Data Visualization

Python and R for Data Science

Data Science and Management

Package `matplotlib`

`matplotlib`: installation and import

In [1]:
```
! pip install matplotlib pandas numpy
```

```
Requirement already satisfied: matplotlib in /home/user/labds/v
env/lib/python3.12/site-packages (3.9.2)
Requirement already satisfied: pandas in /home/user/labds/venv/
lib/python3.12/site-packages (2.2.2)
Requirement already satisfied: numpy in /home/user/labds/venv/l
ib/python3.12/site-packages (2.1.0)
Requirement already satisfied: contourpy>=1.0.1 in /home/user/l
abds/venv/lib/python3.12/site-packages (from matplotlib) (1.3.
0)
Requirement already satisfied: cycler>=0.10 in /home/user/labd
s/venv/lib/python3.12/site-packages (from matplotlib) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /home/user/
labds/venv/lib/python3.12/site-packages (from matplotlib) (4.5
3.1)
Requirement already satisfied: kiwisolver>=1.3.1 in /home/user/
labds/venv/lib/python3.12/site-packages (from matplotlib) (1.4.
5)
Requirement already satisfied: packaging>=20.0 in /home/user/la
bds/venv/lib/python3.12/site-packages (from matplotlib) (24.1)
Requirement already satisfied: pillow>=8 in /home/user/labds/ve
nv/lib/python3.12/site-packages (from matplotlib) (10.4.0)
Requirement already satisfied: pyparsing>=2.3.1 in /home/user/l
abds/venv/lib/python3.12/site-packages (from matplotlib) (3.1.
4)
Requirement already satisfied: python-dateutil>=2.7 in /home/us
```

```
er/labds/venv/lib/python3.12/site-packages (from matplotlib)
(2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in /home/user/labd
s/venv/lib/python3.12/site-packages (from pandas) (2024.1)
Requirement already satisfied: tzdata>=2022.7 in /home/user/lab
ds/venv/lib/python3.12/site-packages (from pandas) (2024.1)
Requirement already satisfied: six>=1.5 in /home/user/labds/ven
v/lib/python3.12/site-packages (from python-dateutil>=2.7->matp
lotlib) (1.16.0)
```

In [2]:

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

To visualize some data... we need the data

We can use `pandas` to load and process the data. For instance:

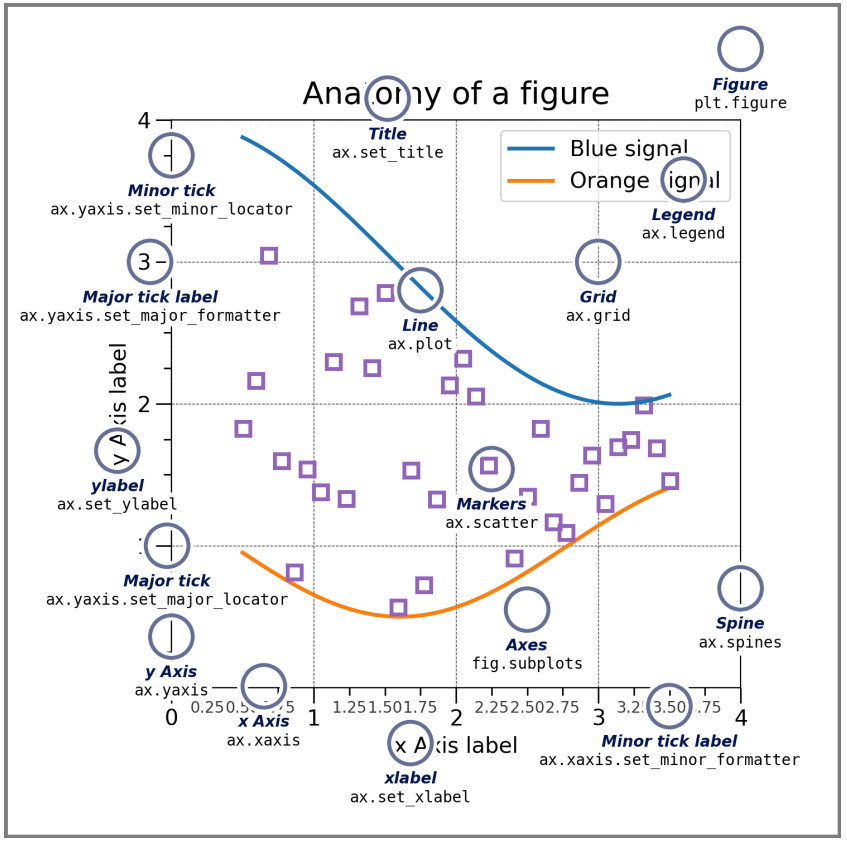
In [3]:
```
url = "nutrients.csv" # "https://ercoppa.github.io/labds/04/nutrients.c
df = pd.read_csv(url)
df = df.set_index('Food')
df = df.sort_values(by='Carbs', ascending=True)
df
```

Out[3]:

Food	Measure	Grams	Calories	Protein	Fat	Sat.Fat	Fiber
Bacon	2 slices	16	95	4	8.00	7.00	0.0
Clams	3 oz.	85	87	12	1.00	0.00	0.0
Asparagus	6 spears	96	18	1	0.01	0.01	0.5
Cows' milk	1 qt.	976	660	32	40.00	36.00	0.0
Butter	1/2 cup	112	113	114	115.00	116.00	117.0

Anatomy of a `matplolib` figure

Example



Key elements

- Figure
- Axes
- Plot type: e.g., line
- Plot title
- Markers
- Grid
- Spine
- Legend
- Axes, {major,minor} ticks
- {x,y}label, {major,minor} tick label

Figure, subplots, and Axes

Figure

A figure contains zero or more subplots (also dubbed *Axes* in `matplotlib`).

It can be explicitly created with:

In [4]:
```
fig = plt.figure()
```

```
<Figure size 640x480 with 0 Axes>
```

In most cases, you may omit to explicitly create it since it will be implicitly generated when creating the subplots (see next slides).

More details at: `matplotlib.figure`

Figure size

By default a figure is 640x480 pixels. However, we can set an arbitrary size:

In [5]:
```
fig = plt.figure(figsize=(10, 5)) # figsize is (width, height) in inche
```

```
<Figure size 1000x500 with 0 Axes>
```

Alternatevely, we can set the figure's DPI ("dots-per-inch"):

In [6]:
```
fig = plt.figure(dpi=300)
```

```
<Figure size 1920x1440 with 0 Axes>
```

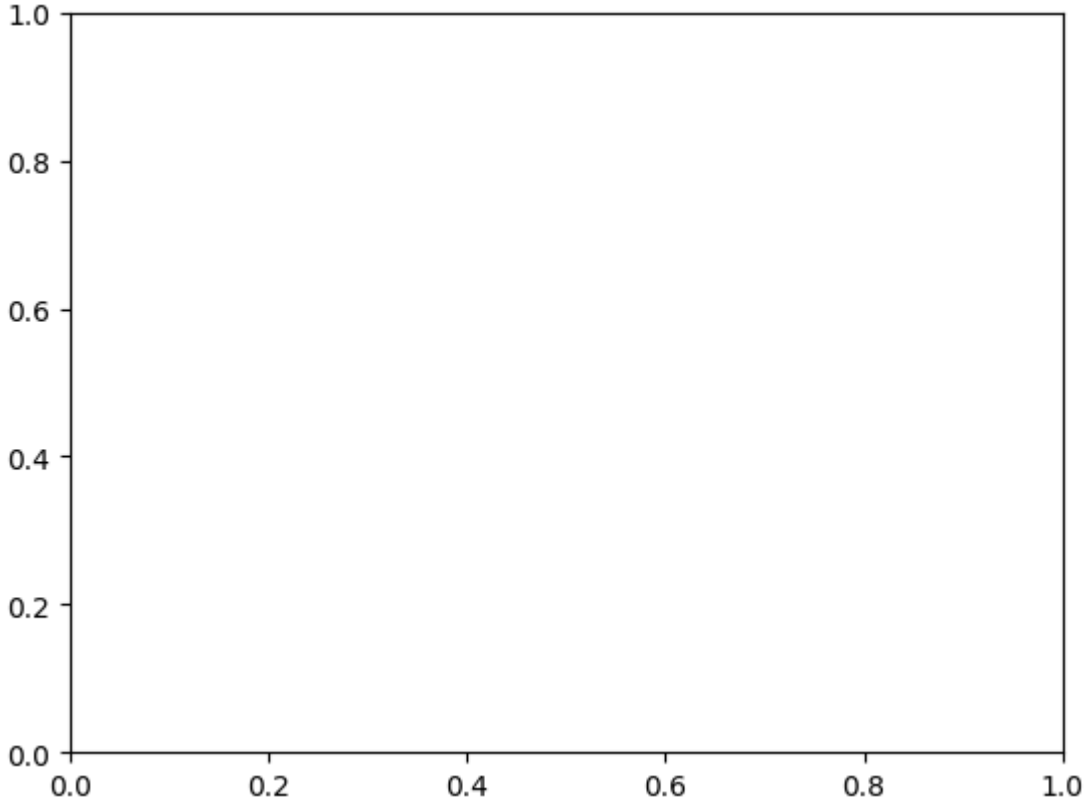
Setting the DPI will preserve the original ratio beetween width and height.

Subplots and Axes

To create a figure with a ***single*** subplot (`Axes`):

In [7]:
```
fig, ax = plt.subplots()
print(fig)
print(ax)
```

```
Figure(640x480)
Axes(0.125,0.11;0.775x0.77)
```



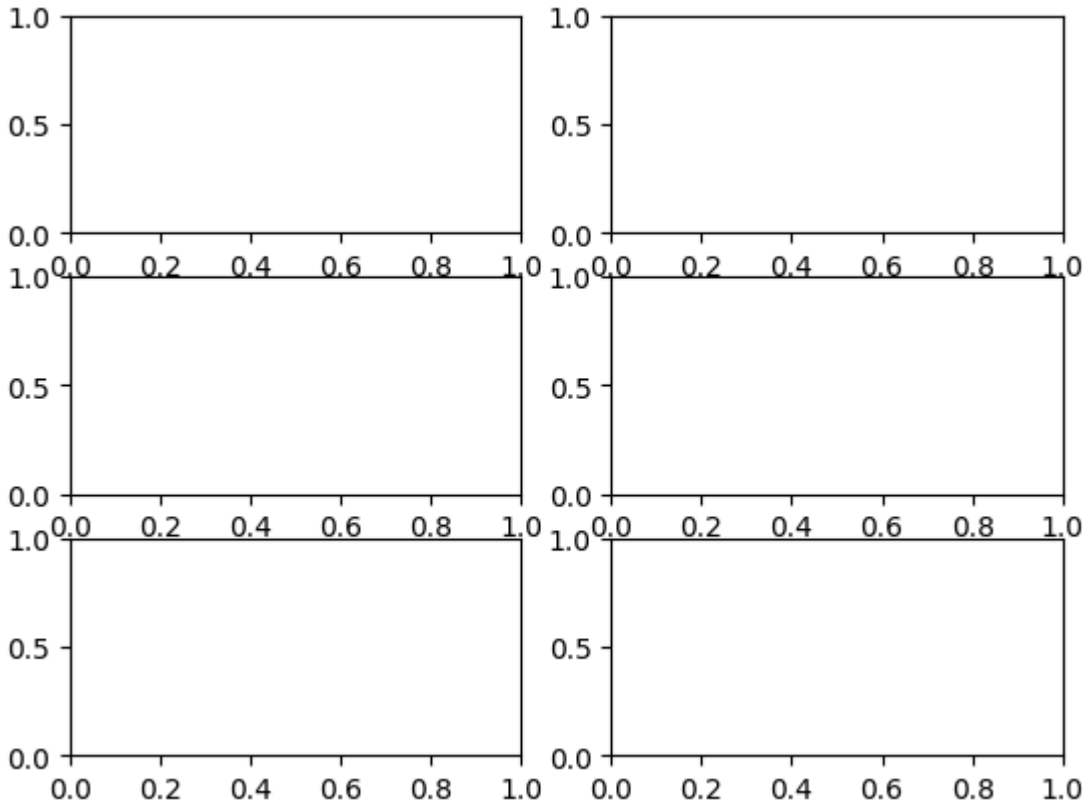
Mere details at: `matplotlib.pyplot.subplots`

Subplots and Axes (cont'd)

To create a figure with with **NxM** (e.g., N=3, M=2) subplots (`Axes`):

In [8]:
```
fig, axs = plt.subplots(3, 2) # 3 rows, 2 columns
print(fig)
print(axs)
```

```
Figure(640x480)
[[<Axes: > <Axes: >]
 [<Axes: > <Axes: >]
 [<Axes: > <Axes: >]]
```

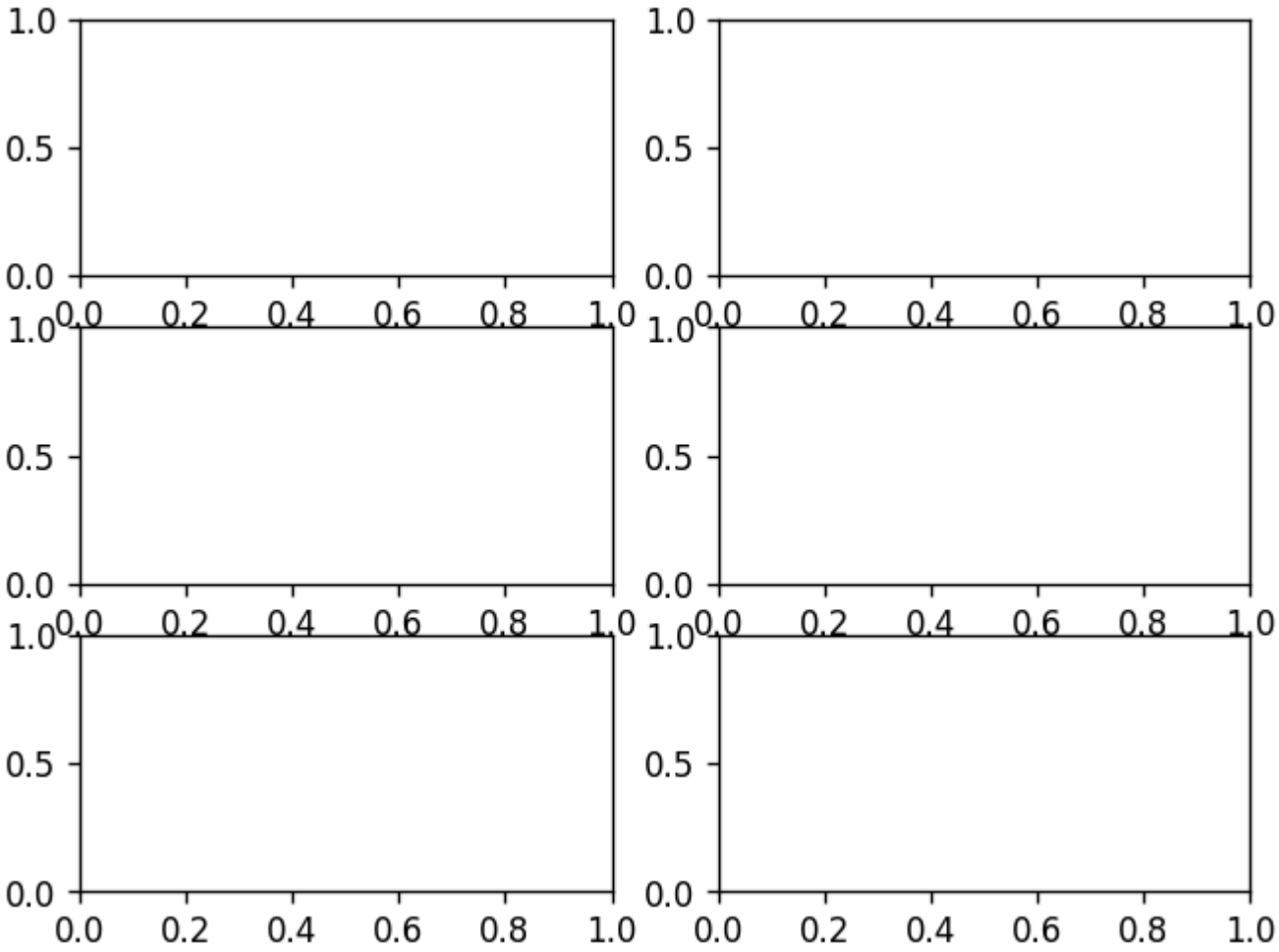

1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0

Subplots and Axes: setting the figure size

When creating the figure from `subplots`, we can still set the figure size using the `figsize` or `dpi` arguments. E.g.:

In [9]:
```
fig, axs = plt.subplots(3, 2, dpi=120) # 3 rows, 2 columns
print(fig)
```

```
Figure(768x576)
```


1.0
0.5
0.0
0.0
0.2
0.4
0.6
0.8
1.0

Functional interface vs. Object-Oriented interface

When using `matplotlib` we have two approaches:

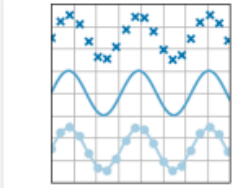
- **Object-Oriented interface (OO)**: given an `Axes`, we call methods over that `Axes` to modify its content. E.g., `ax.set_title("Title")`. ***This is the approach that we will adopt***.
- **Functional interface**: we use functions from `pyplot`, which will modify the state of the *current* `Axes`. E.g., `plt.title("Title")`. This approach is problemetic, e.g., when we want to deal with multiple plots within the same figure since it is not clear which `Axes` we want to update. This approach was inspired by MATLAB.

For more details, see: https://matplotlib.org/matplotblog/posts/pyplot-vs-object-oriented-interface/

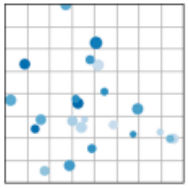
Plot types

Pairwise data

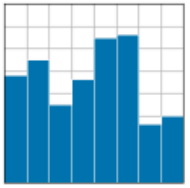
Plots of pairwise (x, y), tabular $(var_0, \cdots, var_n)$, and functional $f(x) = y$ data.



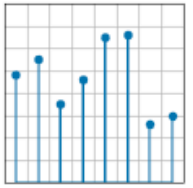
plot(x, y)



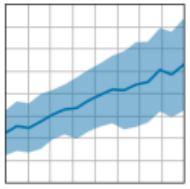
scatter(x, y)



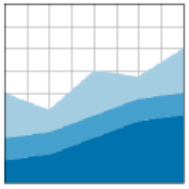
bar(x, height)



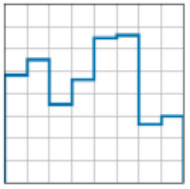
stem(x, y)



fill_between(x, y1, y2)



stackplot(x, y)

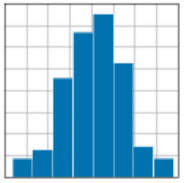


stairs(values)

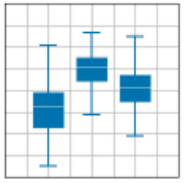
Gallery

Statistical distributions

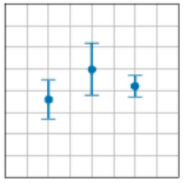
Plots of the distribution of at least one variable in a dataset. Some of these methods also compute the distributions.



hist(x)

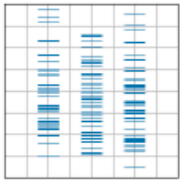


boxplot(X)

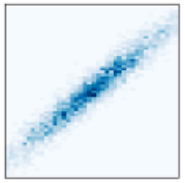


errorbar(x, y, yerr, xerr)

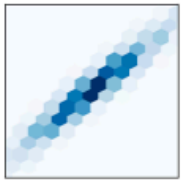
violinplot(D)



eventplot(D)

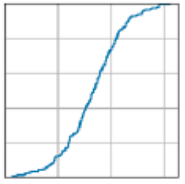


hist2d(x, y)



hexbin(x, y, C)

pie(x)



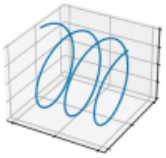
ecdf(x)

Gallery

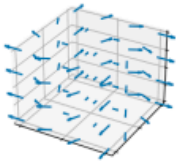
3D and volumetric data

Plots of three-dimensional (x, y, z), surface $f(x, y) = z$, and volumetric $V_{x,y,z}$ data using the `mpl_toolkits.mplot3d` library.

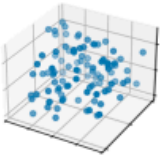
bar3d(x, y, z, dx, dy, dz)



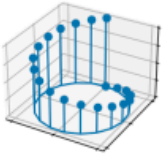
plot(xs, ys, zs)



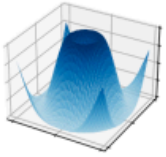
quiver(X, Y, Z, U, V, W)



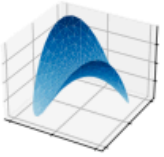
scatter(xs, ys, zs)



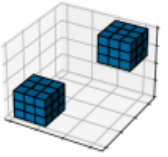
stem(x, y, z)



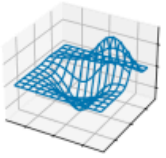
plot_surface(X, Y, Z)



plot_trisurf(x, y, z)



voxels([x, y, z], filled)



plot_wireframe(X, Y, Z)

Gallery

Creating a specific plot type

Given an `Axes`, we can populate it with one or more plots using the methods of `Axes`:

---

matplotlib.axes.Axes.plot
matplotlib.axes.Axes.errorbar
matplotlib.axes.Axes.scatter
matplotlib.axes.Axes.plot_date
matplotlib.axes.Axes.step
matplotlib.axes.Axes.loglog
matplotlib.axes.Axes.semilogx
matplotlib.axes.Axes.semilogy
matplotlib.axes.Axes.fill_between
matplotlib.axes.Axes.fill_betweenx
matplotlib.axes.Axes.bar
matplotlib.axes.Axes.barh
matplotlib.axes.Axes.bar_label
matplotlib.axes.Axes.stem

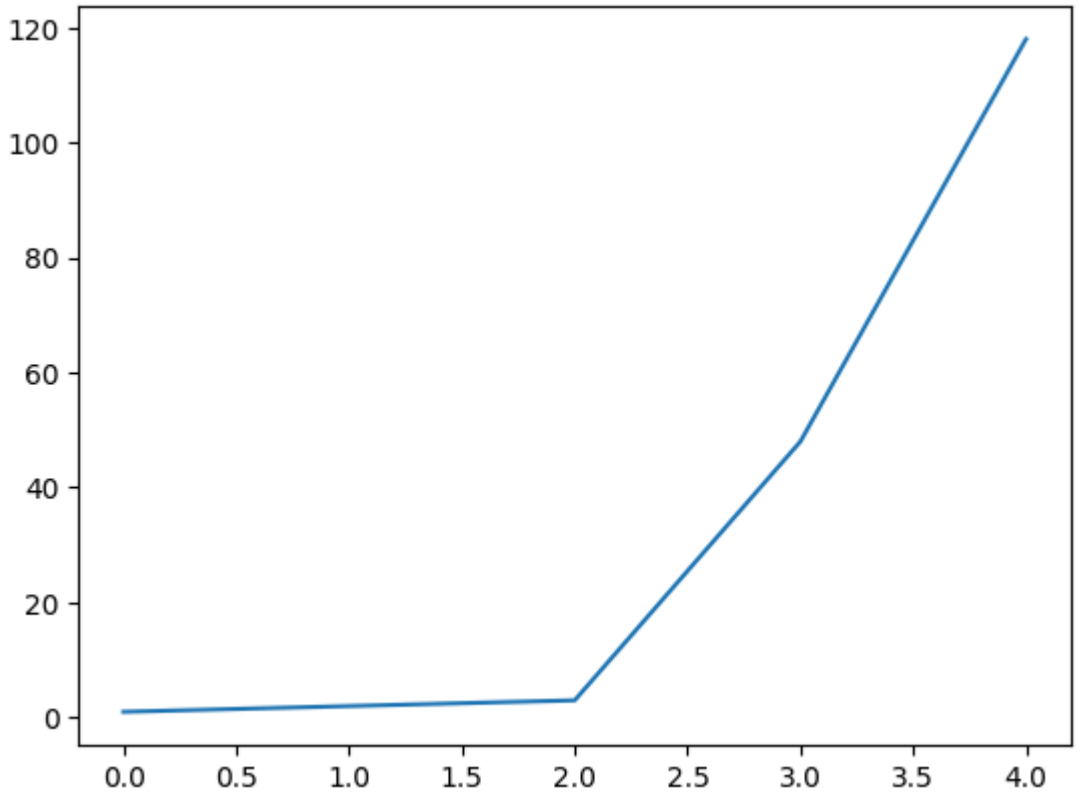
matplotlib.axes.Axes.csd
matplotlib.axes.Axes.magnitude_spect
matplotlib.axes.Axes.phase_spectrum
matplotlib.axes.Axes.psd
matplotlib.axes.Axes.specgram
matplotlib.axes.Axes.xcorr
matplotlib.axes.Axes.ecdf
matplotlib.axes.Axes.boxplot
matplotlib.axes.Axes.violinplot
matplotlib.axes.Axes.bxp
matplotlib.axes.Axes.violin
matplotlib.axes.Axes.hexbin
matplotlib.axes.Axes.hist
matplotlib.axes.Axes.hist2d

matplotlib.axes.Axes.eventplot
matplotlib.axes.Axes.pie
matplotlib.axes.Axes.stackplot
matplotlib.axes.Axes.broken_barh
matplotlib.axes.Axes.vlines
matplotlib.axes.Axes.hlines
matplotlib.axes.Axes.fill
matplotlib.axes.Axes.axhline
matplotlib.axes.Axes.axhspan
matplotlib.axes.Axes.axvline
matplotlib.axes.Axes.axvspan
matplotlib.axes.Axes.axline
matplotlib.axes.Axes.acorr
matplotlib.axes.Axes.angle_spectrum

matplotlib.axes.Axes.contour
matplotlib.axes.Axes.contourf
matplotlib.axes.Axes.imshow
matplotlib.axes.Axes.matshow
matplotlib.axes.Axes.pcolor
matplotlib.axes.Axes.pcolorfast
matplotlib.axes.Axes.pcolormesh
matplotlib.axes.Axes.spy
matplotlib.axes.Axes.tripcolor
matplotlib.axes.Axes.triplot
matplotlib.axes.Axes.tricontour
matplotlib.axes.Axes.tricontourf
matplotlib.axes.Axes.annotate
matplotlib.axes.Axes.text

Line plot

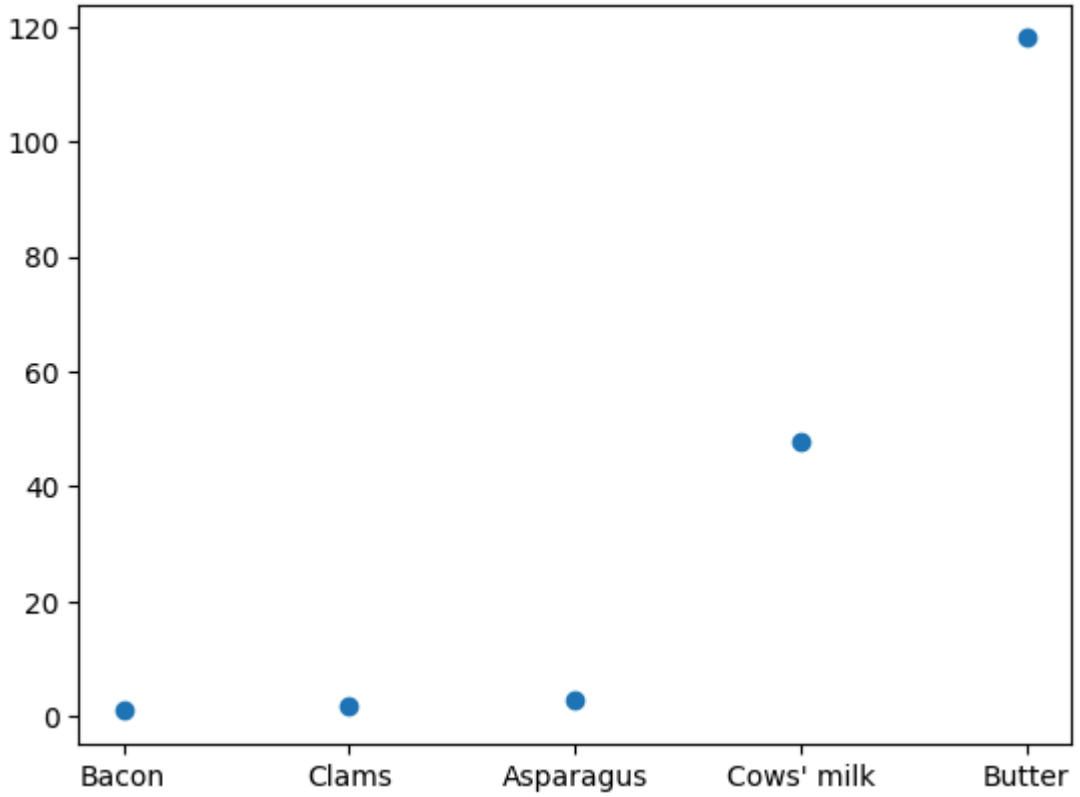
In [10]:
```
fig, ax = plt.subplots()
points = ax.plot(range(df.index.size), df['Carbs'].values)
```



Mere details at: `matplotlib.axes.Axes.plot`

Scatter plot

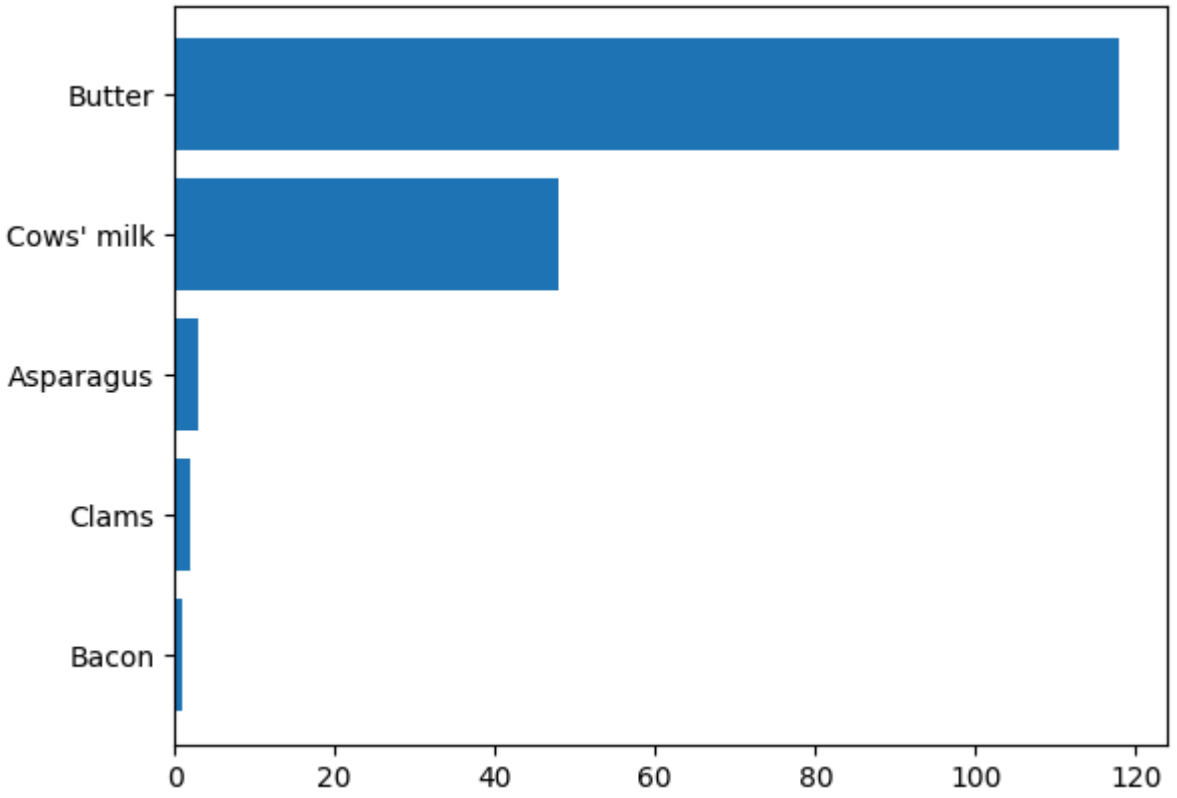
In [11]:
```
fig, ax = plt.subplots()
points = ax.scatter(df.index, df.Carbs)
```



Mere details at: `matplotlib.axes.Axes.scatter`

Horizontal bar plot

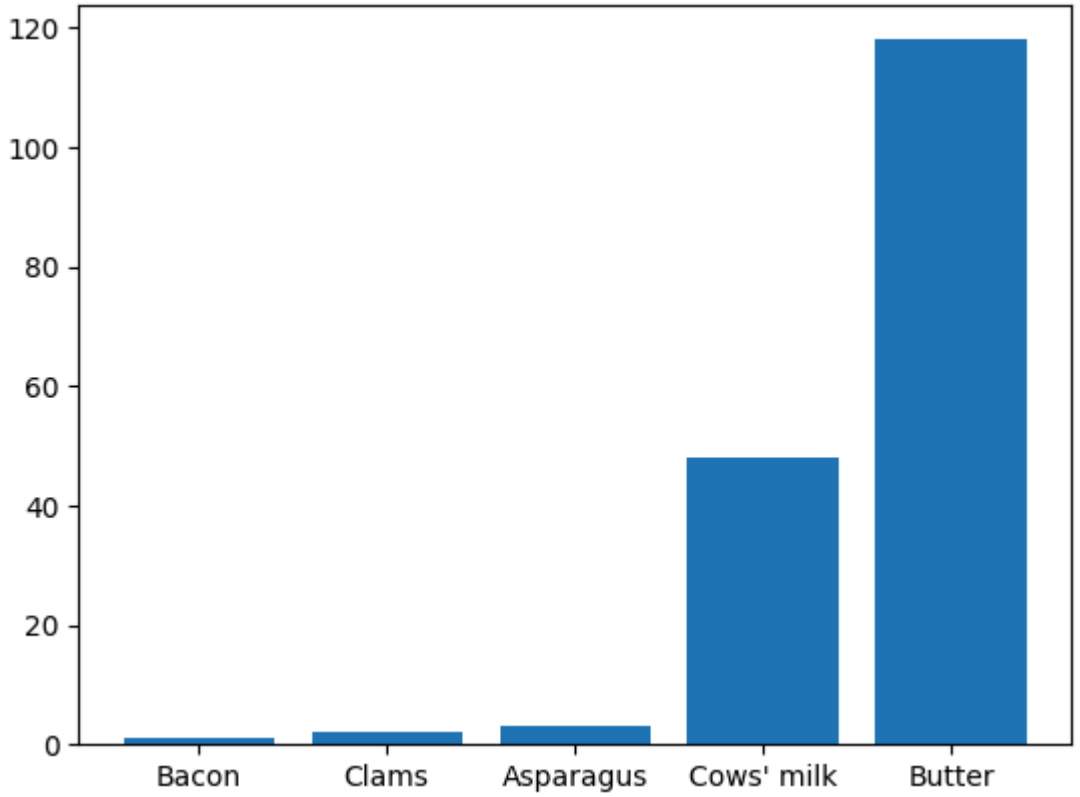
In [12]:
```
fig, ax = plt.subplots()
bars = ax.barh(df.index, df.Carbs)
```



Mere details at: `matplotlib.axes.Axes.barh`

Vertical bar plot

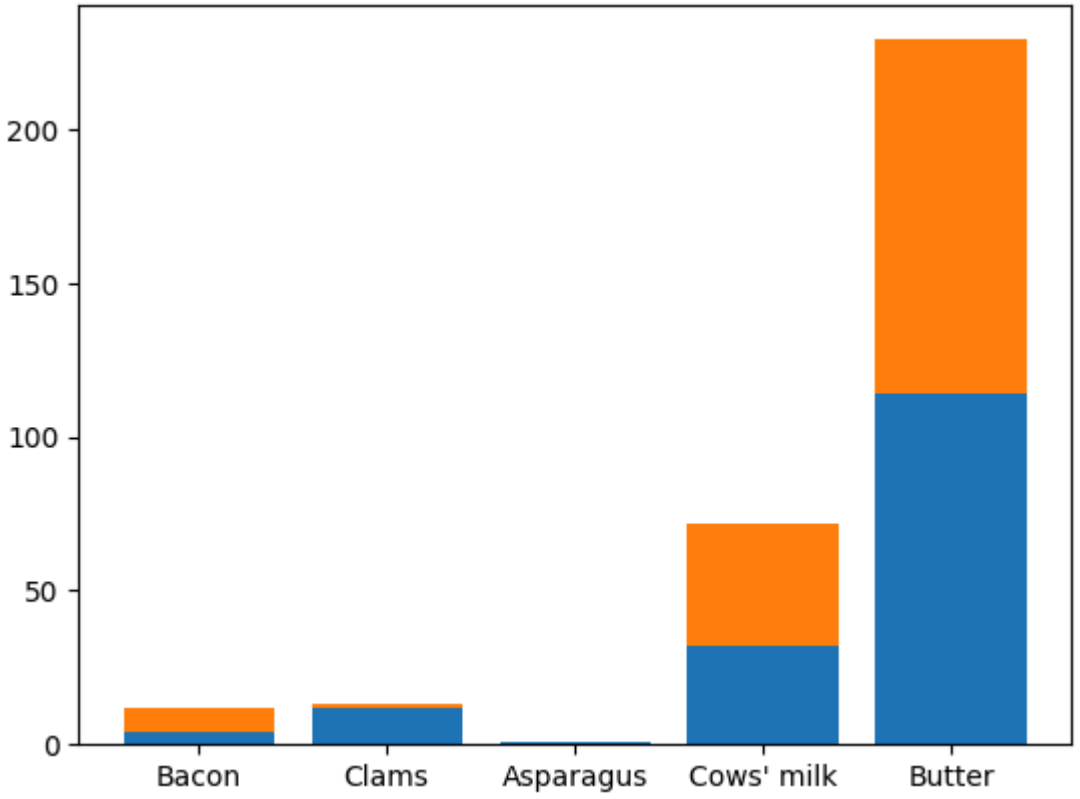
In [13]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df.Carbs)
```



Mere details at: `matplotlib.axes.Axes.bar`

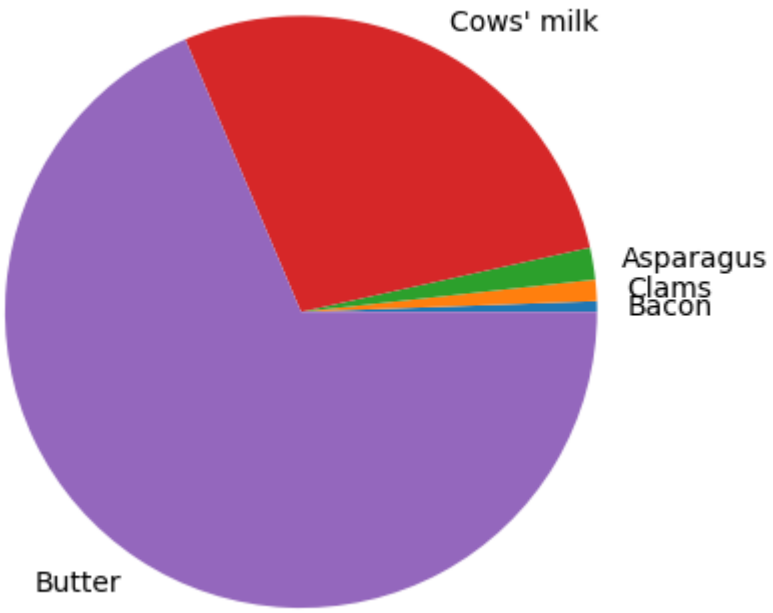
Stacked bar plot

In [14]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df["Protein"])
bars = ax.bar(df.index, df["Fat"], bottom=df["Protein"])
```



Pie chart

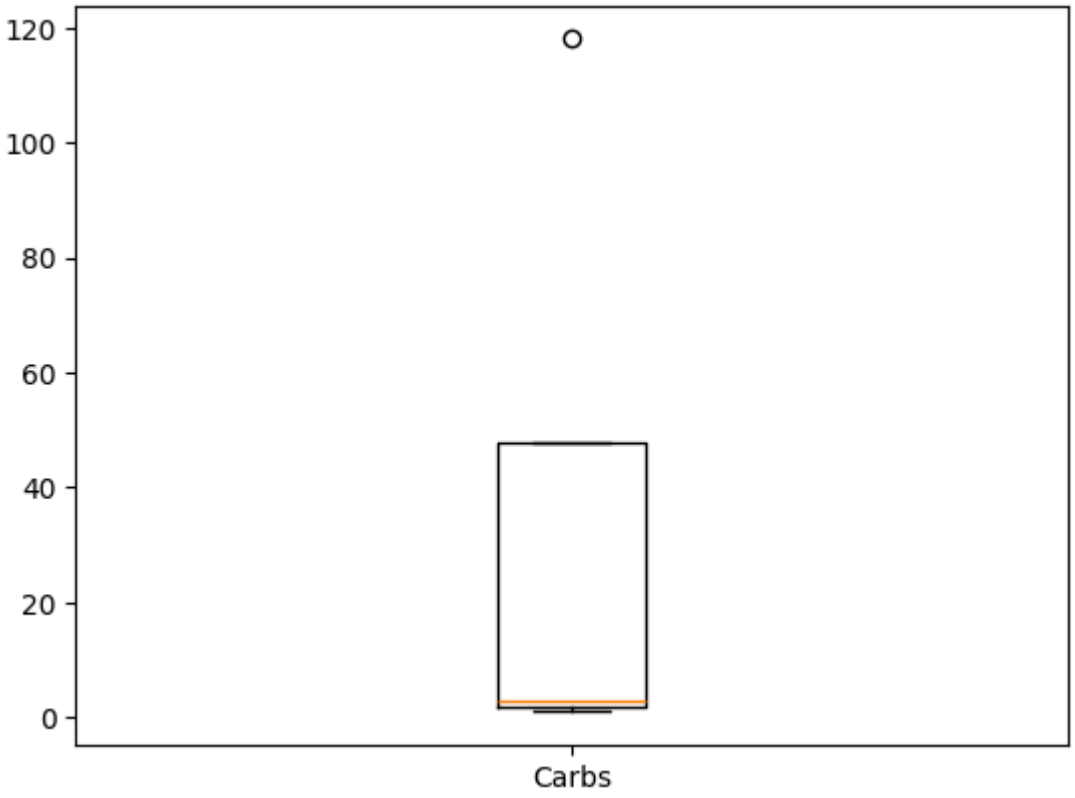
In [15]:
```
fig, ax = plt.subplots()
slices = ax.pie(df.Carbs, labels=df.index)
```



Mere details at: `matplotlib.axes.Axes.pie`

Box plot

In [16]:
```
fig, ax = plt.subplots()
slices = ax.boxplot(df.Carbs, tick_labels=["Carbs"]) # vert=False to ma
```

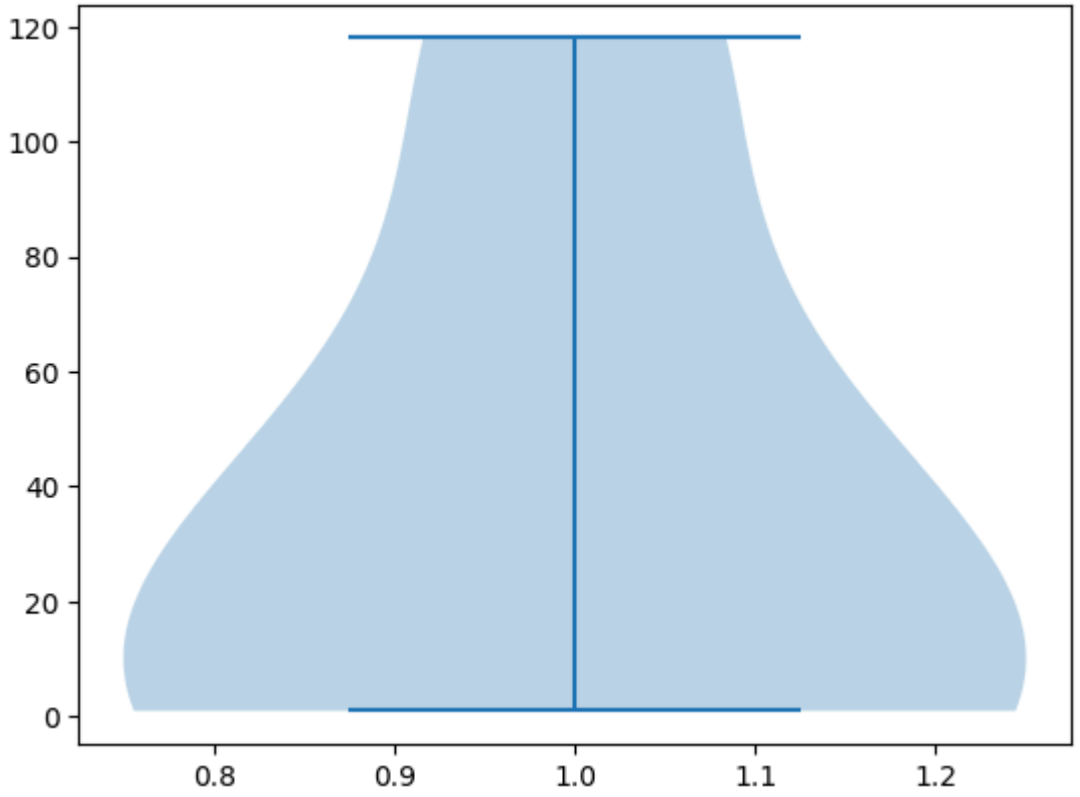


Mere details at: `matplotlib.axes.Axes.boxplot`

Violin plot

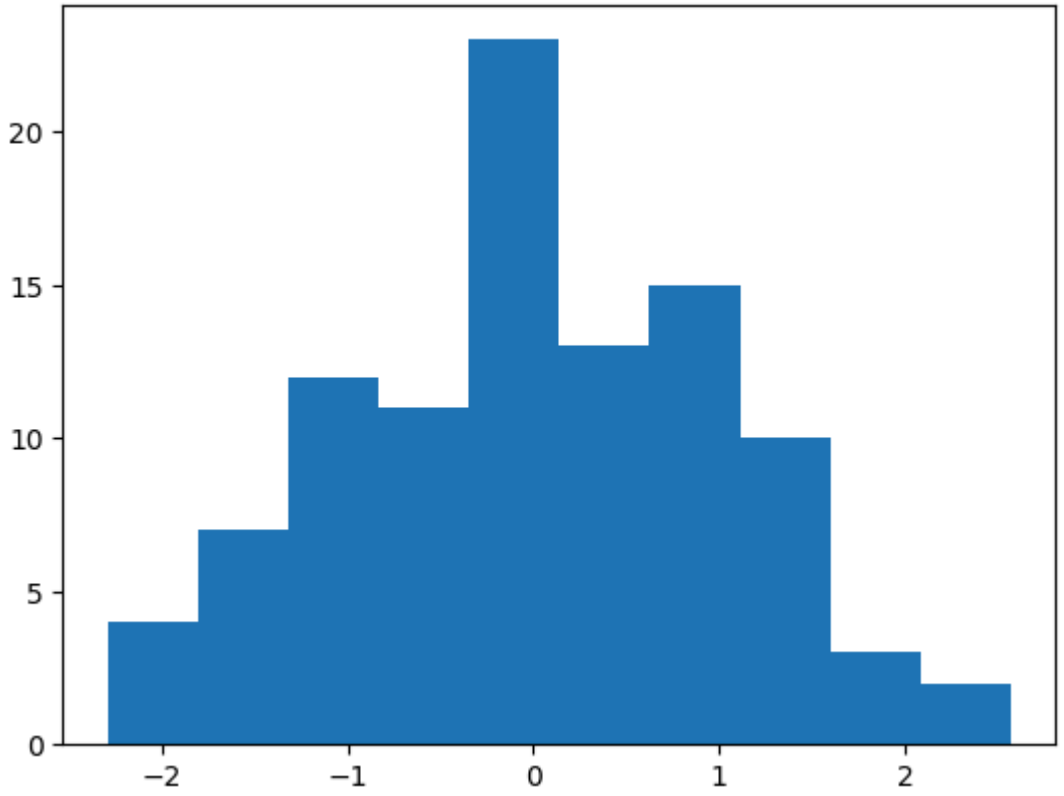
A popular alternative to a boxplot is:

In [17]:
```
fig, ax = plt.subplots()
slices = ax.violinplot(df.Carbs) # vert=False to make it horizontal
```



Histogram

In [18]:
```
fig, ax = plt.subplots()
data = np.random.standard_normal(100) # 100 random numbers
slices = ax.hist(data, bins=10)
```

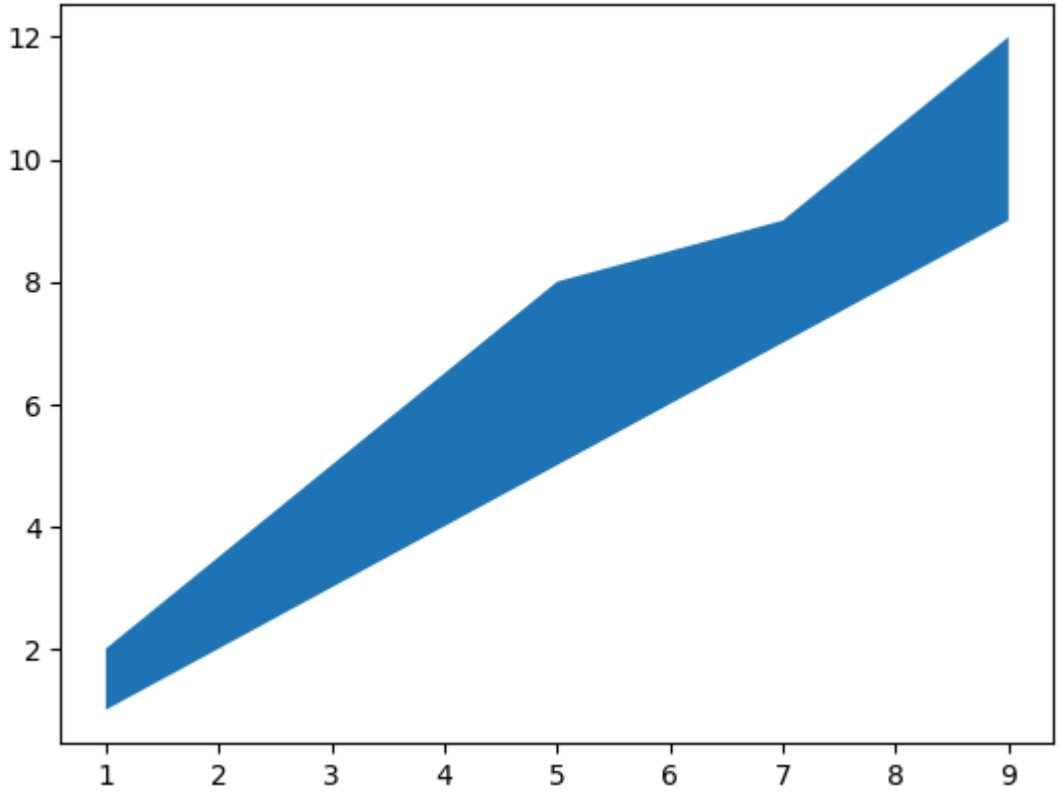


Mere details at: `matplotlib.axes.Axes.hist`

Fill between

In [19]:
```
x = [1, 3, 5, 7, 9]
y1 = [1, 3, 5, 7, 9]
y2 = [2, 5, 8, 9, 12]

fig, ax = plt.subplots()
lines = ax.fill_between(x, y1, y2)
```

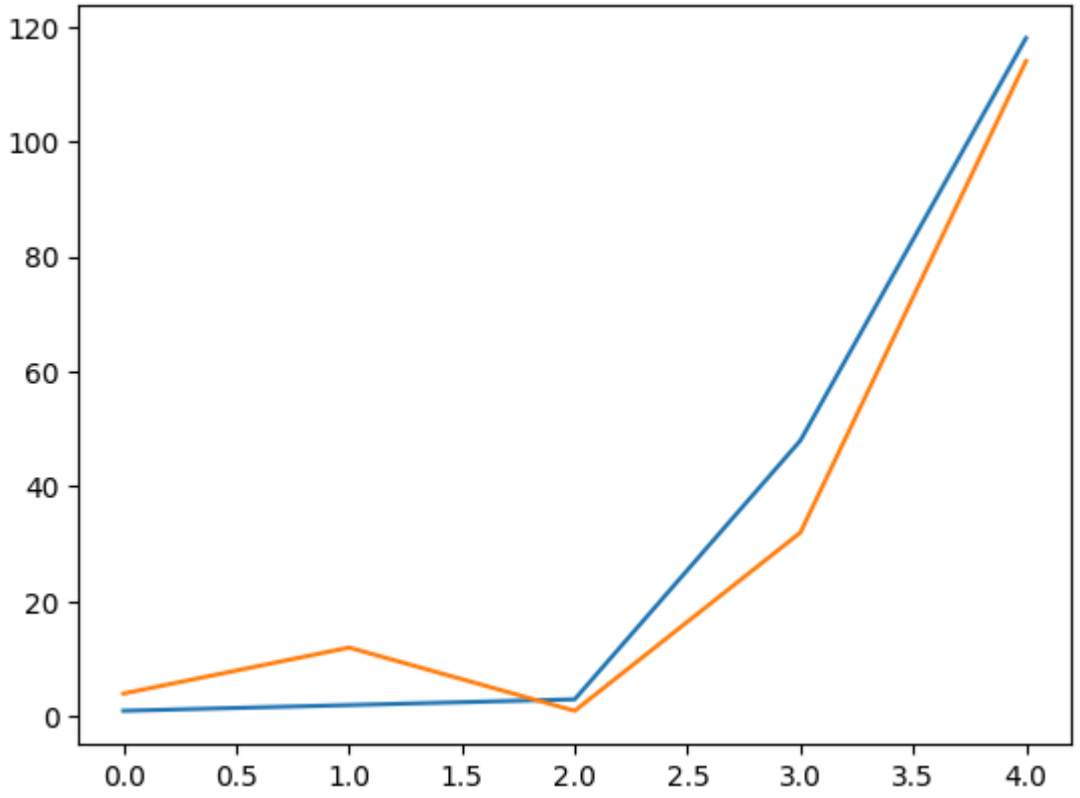


Mere details at: `matplotlib.axes.Axes.fill_between`

Combining different plot types into an Axes

We can add more than one plot within the same `Axes`:

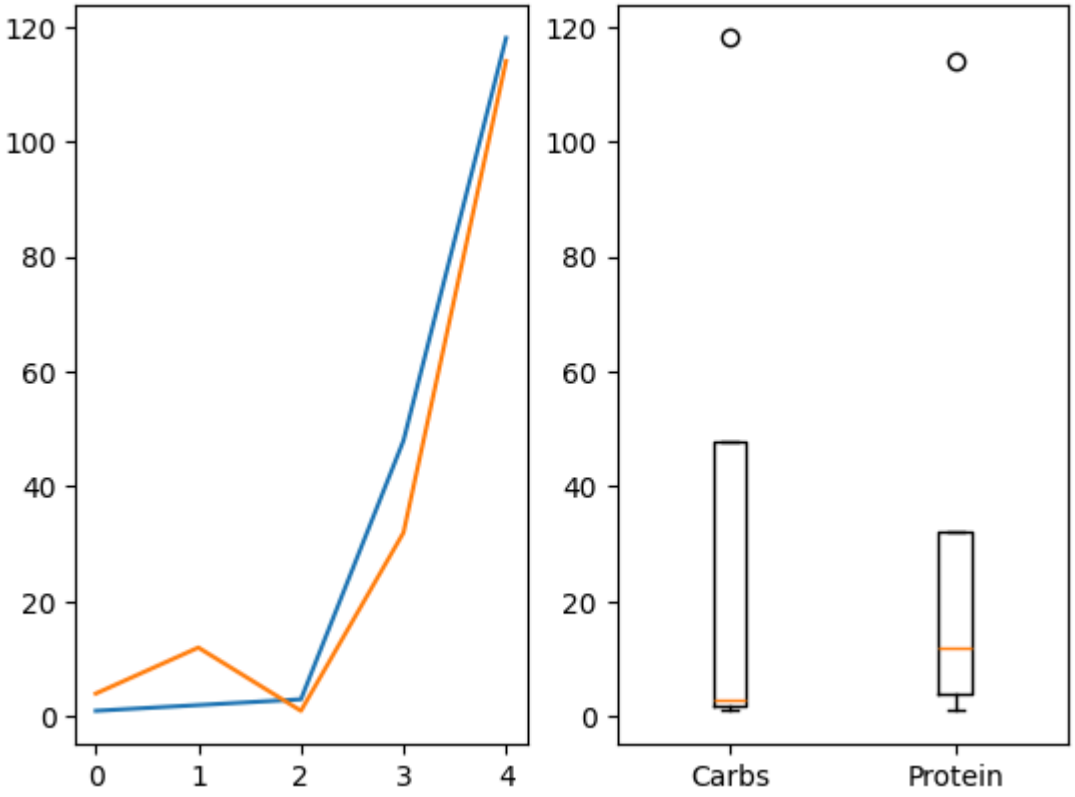
In [20]:
```
fig, ax = plt.subplots()
line = ax.plot(range(df.index.size), df['Carbs'].values)
points = ax.plot(range(df.index.size), df['Protein'].values)
```



Combining different plots types into the same figure

We can also add the plots in distincts axes:

In [21]:
```
fig, axes = plt.subplots(1, 2)
line = axes[0].plot(range(df.index.size), df['Carbs'].values)
points = axes[0].plot(range(df.index.size), df['Protein'].values)
slices = axes[1].boxplot([df.Carbs, df.Protein], tick_labels=["Carbs",
```



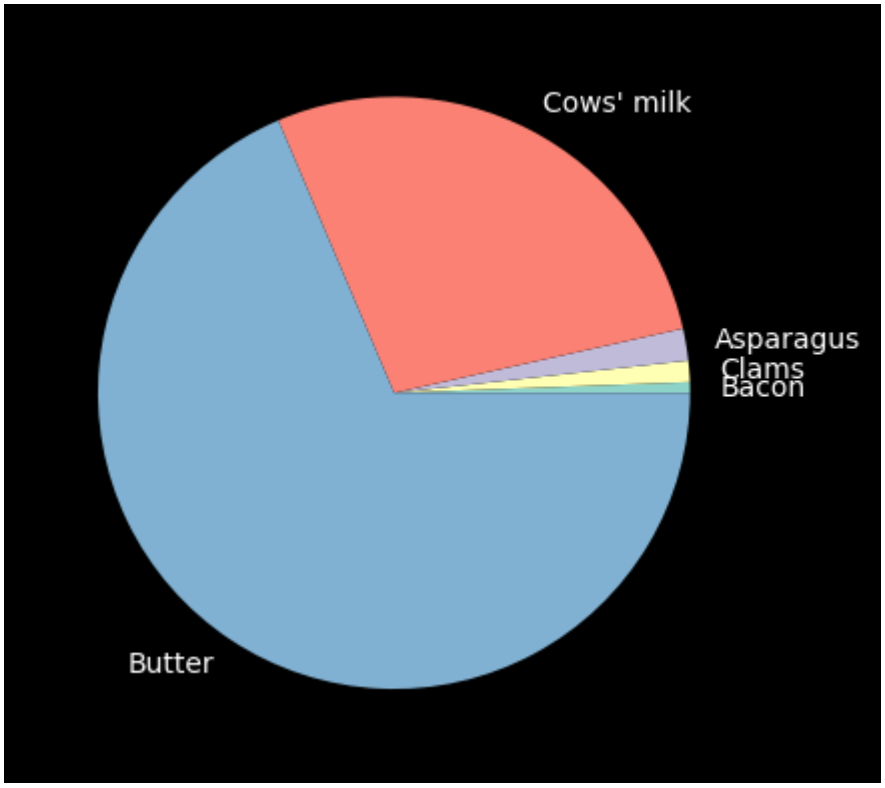
Plot styling

Pick a style

`matplotlib` ships with many styles that can drastically change the look of a plot, e.g., dark theme. Pick your favorite style from: styles.

For instance, given the style `fivethirtyeight`, apply to your plots with:

In [22]:
```
plt.style.use('dark_background')
fig, ax = plt.subplots()
slices = ax.pie(df.Carbs, labels=df.index)
```

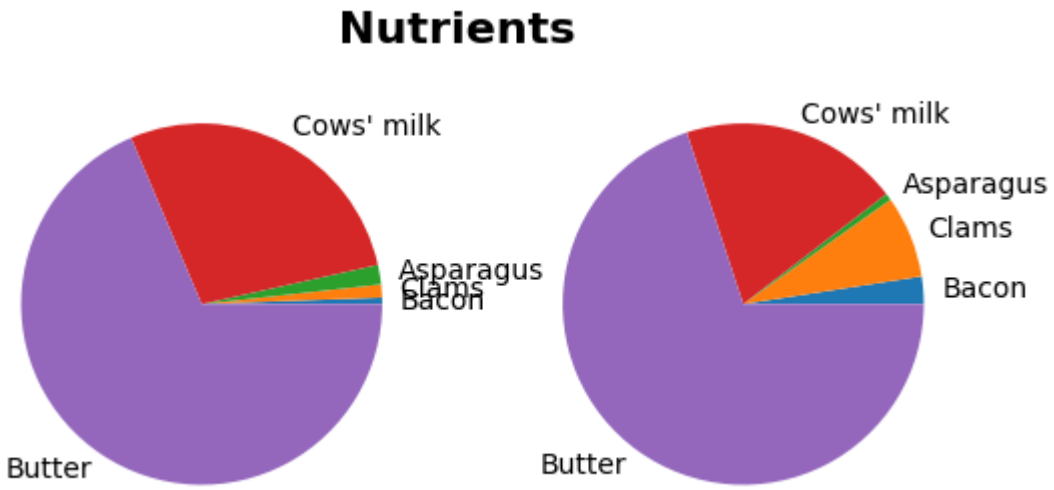


which is quite different from the `default` style:

In [23]:
```
plt.style.use('default')
fig, ax = plt.subplots()
slices = ax.pie(df.Carbs, labels=df.index)
```

Setting a title to the figure

In [24]:
```
fig, axes = plt.subplots(1, 2)
fig.suptitle("Nutrients", fontsize=16, fontweight='bold', y=0.80)
slices = axes[0].pie(df.Carbs, labels=df.index)
slices = axes[1].pie(df.Protein, labels=df.index)
```

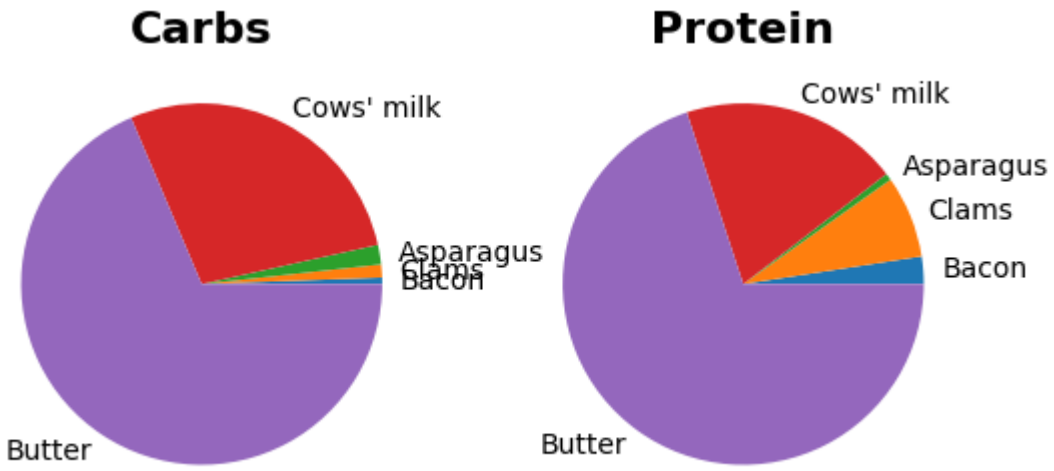


See: `matplotlib.figure.Figure.suptitle`

Setting a title to an Axes

In [25]:
```
fig, axes = plt.subplots(1, 2)
slices = axes[0].pie(df.Carbs, labels=df.index)
axes[0].set_title("Carbs", fontsize=16, fontweight='bold')
slices = axes[1].pie(df.Protein, labels=df.index)
axes[1].set_title("Protein", fontsize=16, fontweight='bold')
```

Out[25]:
```
Text(0.5, 1.0, 'Protein')
```

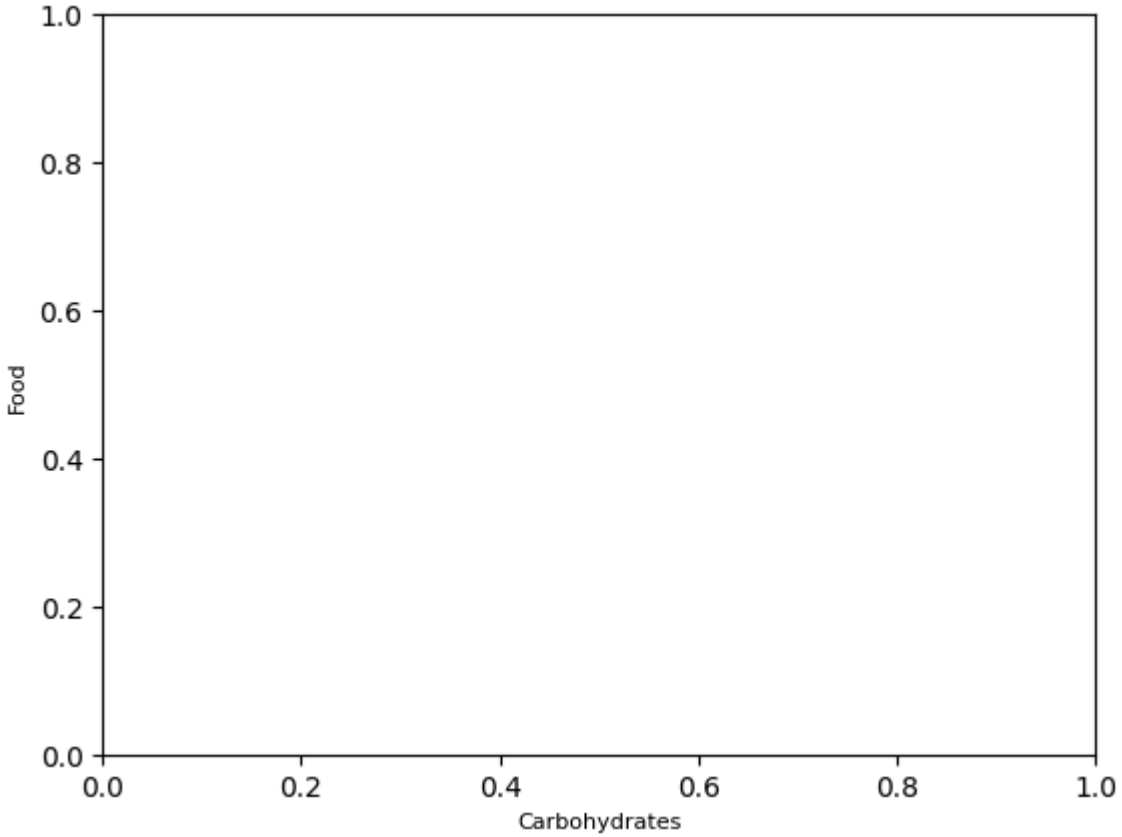


See: `matplotlib.axes.Axes.set_title`

Setting x or y labels

In [26]:
```
fig, ax = plt.subplots()
ax.set_xlabel('Carbohydrates', fontsize = 8)
ax.set_ylabel('Food', fontsize = 8)
```

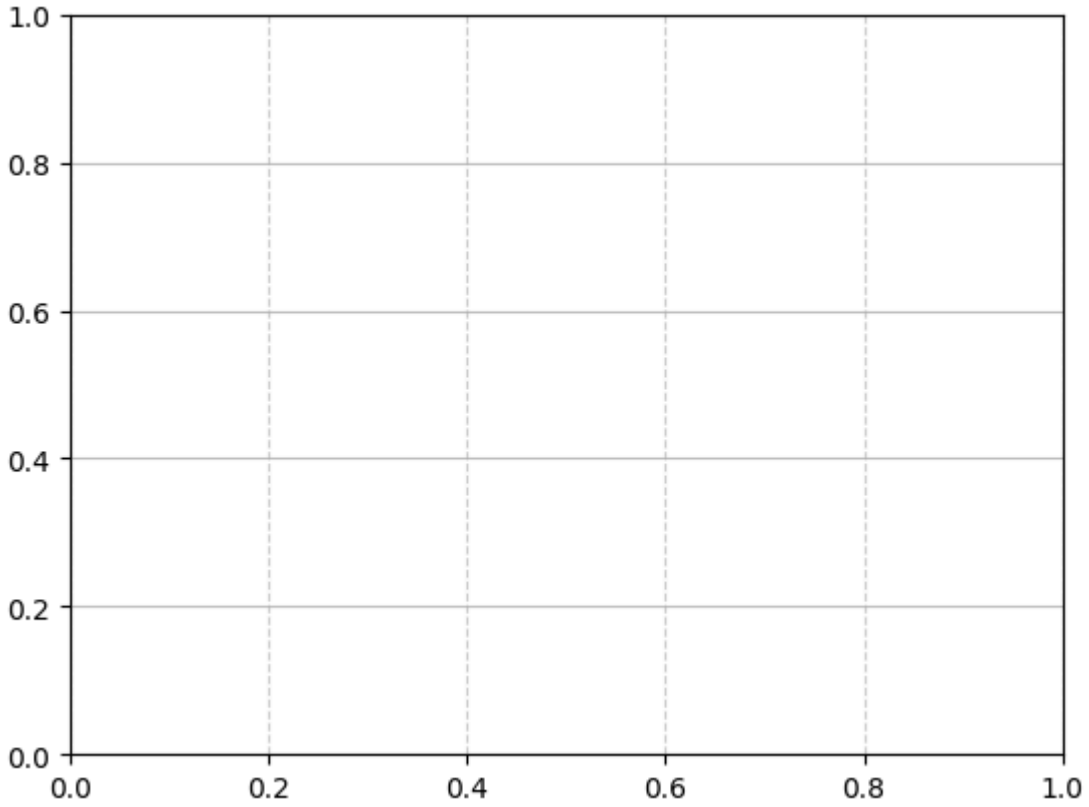
Out[26]:
```
Text(0, 0.5, 'Food')
```



See: `matplotlib.axes.Axes.set_xlabel` and `matplotlib.axes.Axes.set_ylabel`

Adding grid lines

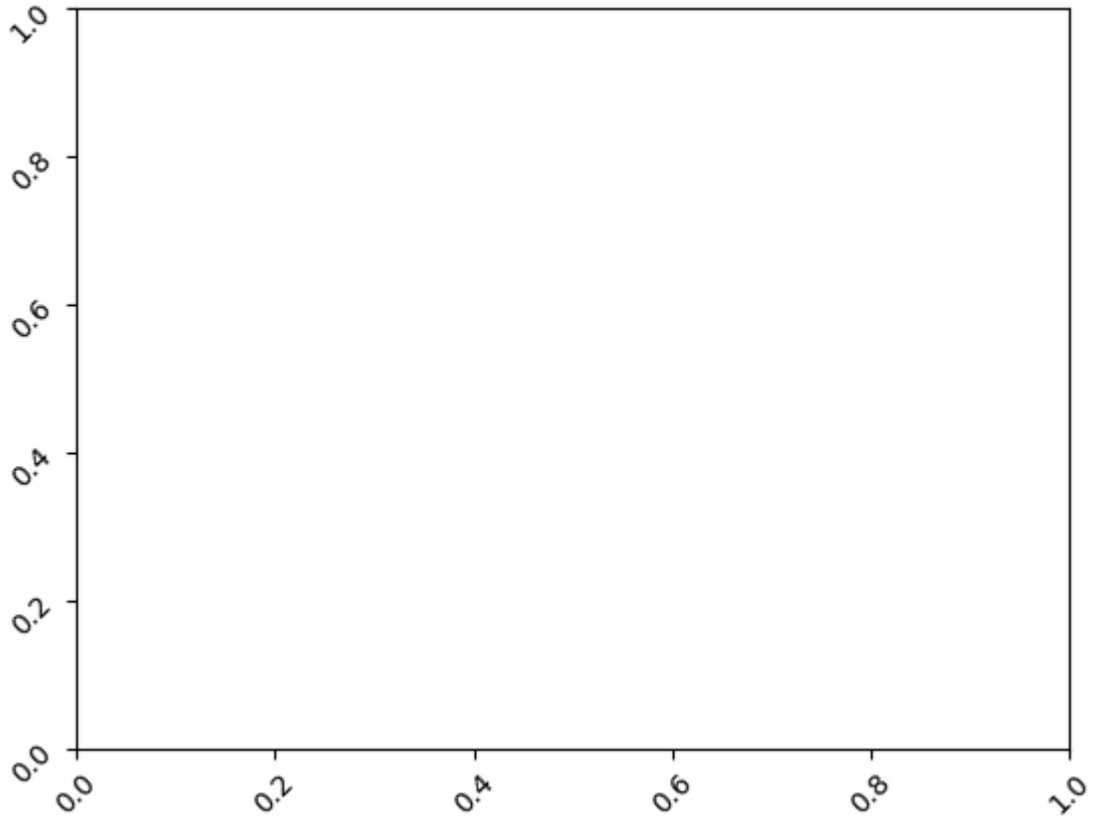
In [27]:
```
fig, ax = plt.subplots()
ax.grid(axis='y', linestyle='-', alpha=0.8)
ax.grid(axis='x', linestyle='--', alpha=0.6)
```



See: `matplotlib.axes.Axes.grid`

Rotate x or y ticks labels

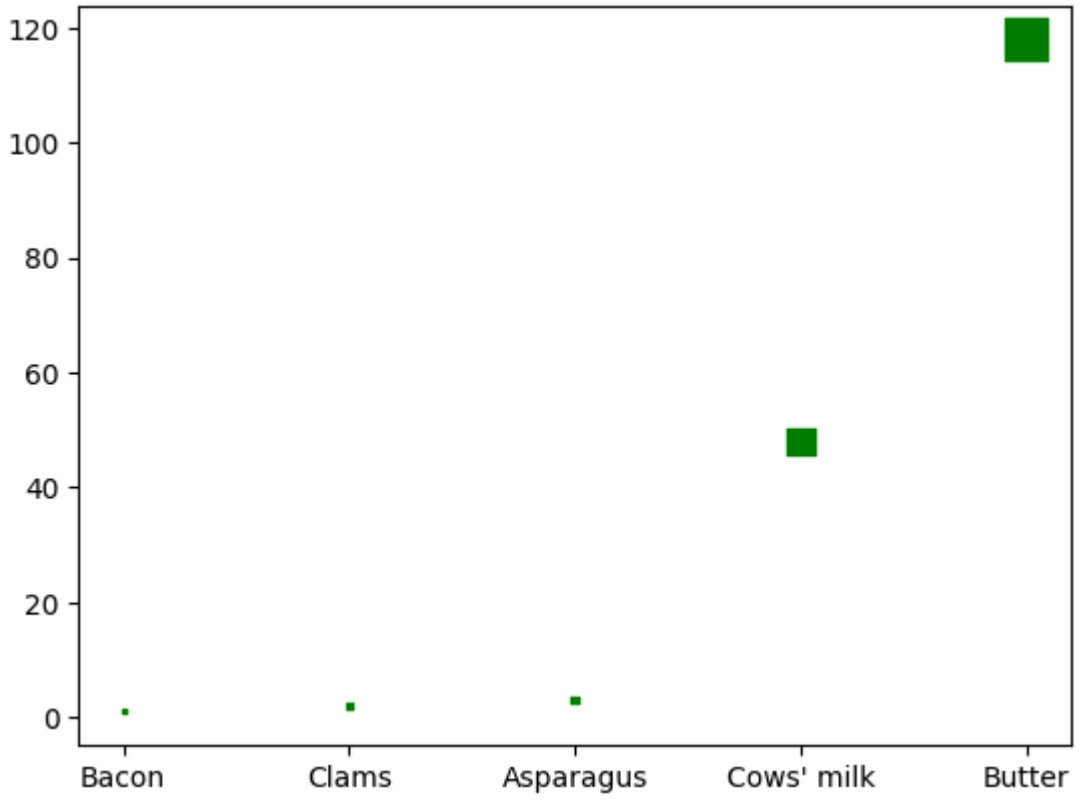
In [28]:
```
fig, ax = plt.subplots()
ax.tick_params(axis='x', labelrotation=45)
ax.tick_params(axis='y', labelrotation=45)
```



See: `matplotlib.axes.Axes.tick_params`

Change color, size, and symbol of the markers in a scatter plot

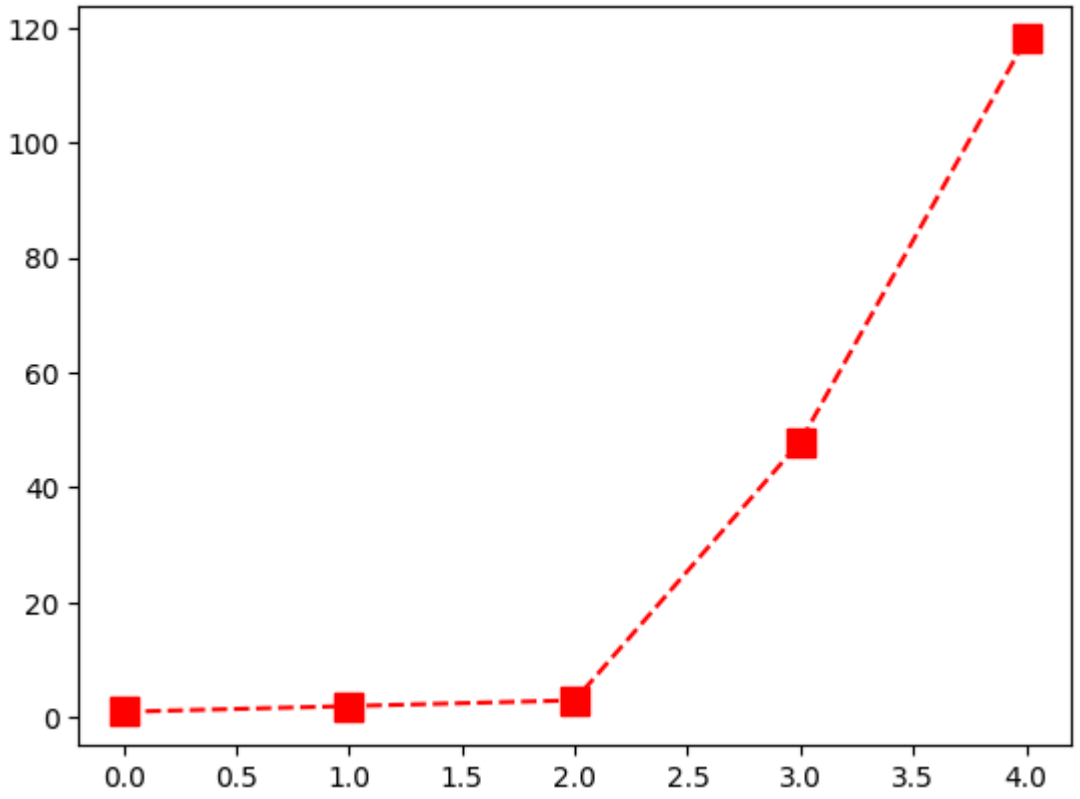
In [29]:
```
fig, ax = plt.subplots()
points = ax.scatter(df.index, df.Carbs,
                    color='green',
                    marker='s',     #
                    s=df.Carbs*2)   # make the size proportional to the val
```



See: `matplotlib.markers`

Change color, size, marker, and style of a line in a plot

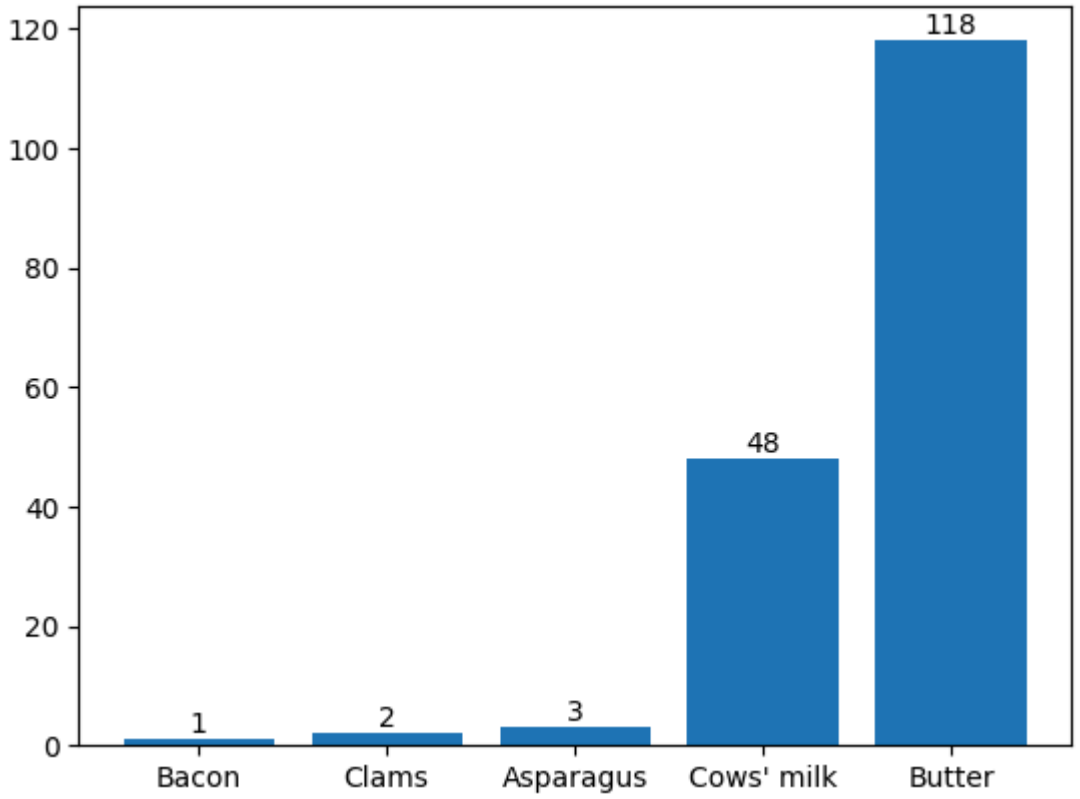
In [30]:
```
fig, ax = plt.subplots()
points = ax.plot(range(df.index.size), df['Carbs'].values,
                 color='red',
                 linestyle='--',
                 marker='s',
                 markersize=10)
```



See: `matplotlib.lines.Line2D` and Linestyles

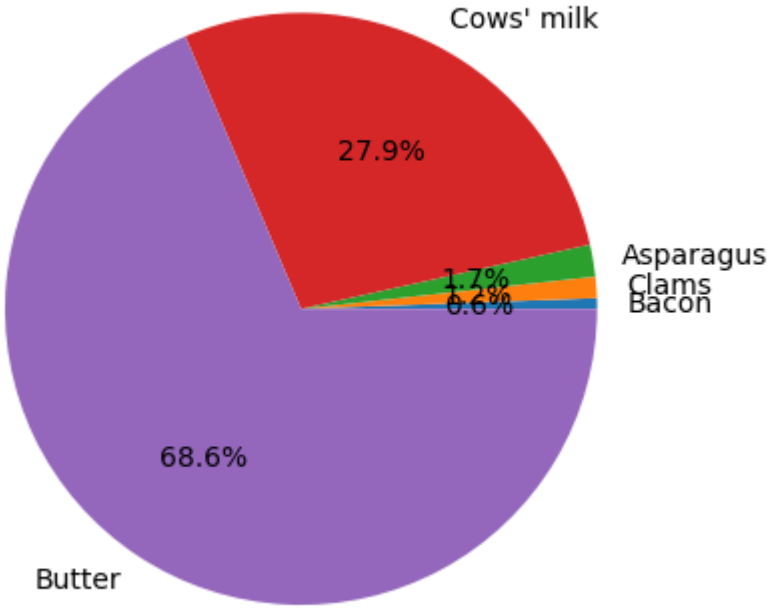
Adding label on top of each bar

In [31]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df.Carbs) # vertical bar plot
for bar in bars:
    yval = bar.get_height()
    ax.text(bar.get_x() + bar.get_width()/2, yval + 0.1, round(yval, 2)
```



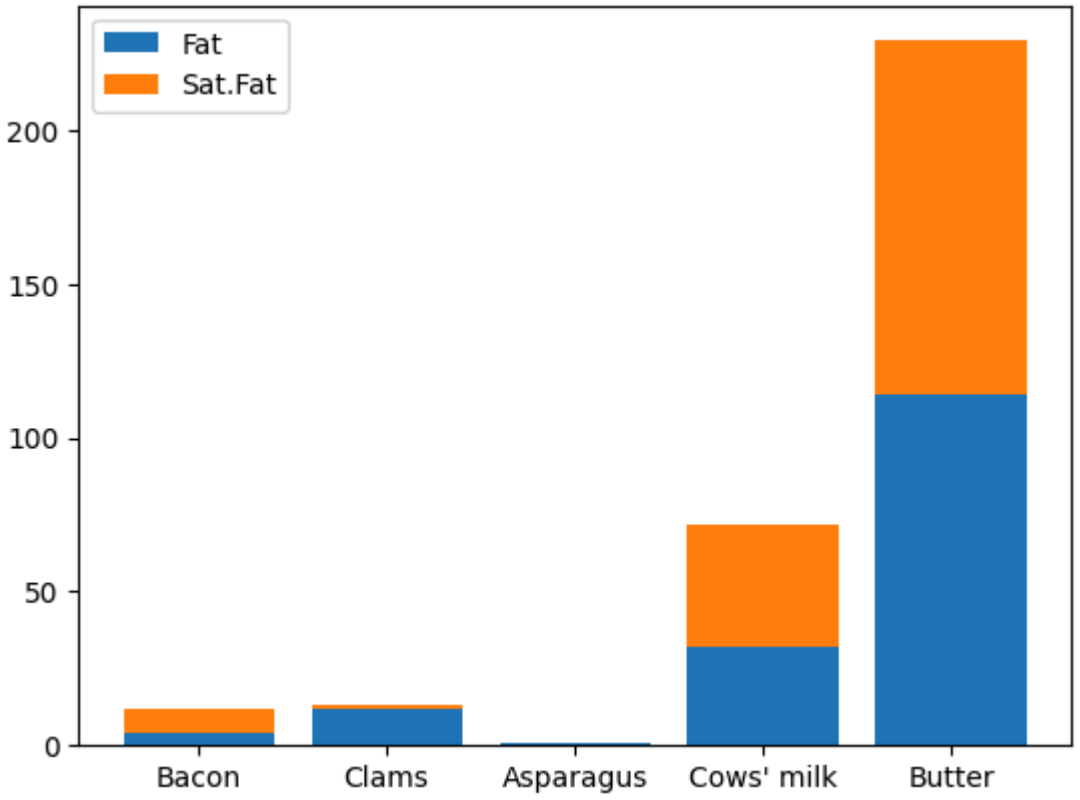
Add percentage label in a pie chart

In [32]:
```
fig, ax = plt.subplots()
slices = ax.pie(df.Carbs, labels=df.index, autopct='%1.1f%%')
```



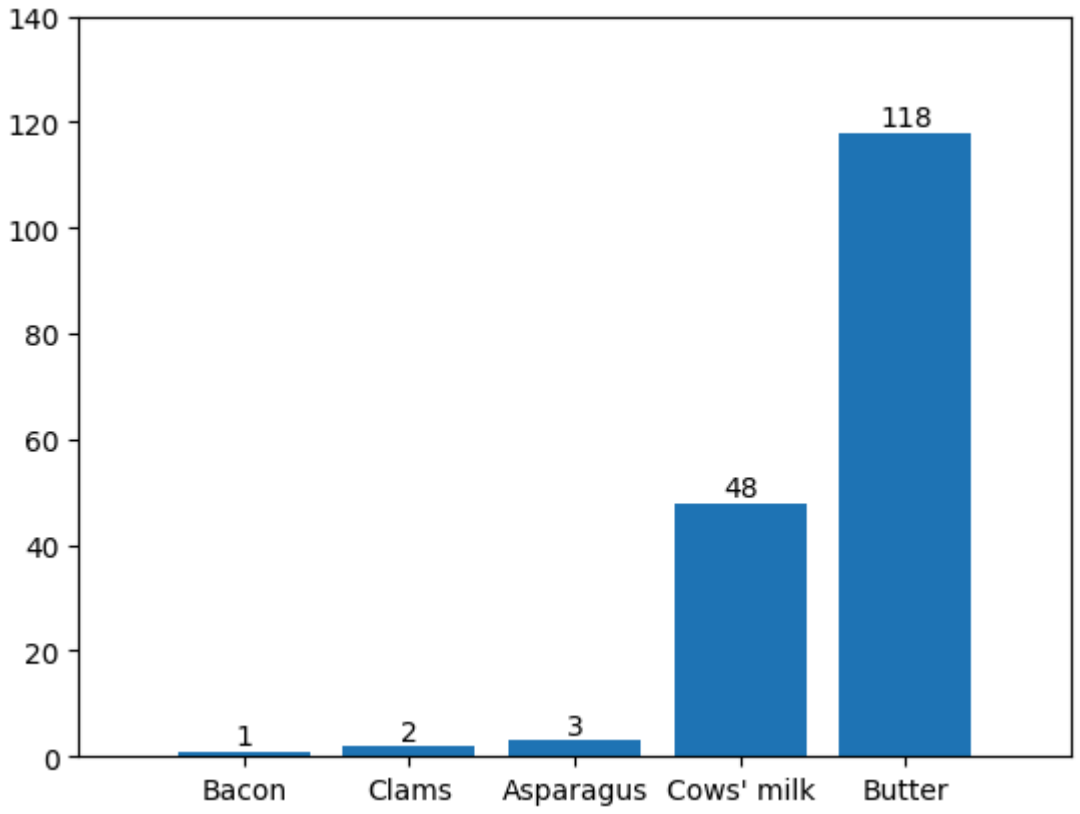
Add a legend

In [33]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df["Protein"])
bars = ax.bar(df.index, df["Fat"], bottom=df["Protein"])
legend = ax.legend(df[["Fat", "Sat.Fat"]].columns)
```



Change x and y limits

In [34]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df.Carbs) # vertical bar plot
for bar in bars:
    ax.text(bar.get_x() + bar.get_width()/2, bar.get_height() + 0.1, rc
ax.set_xlim(-1, 5)
_ = ax.set_ylim(0, 140)
```



Plot exporting (PNG, PDF)

How to visualize a plot

While when working in a notebook any plot is automatically shown, **when writing a Python script**, we have to explitly decide when to show or export a figure.

If we want to visualize the plot in a seperate window:

In [35]:
```
plt.show()
```

How to save a plot

In [36]:
```
fig, ax = plt.subplots()
bars = ax.bar(df.index, df["Protein"])
plt.savefig("file.png") # save in PNG
plt.savefig("file.pdf") # save in PDF
plt.close() # close the figure to avoid displaying it
```

Documentation

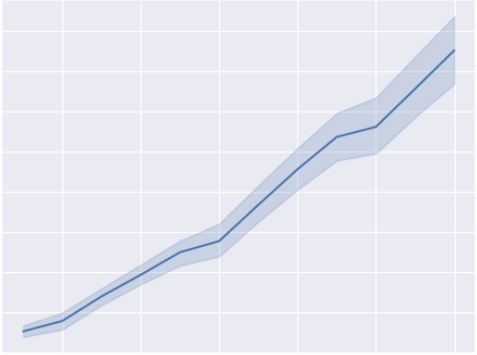
- **User guide**: https://matplotlib.org/stable/users/index.html
- **API**: https://matplotlib.org/stable/api/index.html

Package `seaborn`

Why `seaborn`?

`matplotlib` is *extremely* powerful. However, it can be very tricky when aiming at some *advanced* plots. For instance, given a dataset, if we want to plot:

- a line that represents the average of the data points over a specific x
- the confidence interval for each data points over a specific x

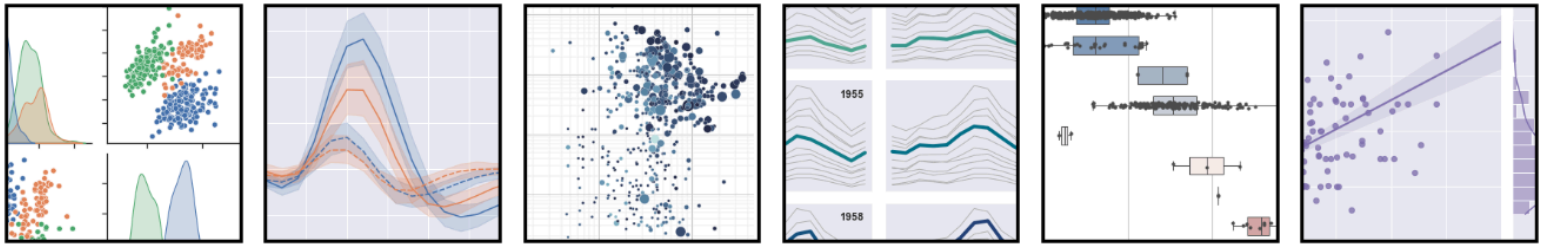


In `matplotlib`, we have to:

- compute the average
- `plot` the line for the average
- compute the confindence interval
- plot the confidence intervals with, e.g., `fill_between`

`seaborn`: `matplotlib` for the humans

`seaborn` is a data visualization library based on `matplotlib`. It provides a high-level interface for drawing *attractive* and **informative statistical** graphics.



It comes with convenient *shortcuts* to build several nice plots using `matplotlib`
Moreover, it naturally fits with `pandas` and `scikit-learn`.

`seaborn`: installation

Install it with `pip3`:

In [37]:
```
! pip install seaborn
```

```
Requirement already satisfied: seaborn in /home/user/labds/ven
v/lib/python3.12/site-packages (0.13.2)
Requirement already satisfied: numpy!=1.24.0,>=1.20 in /home/us
er/labds/venv/lib/python3.12/site-packages (from seaborn) (2.1.
0)
Requirement already satisfied: pandas>=1.2 in /home/user/labds/
venv/lib/python3.12/site-packages (from seaborn) (2.2.2)
Requirement already satisfied: matplotlib!=3.6.1,>=3.4 in /hom
e/user/labds/venv/lib/python3.12/site-packages (from seaborn)
(3.9.2)
Requirement already satisfied: contourpy>=1.0.1 in /home/user/l
abds/venv/lib/python3.12/site-packages (from matplotlib!=3.6.1,
>=3.4->seaborn) (1.3.0)
Requirement already satisfied: cycler>=0.10 in /home/user/labd
s/venv/lib/python3.12/site-packages (from matplotlib!=3.6.1,>=
3.4->seaborn) (0.12.1)
Requirement already satisfied: fonttools>=4.22.0 in /home/user/
labds/venv/lib/python3.12/site-packages (from matplotlib!=3.6.
1,>=3.4->seaborn) (4.53.1)
Requirement already satisfied: kiwisolver>=1.3.1 in /home/user/
labds/venv/lib/python3.12/site-packages (from matplotlib!=3.6.
1,>=3.4->seaborn) (1.4.5)
```

```
Requirement already satisfied: packaging>=20.0 in /home/user/la
bds/venv/lib/python3.12/site-packages (from matplotlib!=3.6.1,>
=3.4->seaborn) (24.1)
Requirement already satisfied: pillow>=8 in /home/user/labds/ve
nv/lib/python3.12/site-packages (from matplotlib!=3.6.1,>=3.4->
seaborn) (10.4.0)
Requirement already satisfied: pyparsing>=2.3.1 in /home/user/l
abds/venv/lib/python3.12/site-packages (from matplotlib!=3.6.1,
>=3.4->seaborn) (3.1.4)
Requirement already satisfied: python-dateutil>=2.7 in /home/us
er/labds/venv/lib/python3.12/site-packages (from matplotlib!=3.
6.1,>=3.4->seaborn) (2.9.0.post0)
Requirement already satisfied: pytz>=2020.1 in /home/user/labd
s/venv/lib/python3.12/site-packages (from pandas>=1.2->seaborn)
(2024.1)
Requirement already satisfied: tzdata>=2022.7 in /home/user/lab
ds/venv/lib/python3.12/site-packages (from pandas>=1.2->seabor
n) (2024.1)
Requirement already satisfied: six>=1.5 in /home/user/labds/ven
v/lib/python3.12/site-packages (from python-dateutil>=2.7->matp
lotlib!=3.6.1,>=3.4->seaborn) (1.16.0)
```

`seaborn`: installation

Import it:

In [38]:
```
import seaborn as sns
```

Some data to plot

In our examples, we reuse a few dummy datasets from `searbon`:

In [39]:
```
tips = sns.load_dataset("tips")
tips
```

Out[39]:

	total_bill	tip	sex	smoker	day	time	size
0	16.99	1.01	Female	No	Sun	Dinner	2
1	10.34	1.66	Male	No	Sun	Dinner	3
2	21.01	3.50	Male	No	Sun	Dinner	3
3	23.68	3.31	Male	No	Sun	Dinner	2
4	24.59	3.61	Female	No	Sun	Dinner	4
...	...	...	...	...	...	...	...
239	29.03	5.92	Male	No	Sat	Dinner	3
240	27.18	2.00	Female	Yes	Sat	Dinner	2
241	22.67	2.00	Male	Yes	Sat	Dinner	2
242	17.82	1.75	Male	No	Sat	Dinner	2
243	18.78	3.00	Female	No	Thur	Dinner	2

244 rows × 7 columns

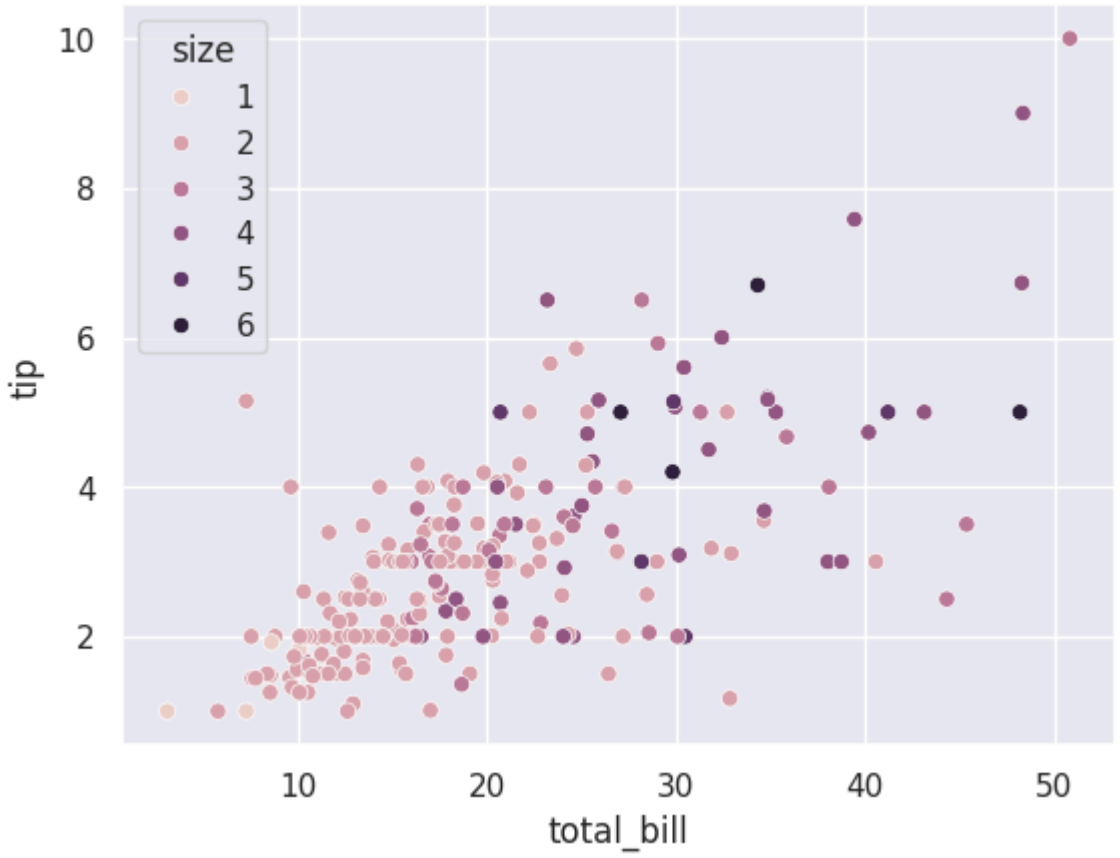
`seaborn` theme

We can use the `matplotlib` style from `seaborn`:

In [40]:
```
# Apply the default theme
sns.set_theme()
```

A nicer scatter plot

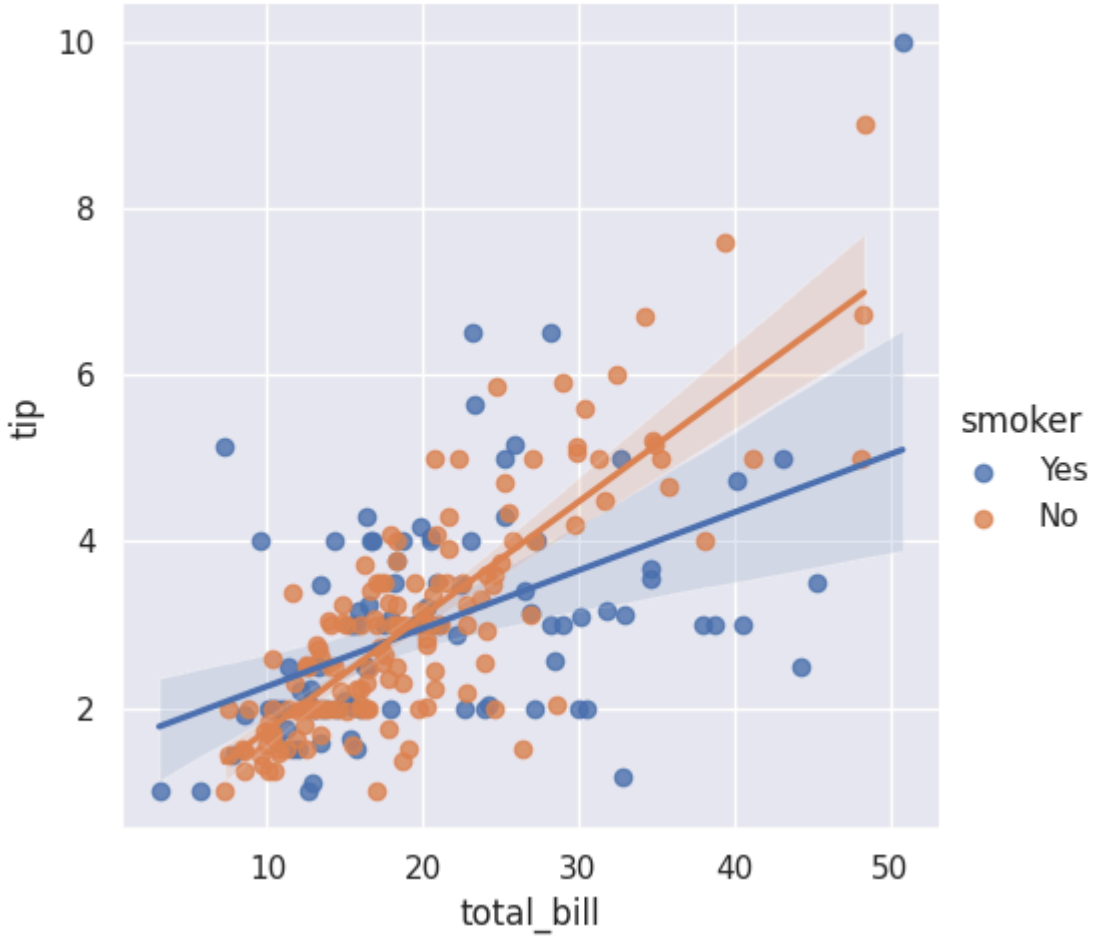
In [41]:
```
ax = sns.scatterplot(data=tips, x="total_bill", y="tip", hue="size")
```



See: `seaborn.scatterplot`

A nicer scatter plot with linear regression

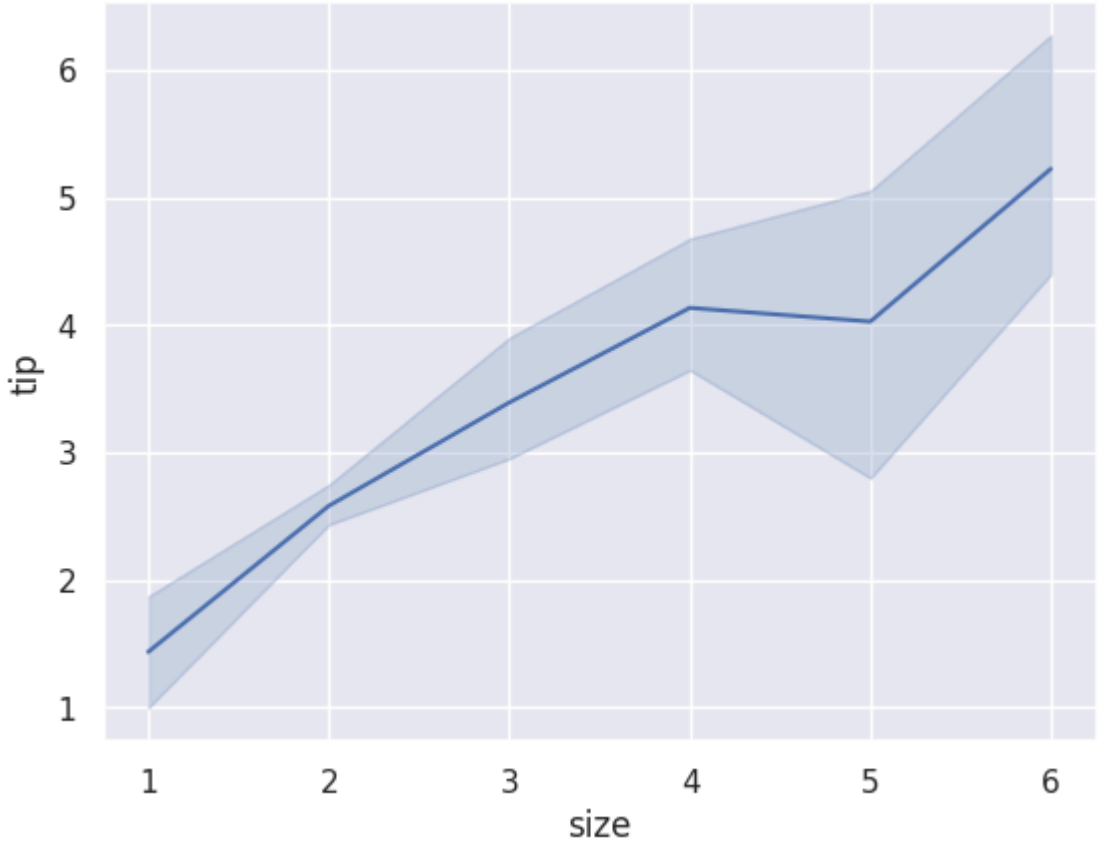
In [42]:
```
l = sns.lmplot(data=tips, x="total_bill", y="tip", hue="smoker")
```



See: `seaborn.lmplot`

A nicer line plot with confidence intervals

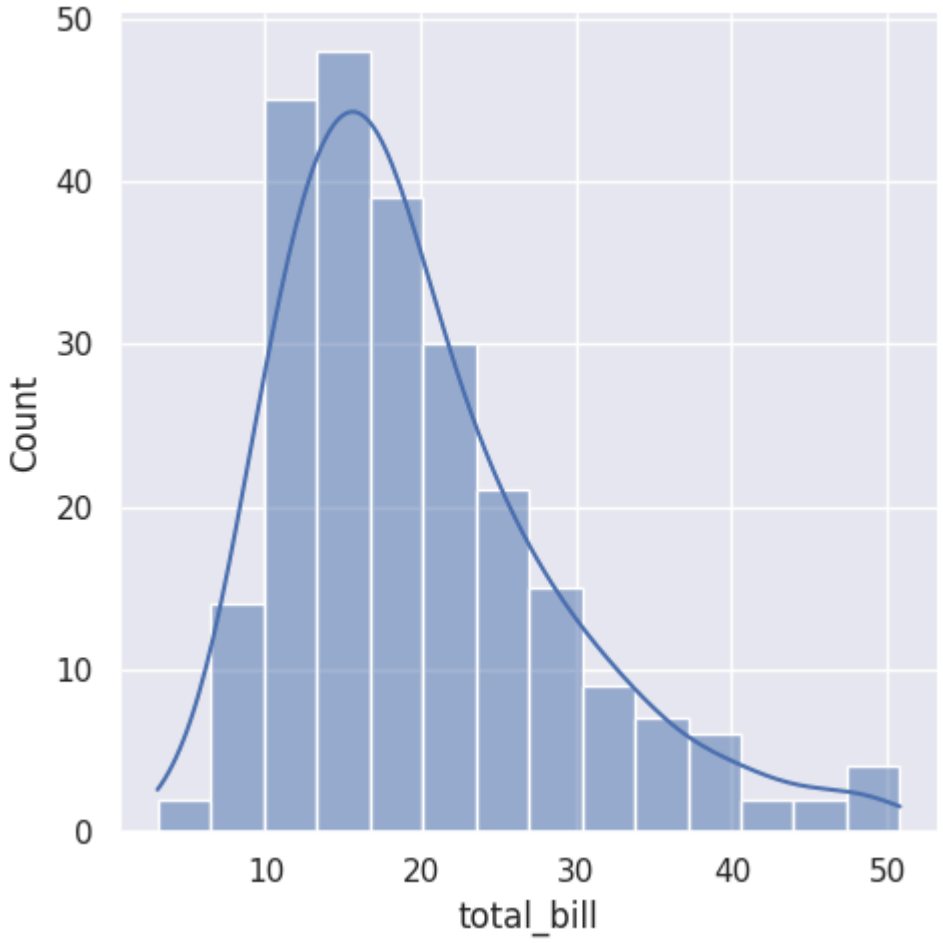
In [43]:
```
lines = sns.lineplot(data=tips, x="size", y="tip", errorbar="ci")
```



See: `seaborn.lineplot`

A nicer histogram

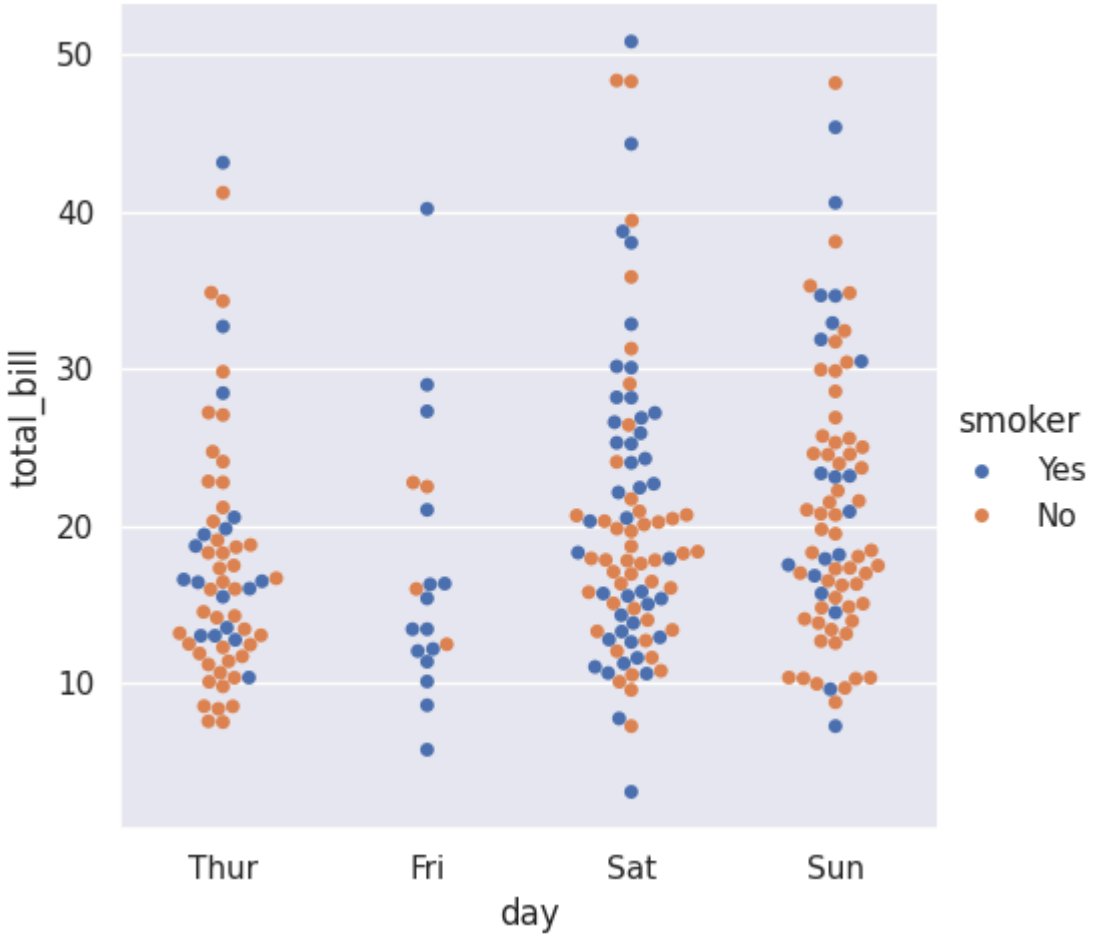
In [44]:
```
s = sns.displot(data=tips, x="total_bill", kde=True)
```



See: `seaborn.displot`

A nice categorical plot

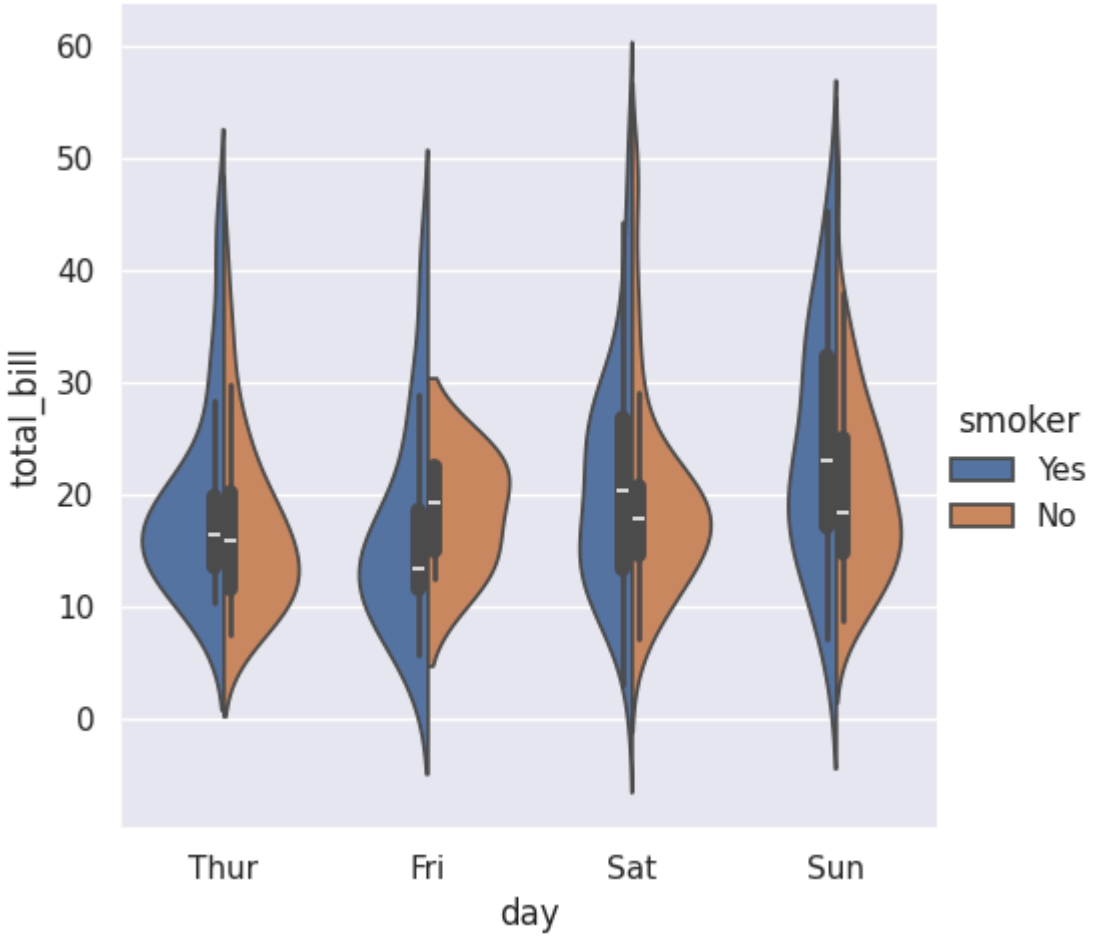
In [45]:
```
s = sns.catplot(data=tips, kind="swarm", x="day", y="total_bill", hue="
```



See: `seaborn.catplot`

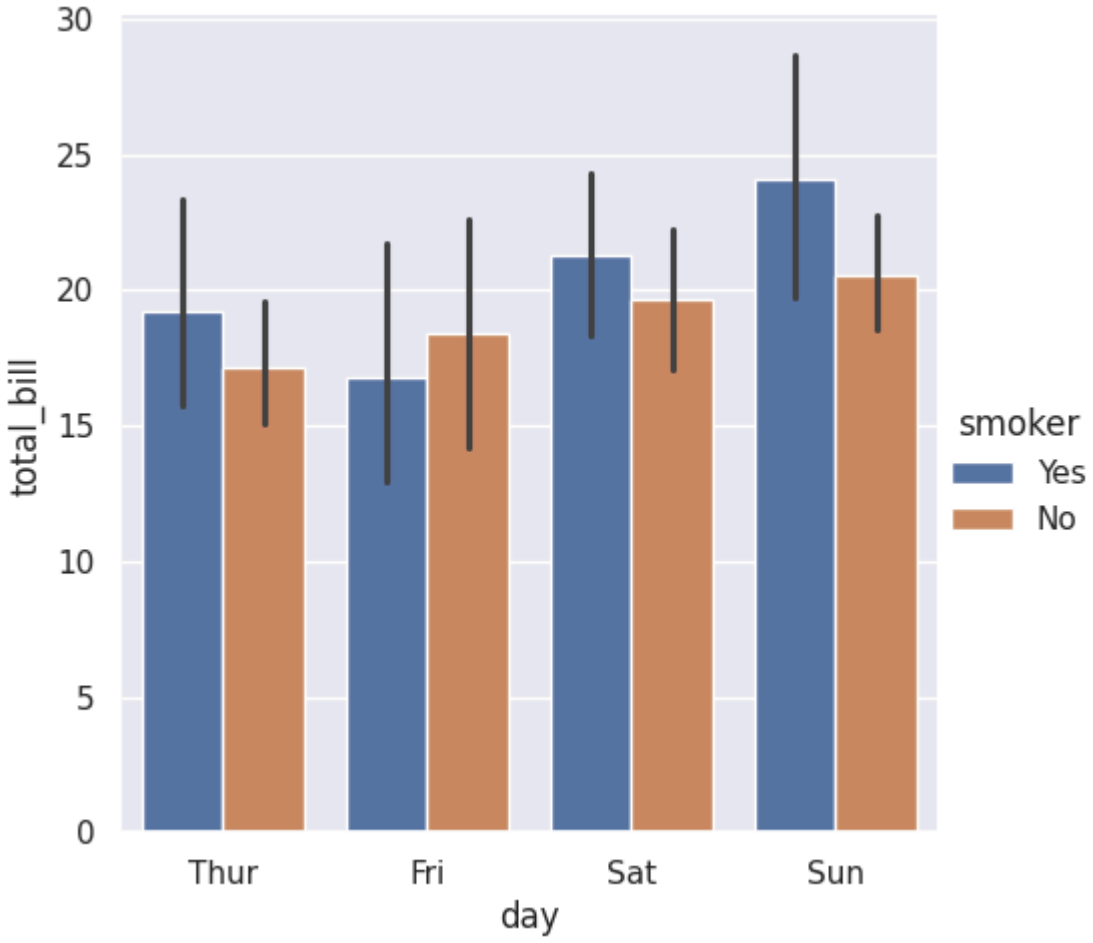
A nice categorical plot with violins

In [46]:
```
s = sns.catplot(data=tips, kind="violin", x="day", y="total_bill", hue=
```



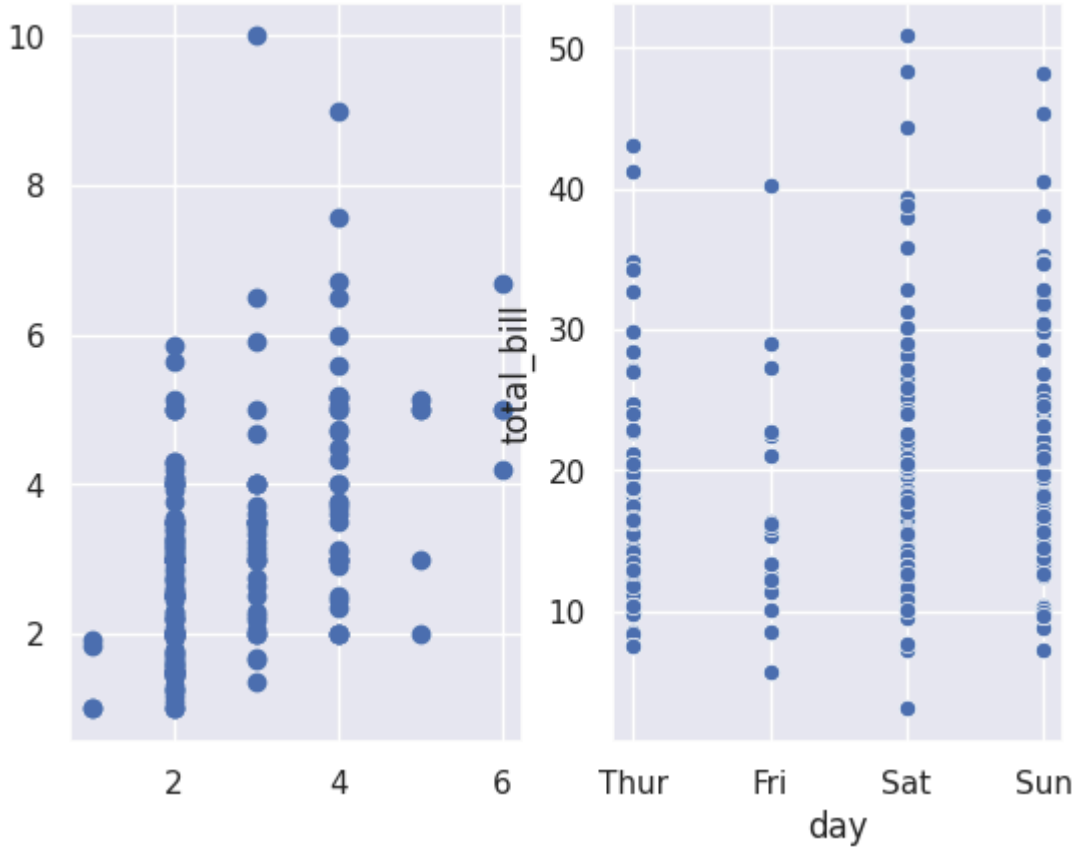
A nice barplot plot with errorbars

In [47]:
```
s = sns.catplot(data=tips, kind="bar", x="day", y="total_bill", hue="sm
```



Combine `matplotlib` and `seaborn` plots

In [48]:
```
fix, axes = plt.subplots(1, 2)
axes[0].scatter(tips['size'].values, tips.tip.values)
s = sns.scatterplot(data=tips, x="day", y="total_bill", ax=axes[1])
```

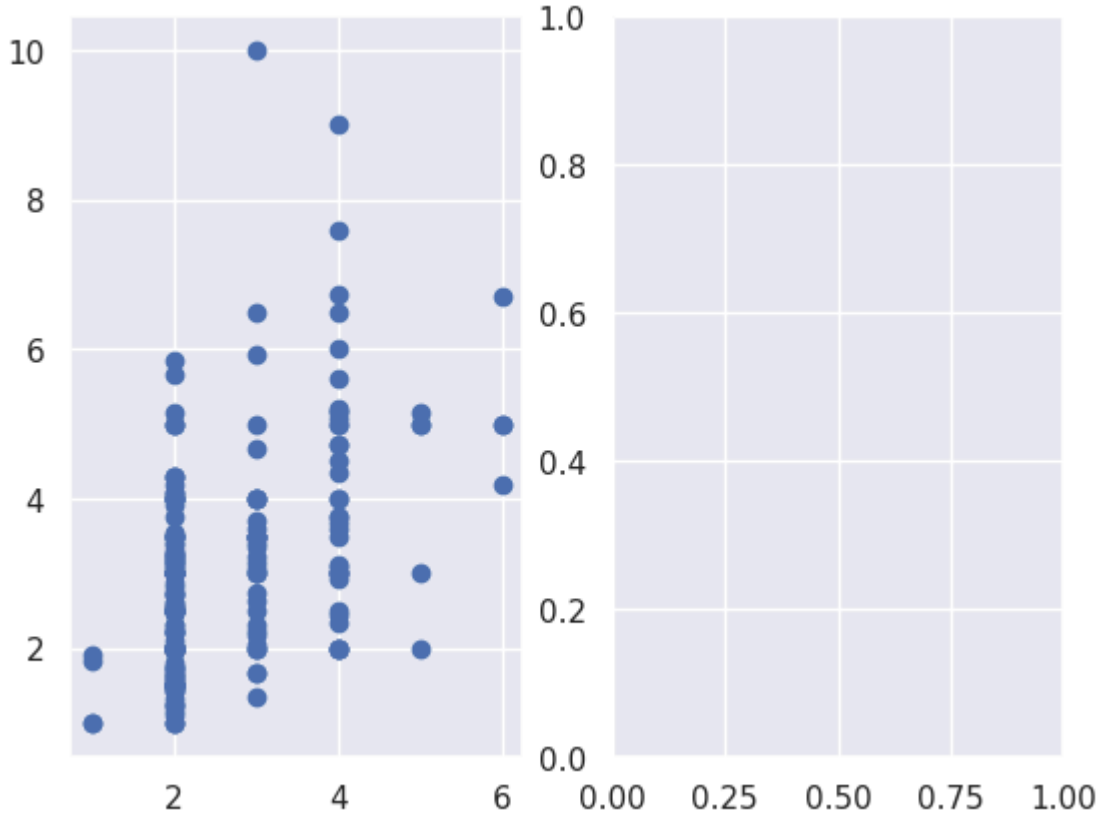


Combine `matplotlib` and `seaborn` plots (cont'd)

Unfortunately, some `seaborn` plots cannot be mixed with `matplotlib` plots within the same figure. Indeed, such plots are dubbed *figure-level*. For instance, `catplot` is figure-level and the following code will generate two distinct figures:

In [49]:
```
fix, axes = plt.subplots(1, 2)
axes[0].scatter(tips['size'].values, tips.tip.values)
s = sns.catplot(data=tips, x="day", y="total_bill", ax=axes[1])
```

```
/home/user/labds/venv/lib/python3.12/site-packages/seaborn/cate
gorical.py:2761: UserWarning: catplot is a figure-level functio
n and does not accept target axes. You may wish to try stripplo
t
  warnings.warn(msg, UserWarning)
```


10
8
6
4
2
1.0
0.8
0.6
0.4
0.2
0.0
2
4
6
0.00
0.25
0.50
0.75
1.00

Documentation

- **Tutorial**: https://seaborn.pydata.org/tutorial.html
- **API**: https://seaborn.pydata.org/api.html