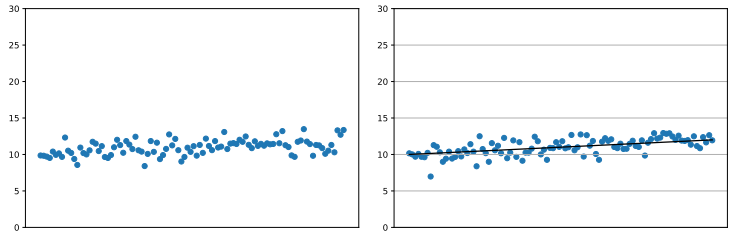
```
fig, ax = plt.figure(), plt.axes()

x = np.linspace(0, 10, 100)
y = 10 + .2*x
points = y + np.random.normal(size = len(x))
ax.scatter(x,points)

ax.set_ylim(0,30)
ax.set_xticks([])
```

y-grid-false.py

```
fig, ax = plt.figure(), plt.axes()

x = np.linspace(0,10, 100)
y = 10 + .2*x
points = y + np.random.normal(size = len(x))
ax.scatter(x,points)

```

```
ax.set_ylim(0,30)
ax.set_xticks([])

# Add grid and line of best fit
ax.yaxis.grid(True)
ax.plot(x, y, color = 'black')
```

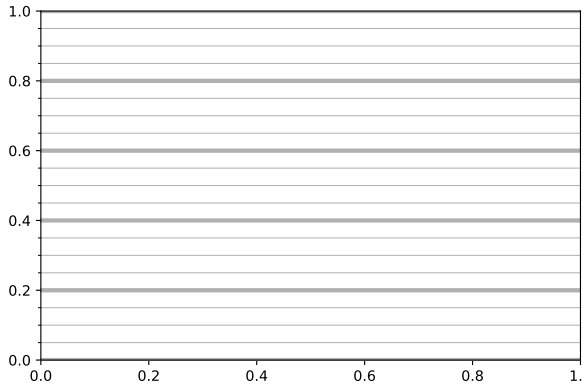
y-grid-true.py



What we learned previously about locating ticks in Section 2.3 can be reapplied here, as seen in the examples further below. The location of gridlines and ticks can be set by the `set_major_locator()` and `set_minor_locator()` methods. `ax.grid()` is used to display the gridlines, but note it features a parameter `which`. The default value of `which` is `'major'`. To include minor gridlines, those minor ticks must be explicitly created (at least in the default style) and then the gridlines must be toggled on with `ax.grid(True, which = 'minor')` or for a single axis with `ax.xaxis.grid(True, which = 'minor')` for example.

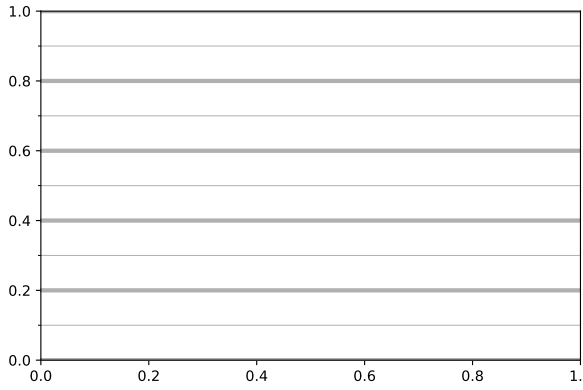
```
fig, ax = plt.figure(), plt.axes()
ax.xaxis.grid(False)
ax.yaxis.grid(True, linewidth = 3)
ax.yaxis.grid(True, which = 'minor', linewidth = 0.5)
ax.yaxis.set_minor_locator(mpl.ticker.AutoMinorLocator()
    )
```

grids-auto.py




```
fig, ax = plt.figure(), plt.axes()
ax.xaxis.grid(False)
ax.yaxis.grid(True, linewidth = 3)
ax.yaxis.grid(True, which = 'minor', linewidth = 0.5)
ax.yaxis.set_minor_locator(mpl.ticker.MultipleLocator
    (.1))
```

grids-multi.py



Chapter 3

Plot Elements and Coordinate Systems

This chapter can be skipped by the reader in a hurry. I include it to establish some vocabulary about the basic plot elements and then discuss the different coordinate systems that can be used within a single plot—not polar vs. Cartesian coordinates but data coordinates vs. figure coordinates, for example. Coordinate systems do come up repeatedly in future chapters.

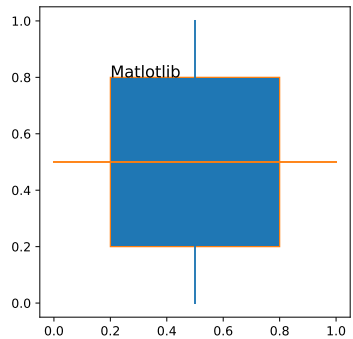
3.1 Primitives and Containers

Once you have a your figure and axis objects, you'll want to add actual plot elements to them, lines for a line chart, bars for a bar chart, annotations, etc. We already did that in Chapter 1, creating line plots. In matplotlib, these elements belong to the Artist class, it being a very general base class. Artists objects are basically the water you've been swimming in this whole time—you just might not have noticed it. Artist objects can be either primitives or containers. Containers include background items like the figure and axes objects. Primitives are the meat of the plot, like the line created by a call to `ax.plot()`. Important primitive Artist objects include Line2D, Patches, and Text.

```
fig, ax = plt.figure(), plt.axes()
ax.set_aspect(1)

# Patches
rect = plt.Rectangle(xy = (0.2, 0.2),
```

```
                        width = 0.6,
                        height = .6,
                        facecolor = 'C0',
                        edgecolor = 'C1')
patch = ax.add_artist(rect)

# Lines
x, y = [0.5, 0.5], [0, 1]
line, = ax.plot(x, y)
lines = ax.plot(y,x)

# Text
text = ax.text(0.2, 0.8, 'Matlotlib', size = 13)
```

artists.py



What might be unusual in the above is that we don't simply run `ax.plot(x, y)`. Instead we actually assign the plot call to a variable, `line, = ax.plot(x,y)`. Usually, this isn't necessary, but this allows us to reference the same object later in the program. The plot method creates a tuple of Line2D objects. In this case, that tuple contains only one item and it is assigned to the variable `line`.

Now that we have the object as `line`, we can get properties or make changes. You can obtain the color with the `get_color()` method or change it with `set_color()`. You can even remove the plot element with `line.remove()`. These are all niche uses. However, we will later make use of `remove()` when iteratively centering text. We'll also use the `get_window_extent()` artist method frequently to help space objects in the plot.

3.1.1 Ordering with `zorder`

Default Ordering

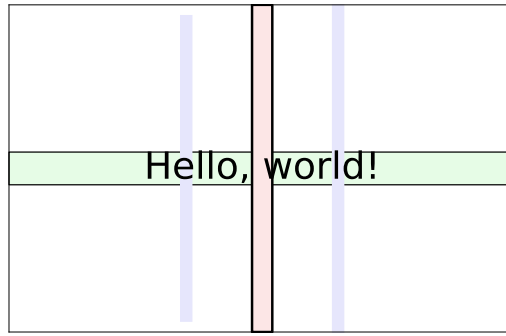
By default, text is plotted over lines and lines are plotted over patches, like the fill created by `fill_between()`. Within each of these three categories, objects created later in the program are plotted over previously created objects. The `zorder` parameter can be used to create a different ordering. Objects with a greater `zorder` value are ordered further to the front.

First, we create and plot without specifying the `zorder` for any object to observe default behavior. We also print the zorder for each object using `get_zorder()`. Text has a `zorder` of 3, lines have a `zorder` of 2, and each patch object will have `zorder = 1`. Note `patch1` and `patch2` have the same `zorder`, but the red `patch2` is added later in the program so it is plotted over the green `patch1`, being as if `patch1` has a lower `zorder`.

```
fig, ax = plt.figure(), plt.axes()
ax.set_xlim(0,1)
ax.set_ylim(0,1)
ax.set_xticks([])
ax.set_yticks([])

# make colors
green = (.9, .99, .9)
blue = (.9, .9, .99)
red = (.99, .9, .9)

# Text with default zorder of 3
text = ax.text(0.5, 0.5, "Hello, world!",
               size = 30,
               ha = 'center',
               va = 'center')

# Lines with default zorder of 2
line1 = ax.axvline(0.65,
                   linewidth = 10,
                   color = blue)
line2 = ax.plot([0.35, 0.35], [.05, .95],
                linewidth = 10,
                color = blue)

# Patches with default zorder of 1
patch1 = ax.fill_between([0,1], 0.45, .55,
                         facecolor = green,
                         edgecolor = 'black')
patch2 = ax.fill_between([.48,.52], 0, 1,
                         facecolor = red,
                         edgecolor = 'black',
```

```
                            linewidth = 2)

# Check zorders
print(text.get_zorder())
print(line1.get_zorder())
print(line2[0].get_zorder())
print(patch1.get_zorder())
print(patch2.get_zorder())
```

default-z.py

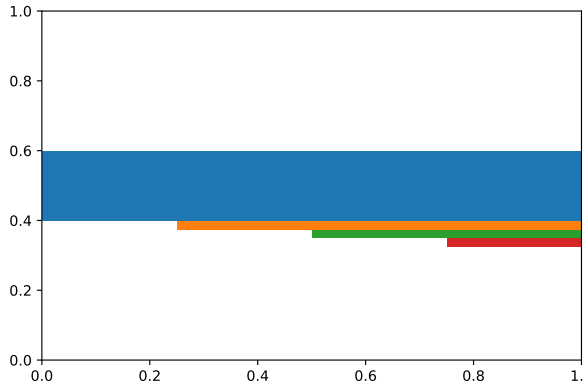


Custom Ordering

Then, we reverse the ordering.

```
fig, ax = plt.figure(), plt.axes()

print(fig.get_zorder())
print(ax.get_zorder())

for i in [0, 0.25, .5, .75]:

    t = ax.fill_between([i, 1], 0.4 - i/10, .6 - i/20,
                        zorder = 1 - i)
    print(t.get_zorder())

ax.set_xlim(0,1)
ax.set_ylim(0,1)
```

reverse-z.py

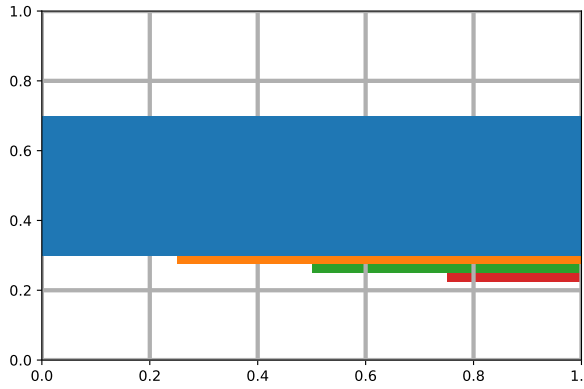


Axes and Tick Ordering

Notice that by default, gridlines are ordered below artists added to a plot regardless of where the call to show the gridlines is placed. This can be changed using `ax.set_axisbelow()`, which also reorders the ticks. The `XAxis` and YAxis can be ordered independently using the `set_order()` axis method.

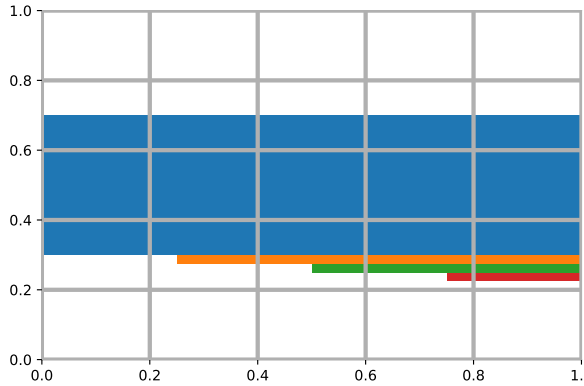
```
fig, ax = plt.figure(), plt.axes()
for i in [0, 0.25, .5, .75]:
    ax.fill_between([i,1], 0.3 - i/10, .7 - i/20,
                    zorder = 2-i)
ax.grid(True, linewidth = 3)
ax.set_xlim(0,1)
ax.set_ylim(0,1)
print(ax.get_zorder())
```

default-axes.py




```
fig, ax = plt.figure(), plt.axes()
for i in [0, 0.25, .5, .75]:
    ax.fill_between([i,1], 0.3 - i/10, .7 - i/20,
                    zorder = 2-i)
ax.grid(True, linewidth = 3)
ax.set_xlim(0,1)
ax.set_ylim(0,1)
ax.set_axisbelow(False)
print(ax.get_zorder())
```

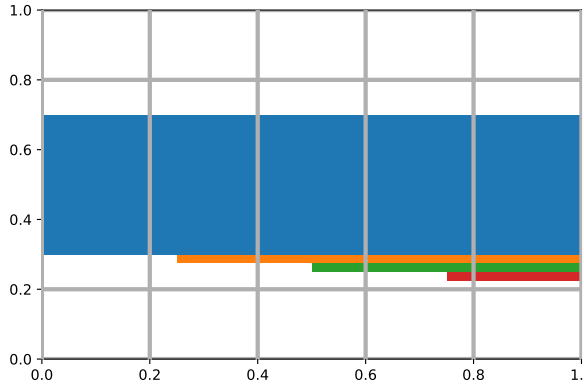
front-axes.py




```
fig, ax = plt.figure(), plt.axes()
for i in [0, 0.25, .5, .75]:
    ax.fill_between([i,1], 0.3 - i/10, .7 - i/20,
                    zorder = 2-i)
```

```
ax.grid(True, linewidth = 3)
ax.set_xlim(0,1)
ax.set_ylim(0,1)
ax.xaxis.set_zorder(3)
```

front-xaxis.py



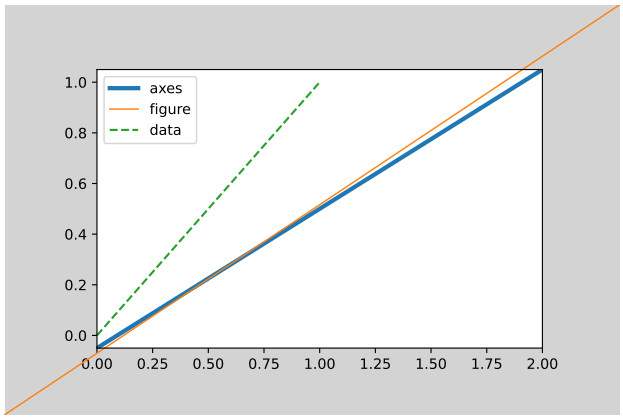
3.2 Coordinate Systems and Transformations

So far we have worked with data coordinates and you might not even realize there could be anything else. When we plotted a line between the points $(0, 0)$ and $(1, 1)$, we meant those as values in the usual xy-plane. But with use of transformations, we might also plot according to axes, figure, and display coordinates. In axes coordinates, $(0, 0)$ is the bottom left of the axes and $(1, 1)$ is the top right. Similarly, in figure coordinates, $(0, 0)$ is the bottom left of the figure and $(1, 1)$ is the top right. We won't cover the fourth type, display coordinates, which is the pixel coordinate system (for certain backends). The matplotlib documentation cautions that you should rarely work with display coordinates. However, display coordinates are a necessary evil when converting from one system to another. Note, it is important not to manipulate the figure or axes dimensions after referencing the display coordinate system or you might encounter unexpected behavior.

The plot below features a group of plot calls using axes coordinates, then a group using figure coordinates, and then a single call using data coordinates.

```
fig, ax = plt.figure(facecolor = 'lightgray'), plt.axes
    ()

ax.plot([0, 1], [0, 1],
        linewidth = 3,
        transform = ax.transAxes,
        label = 'axes')

ax.plot([0, 1], [0, 1],
        color = 'C1',
        linewidth = 1,
        transform = fig.transFigure,
        clip_on = False,
        label = 'figure')

ax.plot([0, 1], [0, 1],
        color = 'C2',
        linestyle = 'dashed',
        clip_on = False,
        label = 'data')

ax.set_xlim(0,2)
ax.legend()
```

coords.py

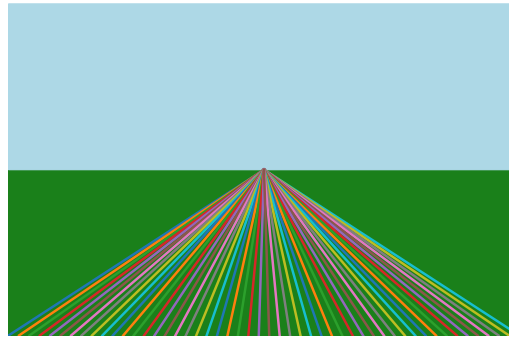


Axes and figure coordinates are often useful when you would like placement to be independent of the data, perhaps to enforce that something remain in the center of the plot by using an axes coordinate of 0.5. Below, we make use of that to set a vanishing point at the vertical halfway point.

```
fig, ax = plt.figure(), plt.axes()
ax.axis('off')
```

```
# lines to horizon
for i in np.linspace(0,1,50):
    ax.plot([i,.5], [0.00, .5],
            transform = ax.transAxes,
            linewidth = 2,
            zorder = 10-(i-0.5)**2)

# fill bottom half
green = (.1, .5, .1)
ax.fill_between(x = (0,1),
                y1 = 0,
                y2 = 0.5,
                transform = ax.transAxes,
                color = green)

# fill top half
ax.fill_between(x = (0,1),
                y1 = 0.5,
                y2 = 1,
                transform = ax.transAxes,
                color = 'lightblue')
```

coord-horizon.py

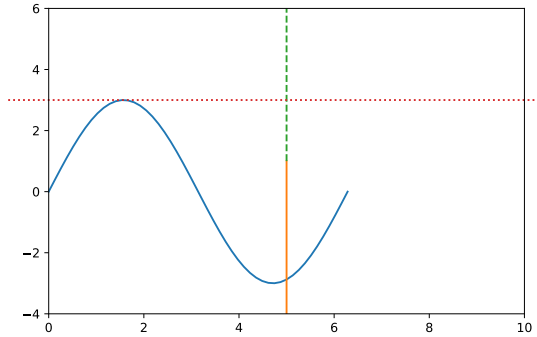


We can convert a point or sequence of points from one coordinate system to another using the appropriate transform object. `ax.transData.transform([x,y])` converts `x,y` from data coordinates to display coordinates. Simply replacing `ax.transData` with `ax.transAxes` or `fig.transFigure` converts from the corresponding coordinate system to display coordinates. The opposite direction is achieved by inverting the transformation—`ax.transData.inverted().transform([x,y])`. To go from data coordinates to figure or axes coordinates, you can make a pit stop in display coordinates. For example, `ax.transData.inverted().transform(ax.transAxes.transform([0.5, 0.5]))` returns the middle of the axes window in data coordinates.

The example below breaks this up into two steps. Again, take note that all plotting is done after setting a tight layout and after setting the axes limits to avoid resizing the figure and endangering the reliability of our coordinate transformations.

```
# Plot setup
fig, ax = plt.figure(), plt.axes()
x = np.linspace(0, 2*np.pi)
sin, = ax.plot(x, 3*np.sin(x))
ax.set_xlim(0, 10)
ax.set_ylim(-4, 6)
fig.tight_layout()

# Vertical line with axes coordinates
middle = [0.5, 0.5]
bottom_half = [0, 0.5]
ax.plot(middle, bottom_half,
        transform = ax.transAxes)

# Continue vertical line with data coordinates
mid_in_display = ax.transAxes.transform([0.5, 0.5])
mid_in_data = ax.transData.inverted().transform(
    mid_in_display)
top_mid_in_display = ax.transAxes.transform([0.5, 1])
top_mid_in_data = ax.transData.inverted()\
                        .transform(top_mid_in_display)
x = mid_in_data[0], top_mid_in_data[0]
y = mid_in_data[1], top_mid_in_data[1]
ax.plot(x, y, linestyle = 'dashed')

# Horizontal lines in figure coordinates
top_wave_display = ax.transData.transform([np.pi/2, 3])
top_wave_figure = fig.transFigure.inverted()\
                         .transform(top_wave_display)

y = top_wave_figure[1],  top_wave_figure[1]
ax.plot([0,1], y,
        transform = fig.transFigure,
        linestyle = 'dotted',
        clip_on = False)
```

coord-trans.py



3.3 Window Extents

Another useful method is `get_window_extent()`, which allows you to find the bounding box for something added to a plot. This can be used to find the coordinates for where an annotate begins or ends, for example.

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