Working with 2D arrays

Reminder: NumPy arrays

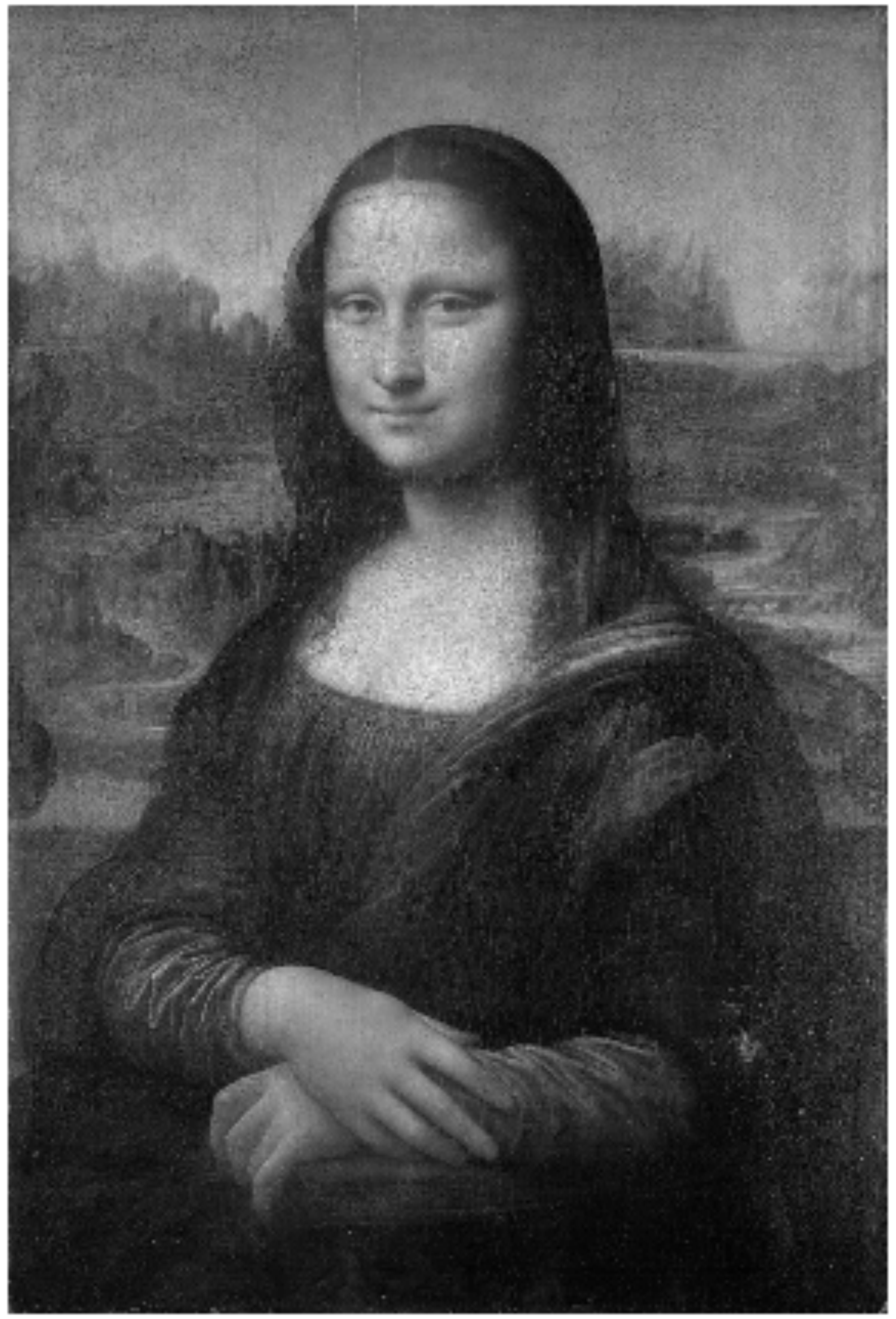
- Homogeneous in type
- Calculations all at once
- Indexing with brackets:
    - A[*index*] for 1D array
    - A[*index0*, *index1*] for 2D array

Reminder: slicing arrays

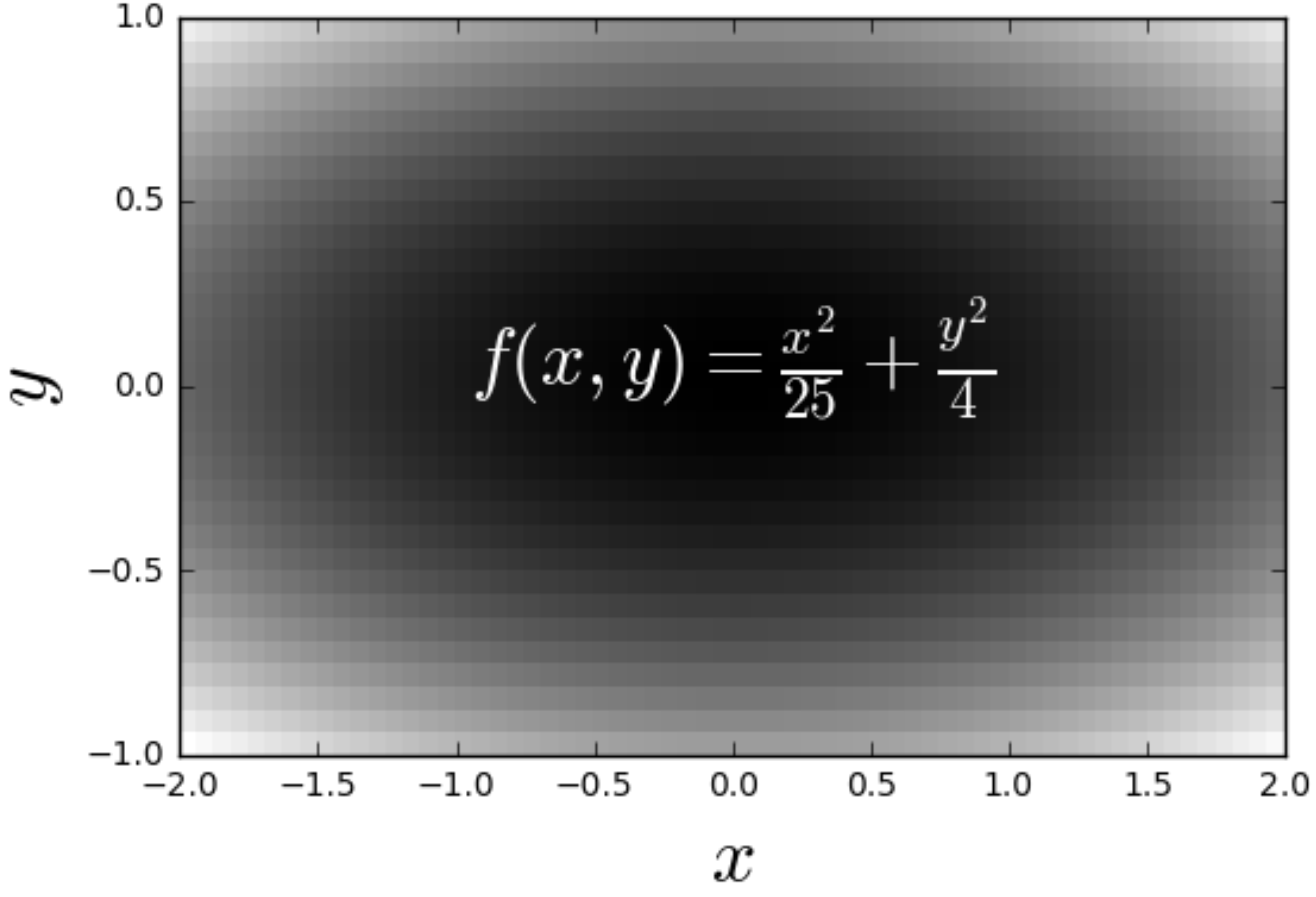
- Slicing: 1D arrays: A[*slice*], 2D arrays: A[*slice0*, *slice1*]
- Slicing: *slice* = *start:stop:stride*
    - Indexes from *start* to *stop-1* in steps of *stride*
    - Missing *start*: implicitly at *beginning* of array
    - Missing *stop*: implicitly at *end* of array
    - Missing *stride*: implicitly *stride 1*
- Negative indexes/slices: count from *end of array*

2D arrays & images

0.434	0.339	0.337	0.367	...
0.434	0.421	0.404	0.395	...
0.350	0.388	0.340	0.340	...
0.328	0.384	0.308	0.308	...
...	...	...	...	...



2D arrays & functions



Using meshgrid()

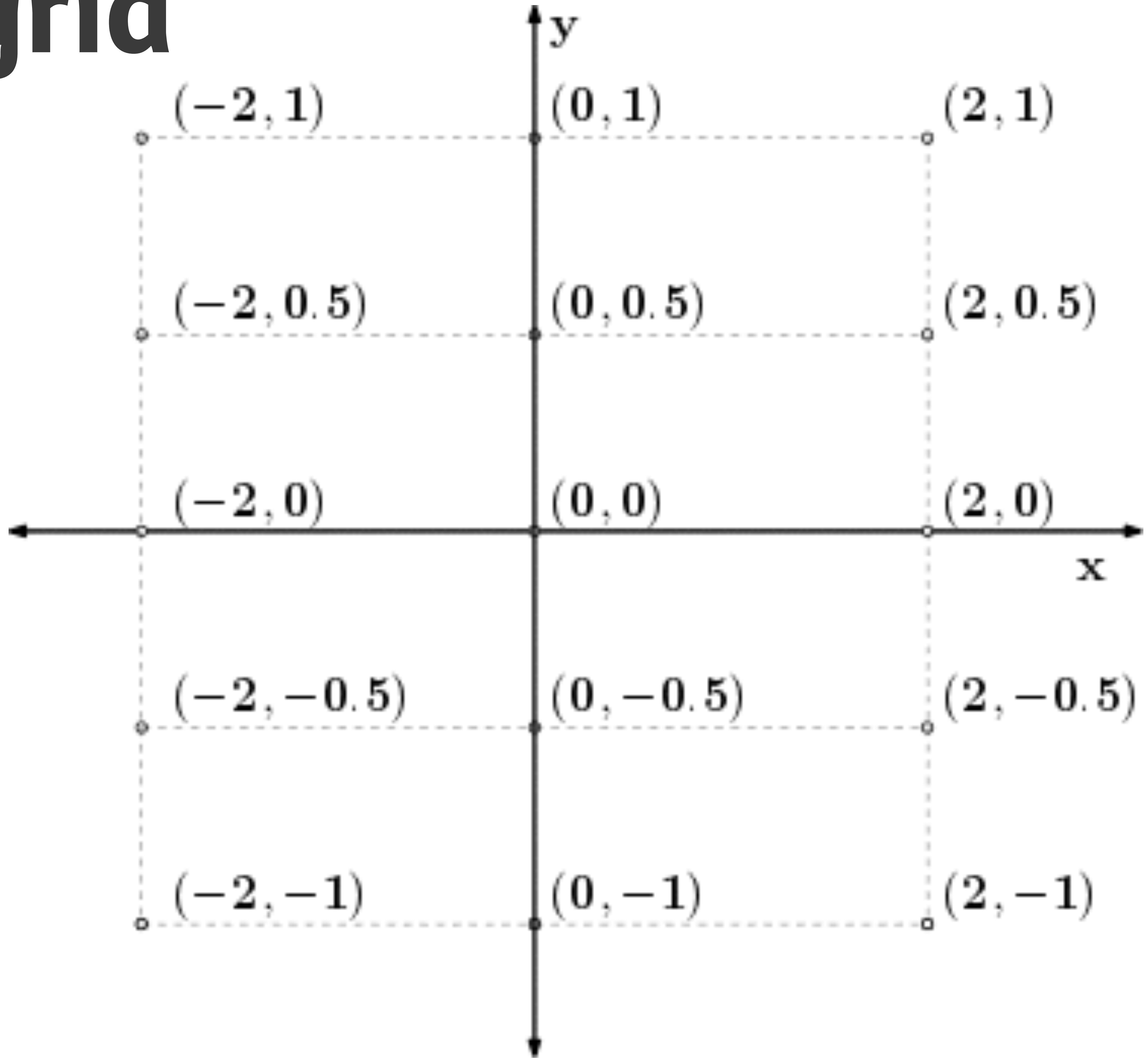
meshgrids.py

```
import numpy as np

u = np.linspace(-2, 2, 3)

v = np.linspace(-1, 1, 5)

X,Y = np.meshgrid(u, v)

Z = X**2/25 + Y**2/4
```

Using meshgrid()

```
X:
 [[-2.  0.  2.]
 [-2.  0.  2.]
 [-2.  0.  2.]
 [-2.  0.  2.]
 [-2.  0.  2.]]

Y:
[[-1.  -1.  -1. ]
 [-0.5 -0.5 -0.5]
 [ 0.   0.   0. ]
 [ 0.5  0.5  0.5]
 [ 1.   1.   1. ]]
```

Meshgrid



Sampling on a grid

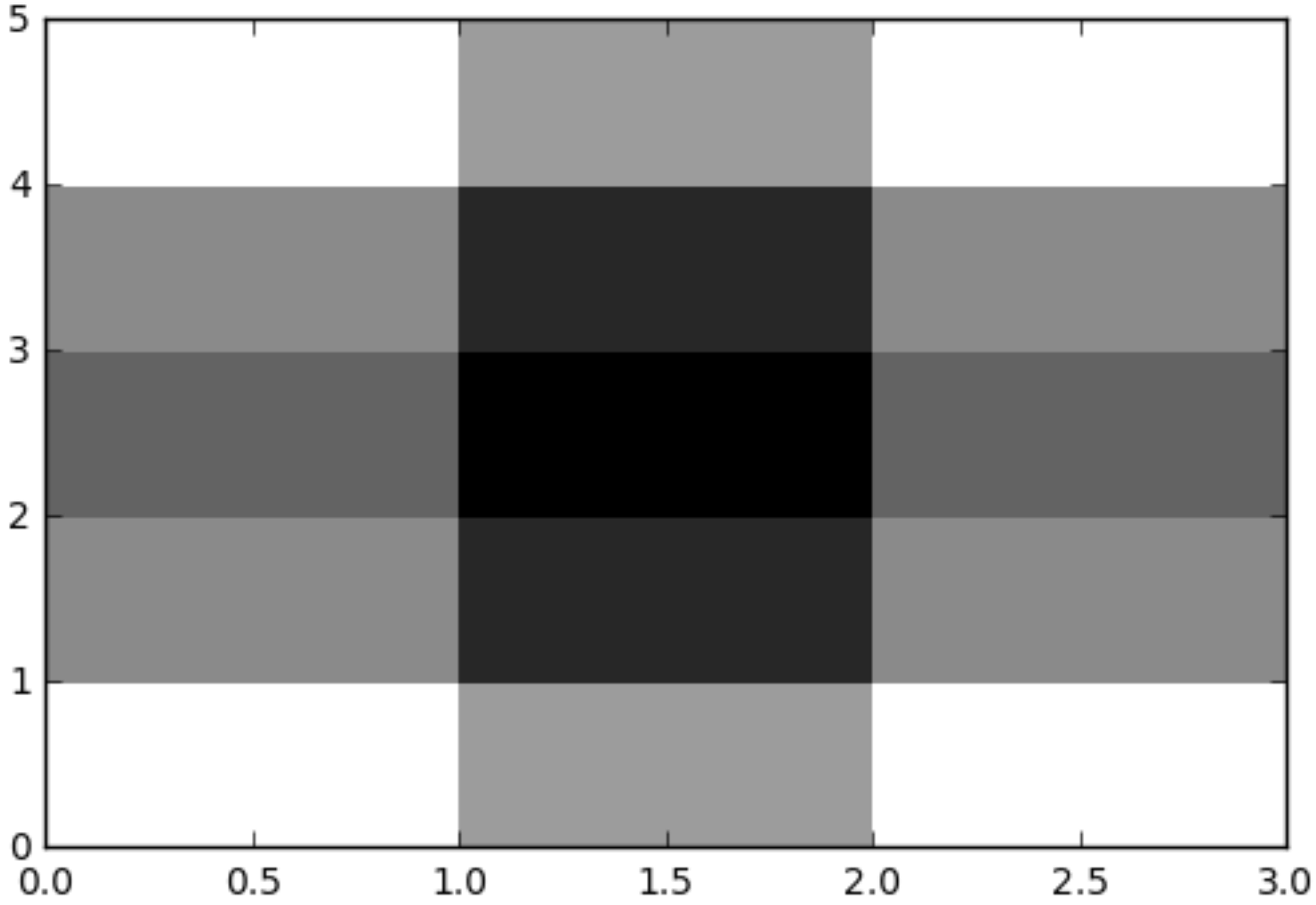
meshgrids.py

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

u = np.linspace(-2, 2, 3)
v = np.linspace(-1, 1, 5)
X,Y = np.meshgrid(u, v)
Z = X**2/25 + Y**2/4

print('Z:\n', Z)
plt.set_cmap('gray')
plt.pcolor(Z)
plt.show()
```

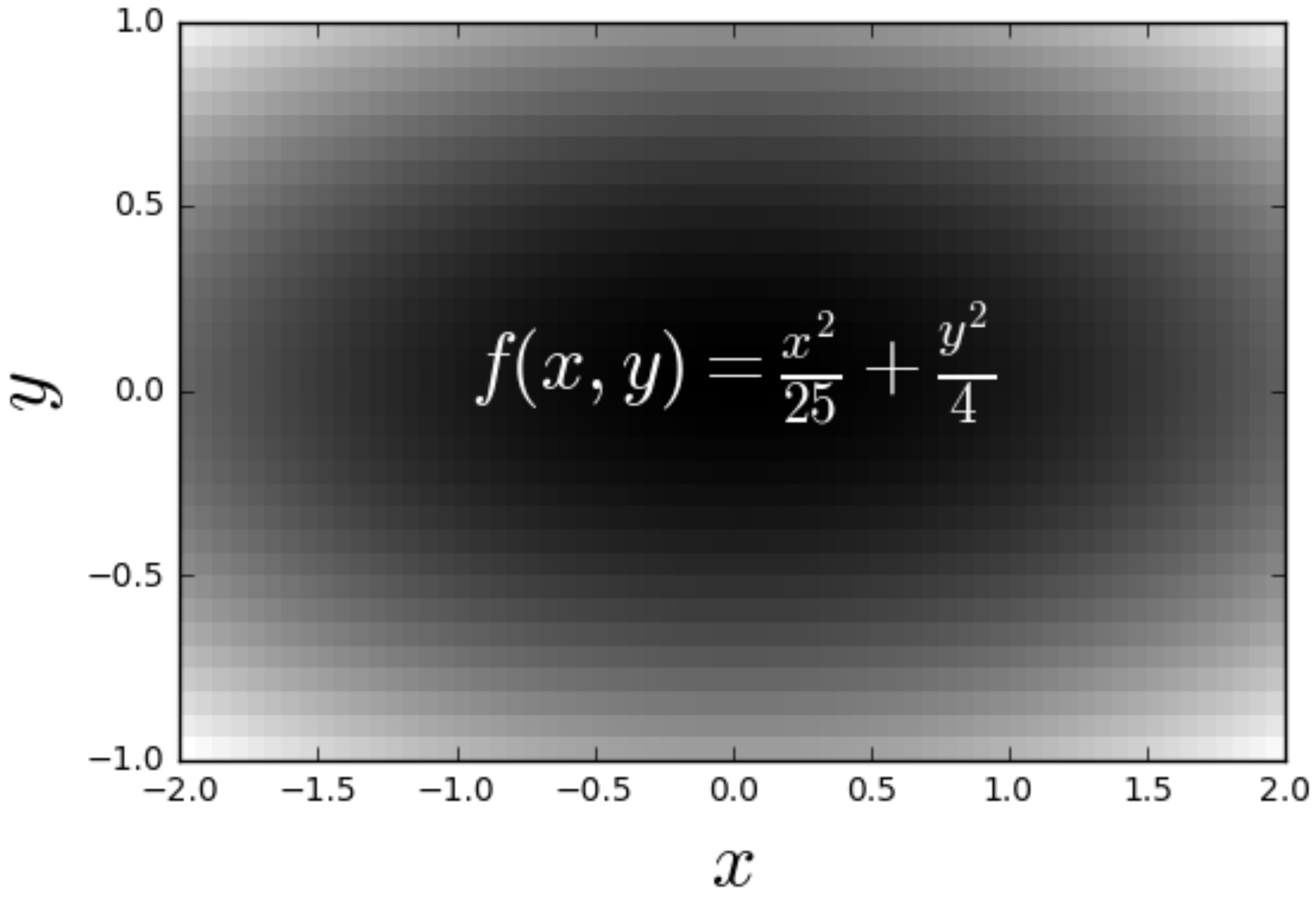
Sampling on a grid

```
Z:
 [[ 0.41    0.25    0.41   ]
 [ 0.2225  0.0625  0.2225]
 [ 0.16    0.      0.16   ]
 [ 0.2225  0.0625  0.2225]
 [ 0.41    0.25    0.41   ]]
```

Sampling on a grid



Sampling on a grid



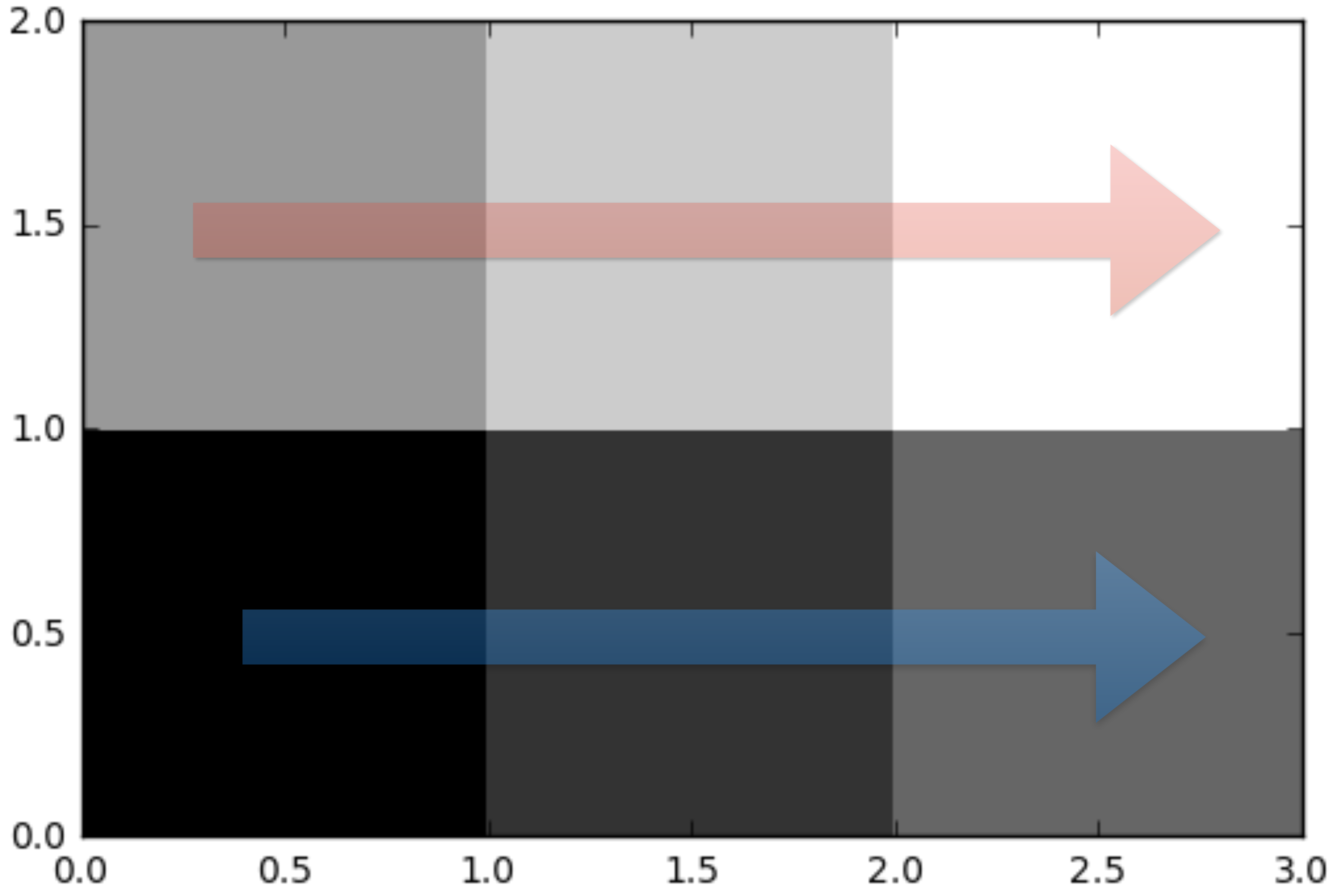
Orientations of 2D arrays & images

orientation.py

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

Z = np.array([[1, 2, 3], [4, 5, 6]])
print('Z:\n', z)

plt.pcolor(Z)
plt.show()
```

Orientations of 2D arrays & images

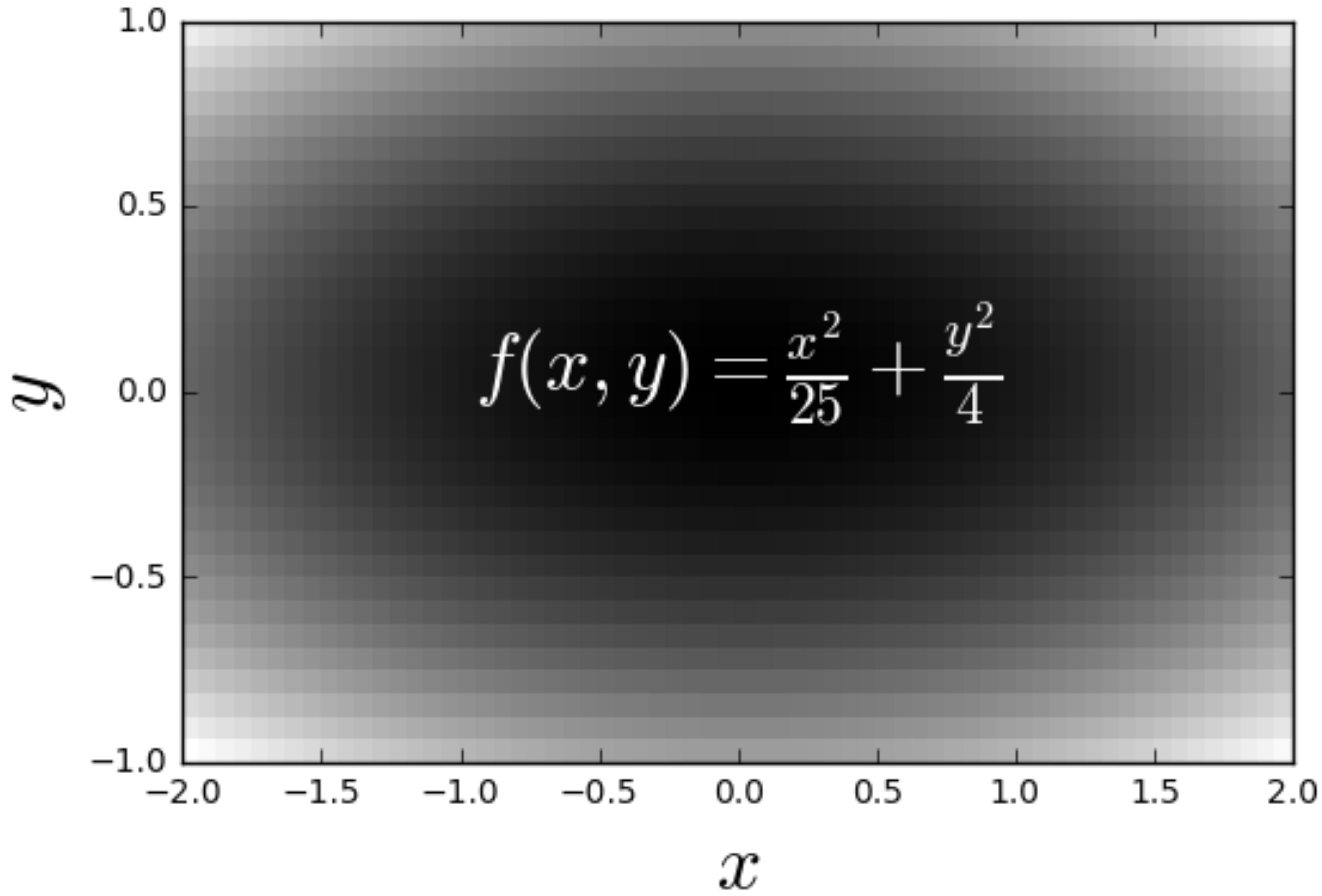
```
Output:
Z:
[[1 2 3]
 [4 5 6]]
```



Let's practice!

Visualizing bivariate functions

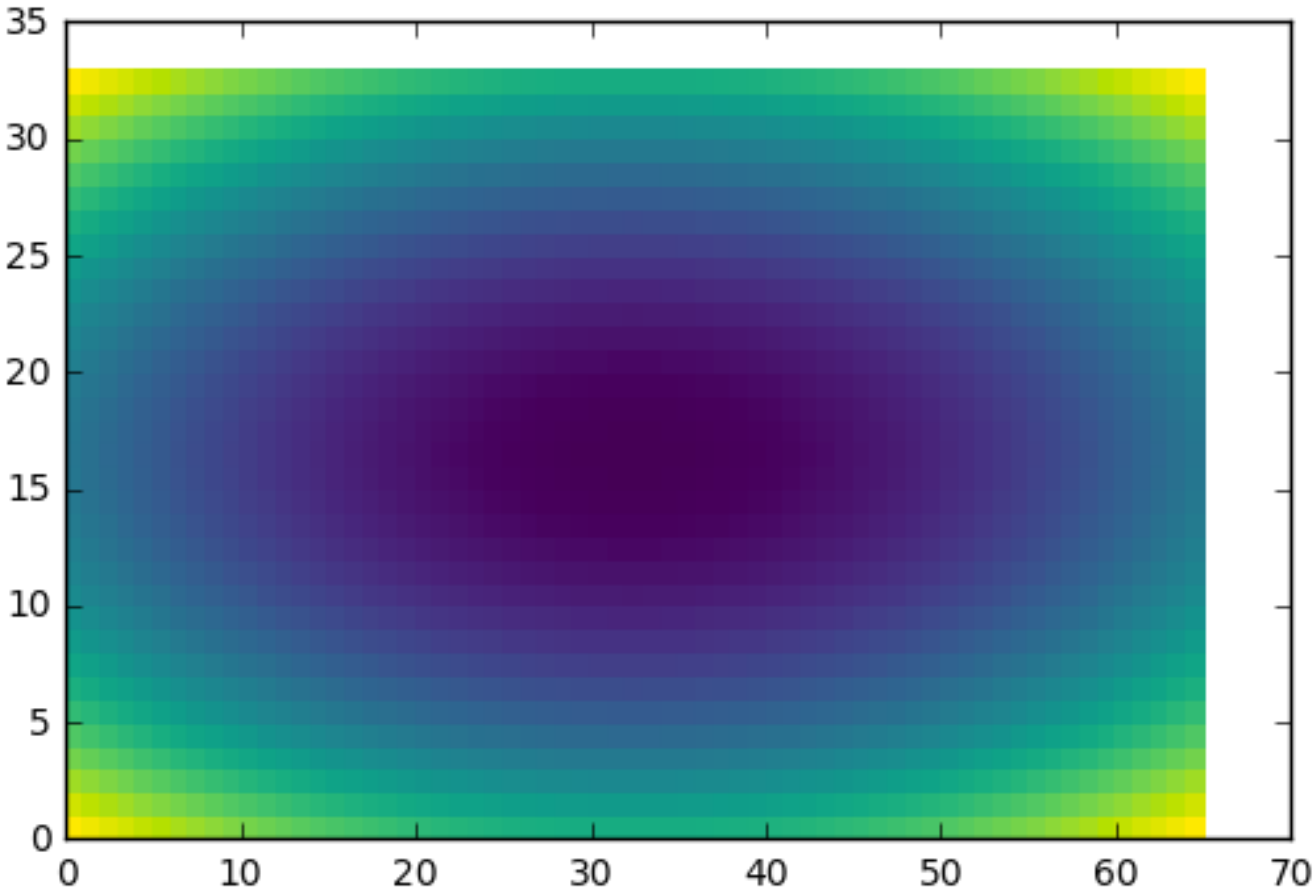
Bivariate functions



Pseudocolor plot

```
In [1]: import numpy as np

In [2]: import matplotlib.pyplot as plt

In [3]: u = np.linspace(-2, 2, 65)

In [4]: v = np.linspace(-1, 1, 33)

In [5]: X,Y = np.meshgrid(u, v)

In [6]: Z = X**2/25 + Y**2/4

In [7]: plt.pcolor(Z)

In [8]: plt.show()
```

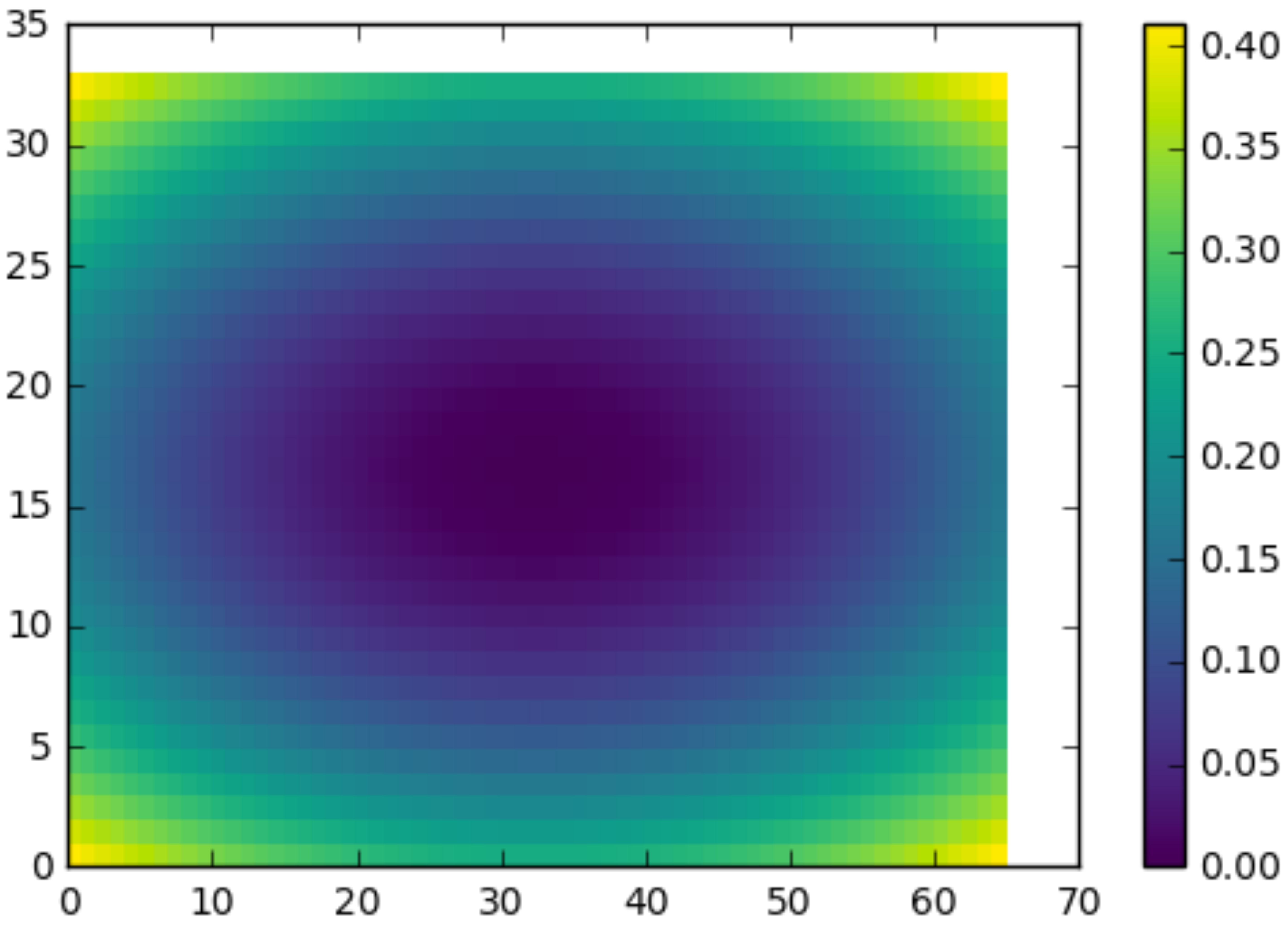
Pseudocolor plot



Color bar

```
In [9]: plt.pcolor(Z)

In [10]: plt.colorbar()

In [11]: plt.show()
```

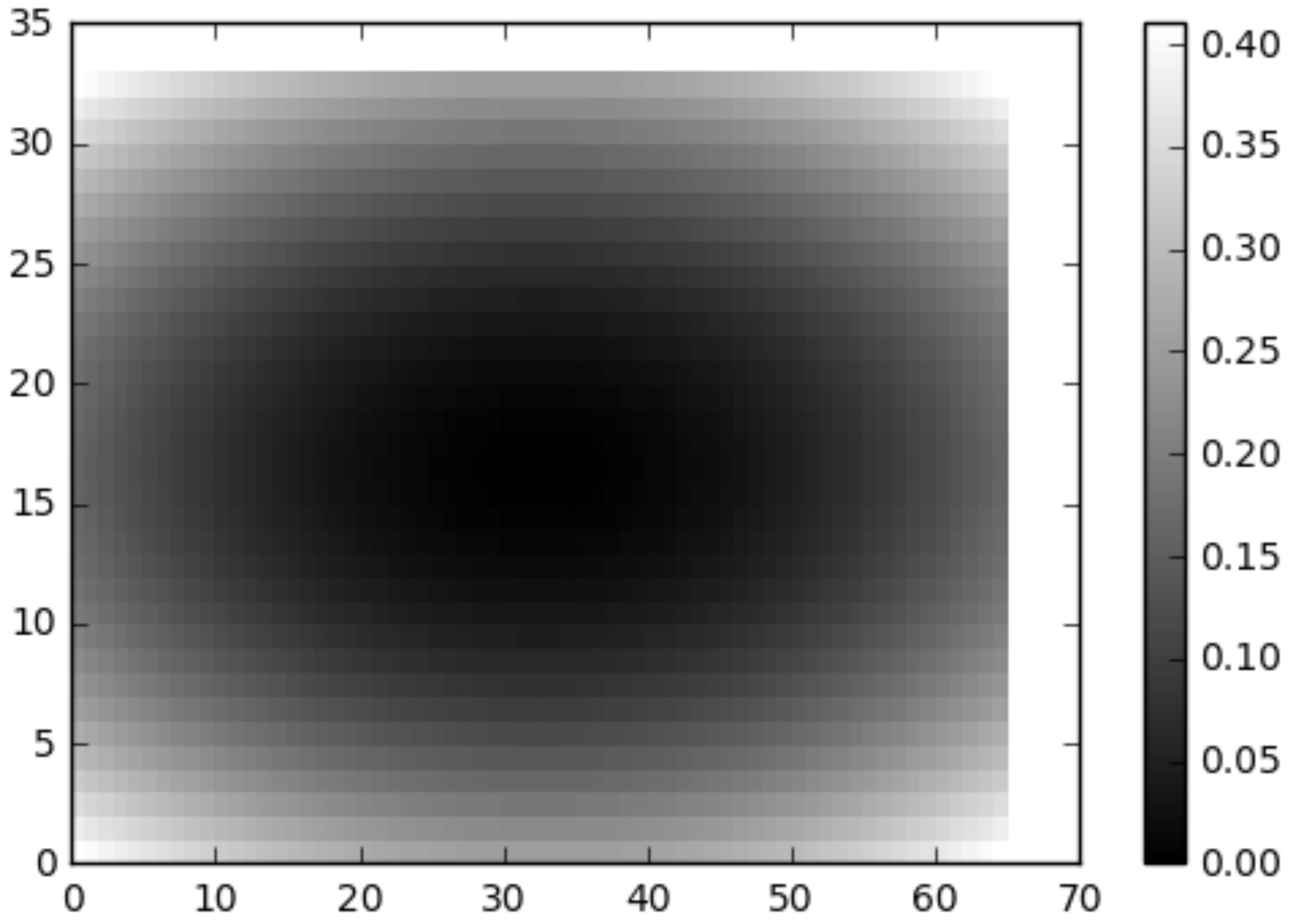
Color bar


35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

Color map

```
In [12]: plt.pcolor(Z, cmap= 'gray')

In [13]: plt.colorbar()

In [14]: plt.show()
```

Color map

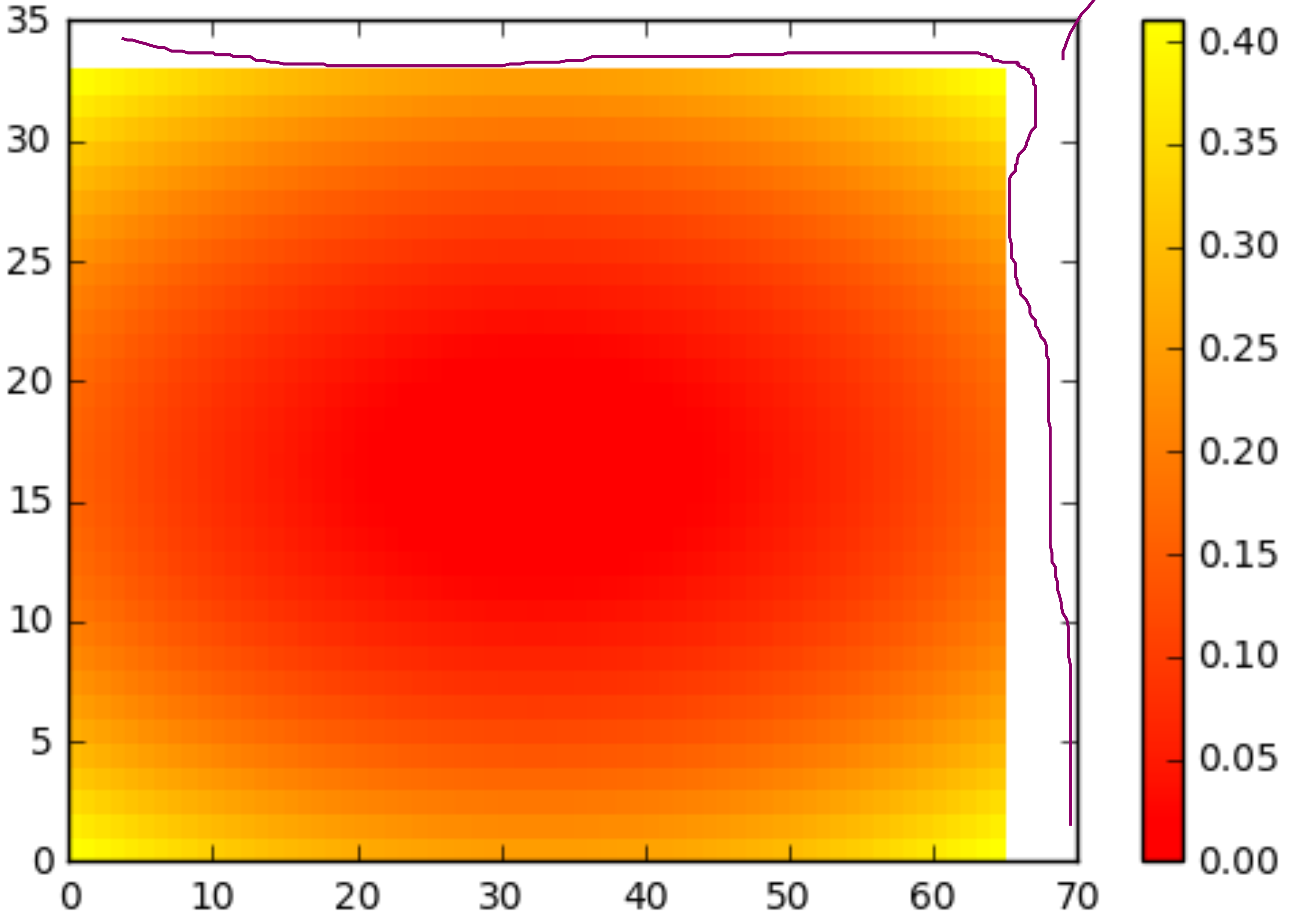

35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

Color map

```
In [15]: plt.pcolor(Z, cmap= 'autumn')

In [16]: plt.colorbar()

In [17]: plt.show()
```

Color map

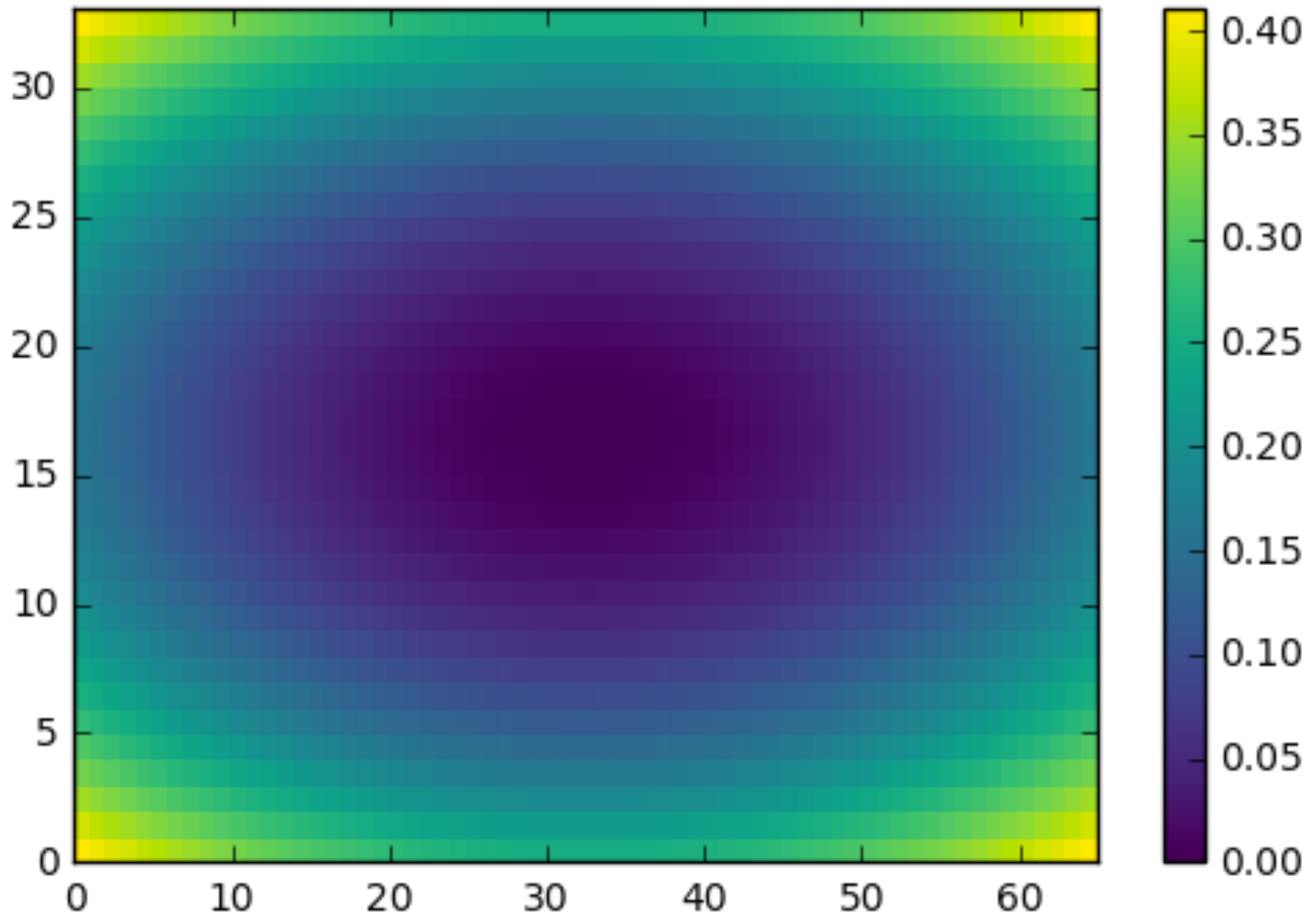
white space



Axis tight

```
In [18]: plt.pcolor(Z)

In [19]: plt.colorbar()

In [20]: plt.axis('tight')

In [21]: plt.show()
```

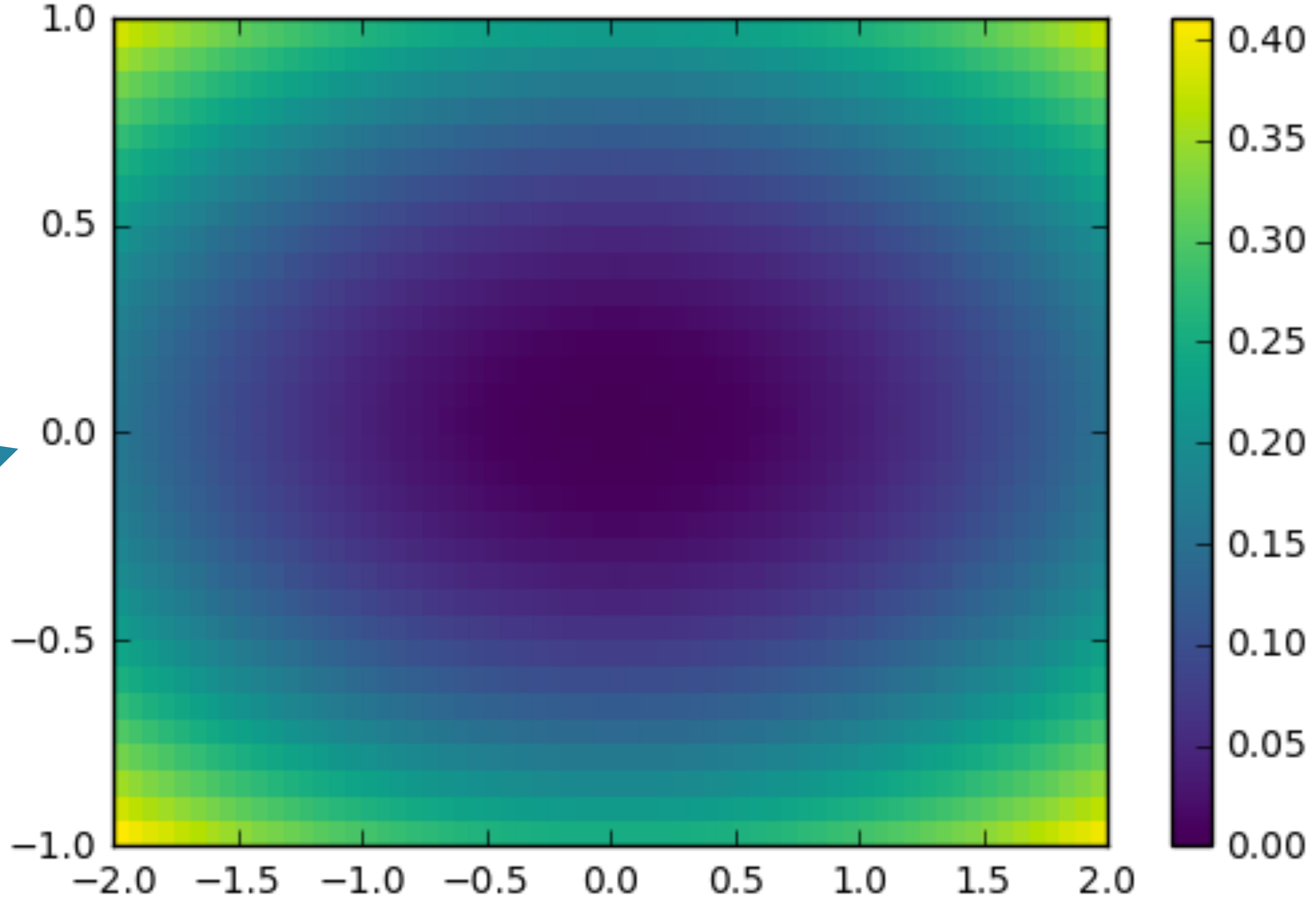
Axis tight


30
25
20
15
10
5
0
0
10
20
30
40
50
60
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00

Plot using mesh grid

```
In [22]: plt.pcolor(X, Y, Z) # X, Y are 2D meshgrid

In [23]: plt.colorbar()

In [24]: plt.show()
```

Plot using mesh grid

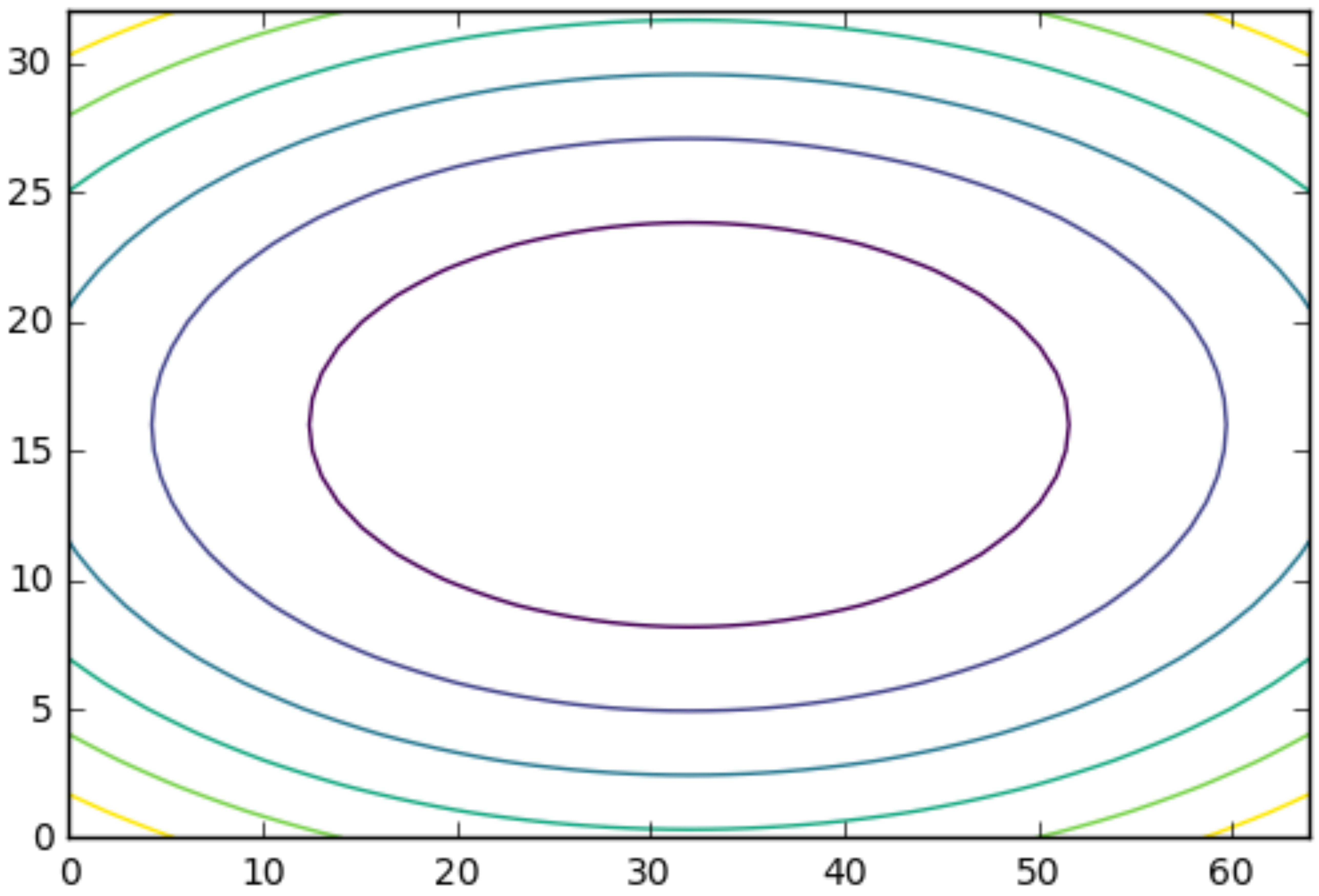


Axes determined by mesh grid arrays X, Y

Contour plots

```
In [25]: plt.contour(Z)

In [26]: plt.show()
```

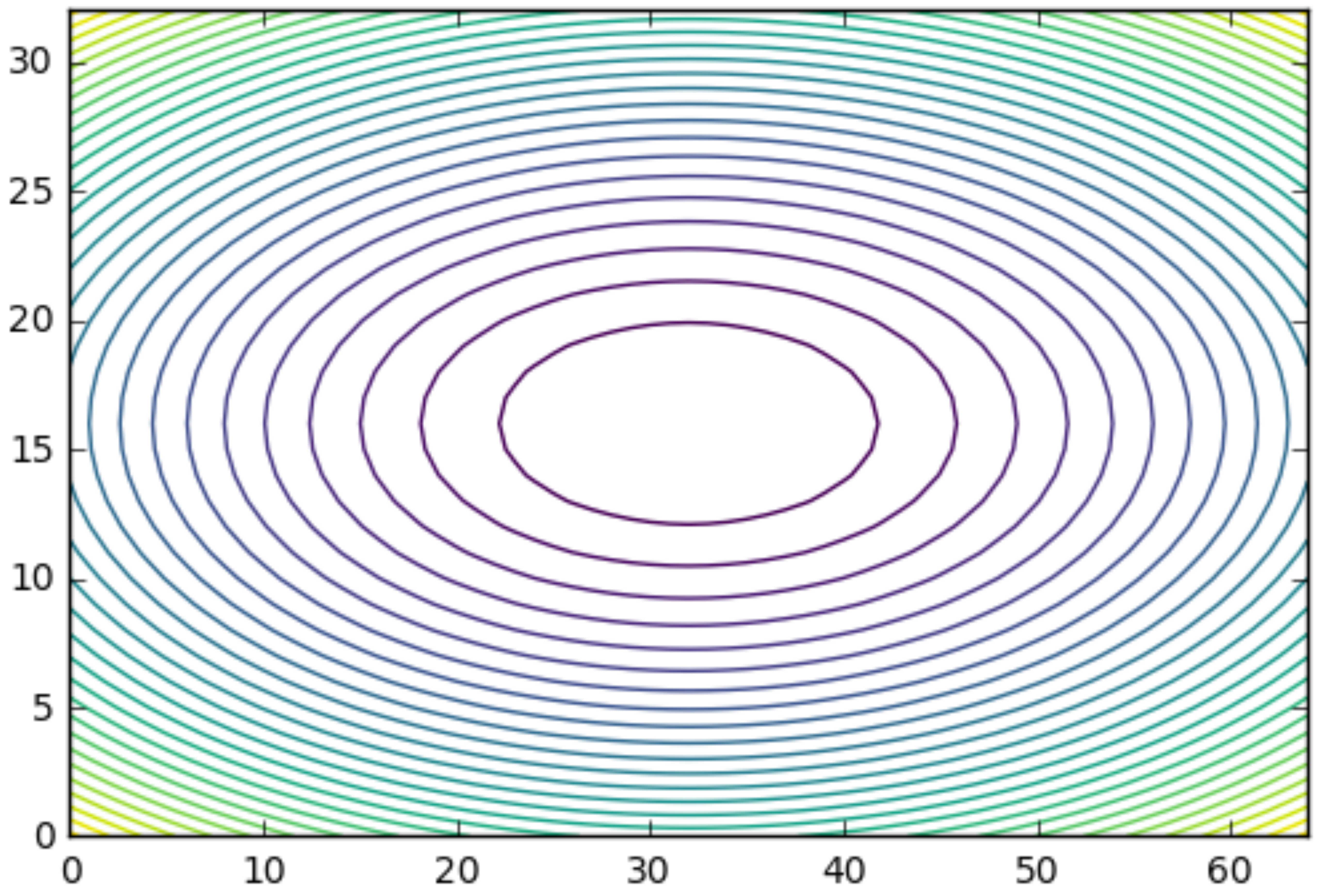
Contour plots



More contours

```
In [27]: plt.contour(Z, 30)

In [28]: plt.show()
```

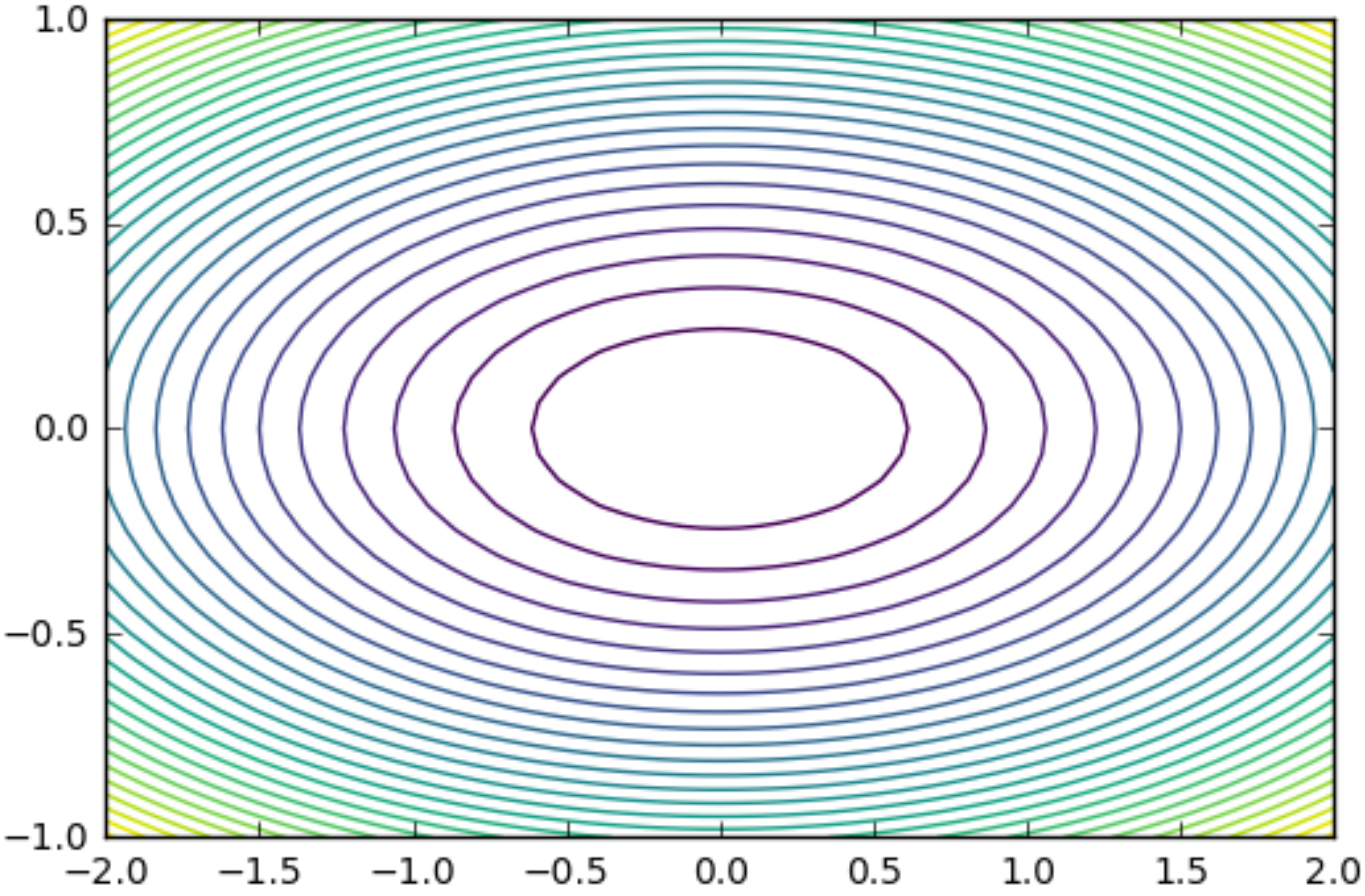
More contours



Contour plot using meshgrid

```
In [29]: plt.contour(X, Y, Z, 30)

In [30]: plt.show()
```

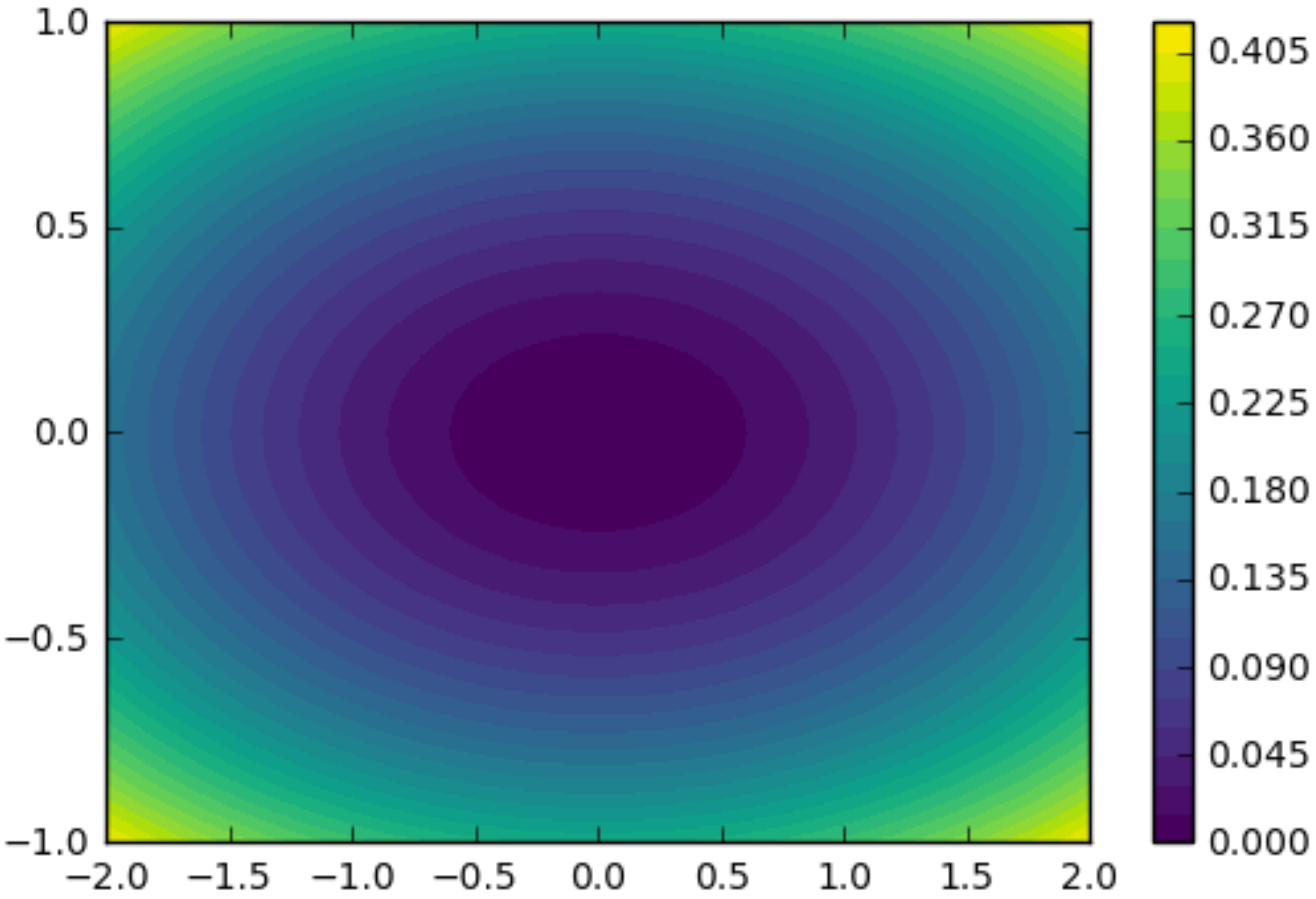
Contour plot using meshgrid



Filled contour plots

```
In [31]: plt.contourf(X, Y, Z, 30)

In [32]: plt.colorbar()

In [33]: plt.show()
```

Filled contour plots



More information

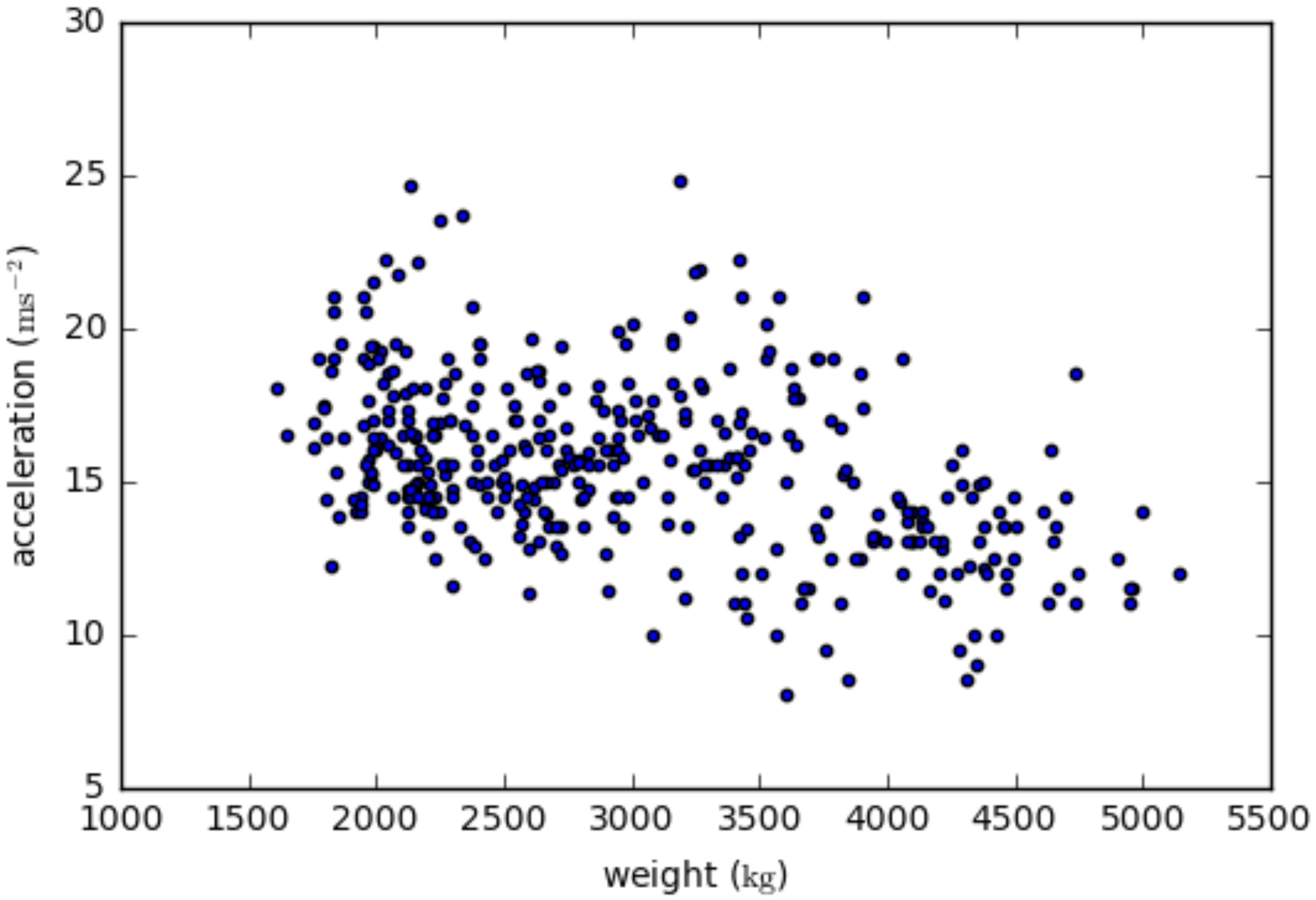
- API has many (optional) keyword arguments
- More in matplotlib.pyplot documentation
- More examples: http://matplotlib.org/gallery.html

Let's practice!

Visualizing bivariate distributions

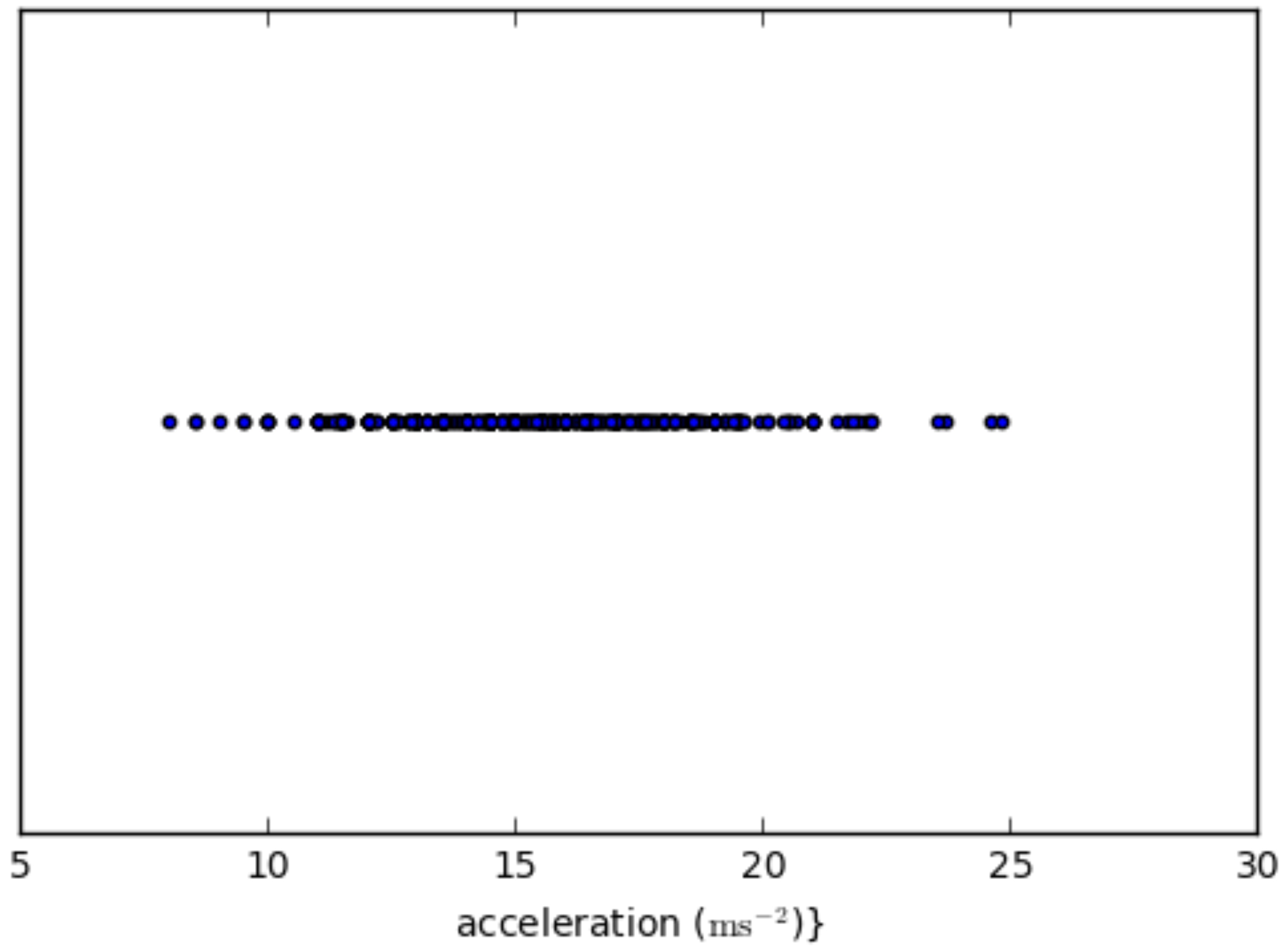
Distributions of 2D points

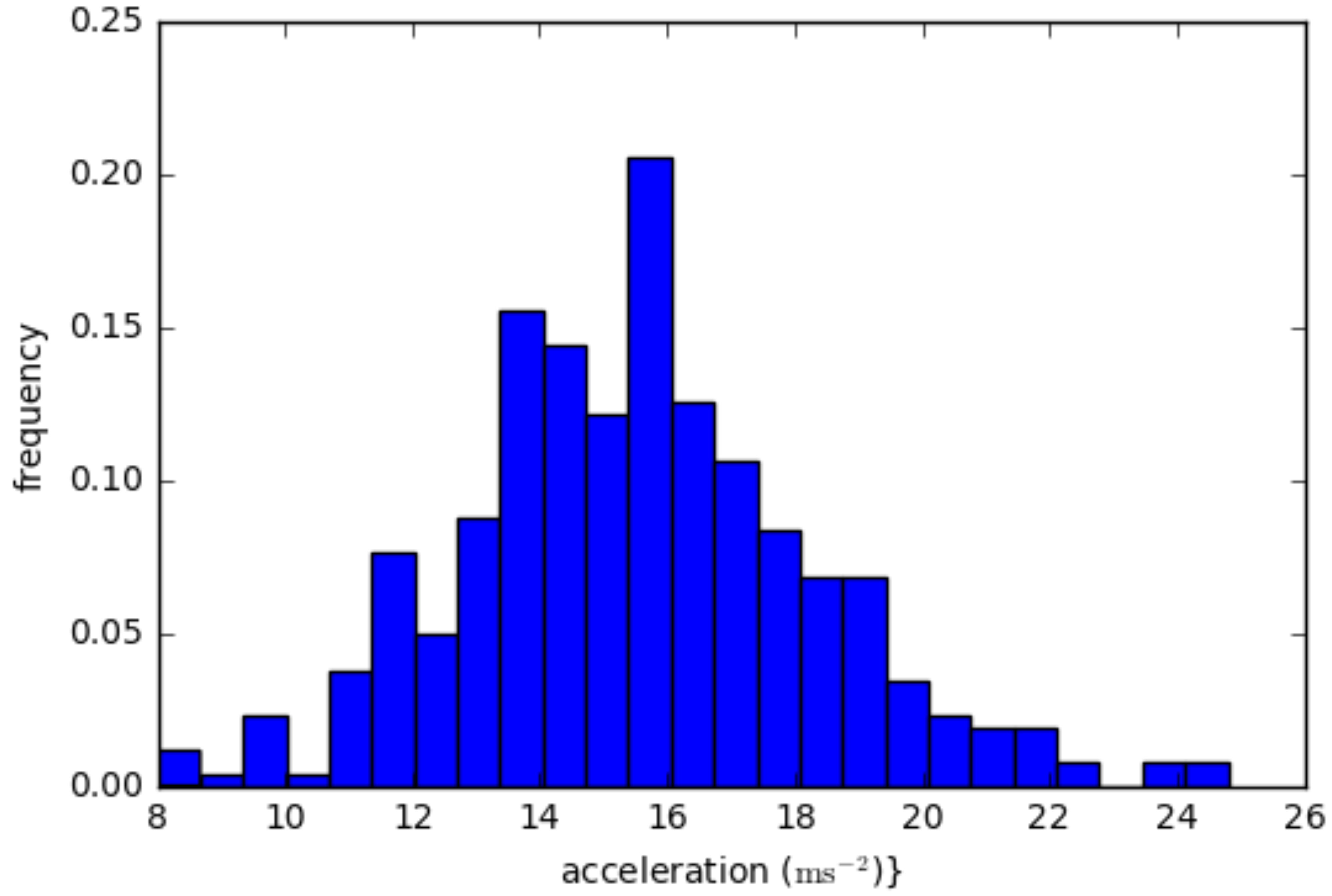
- 2D points given as two 1D arrays x & y
- Goal: generate a 2D histogram from x & y



Histograms in 1D

- Choose bins (intervals)
- Count realizations within bins & plot



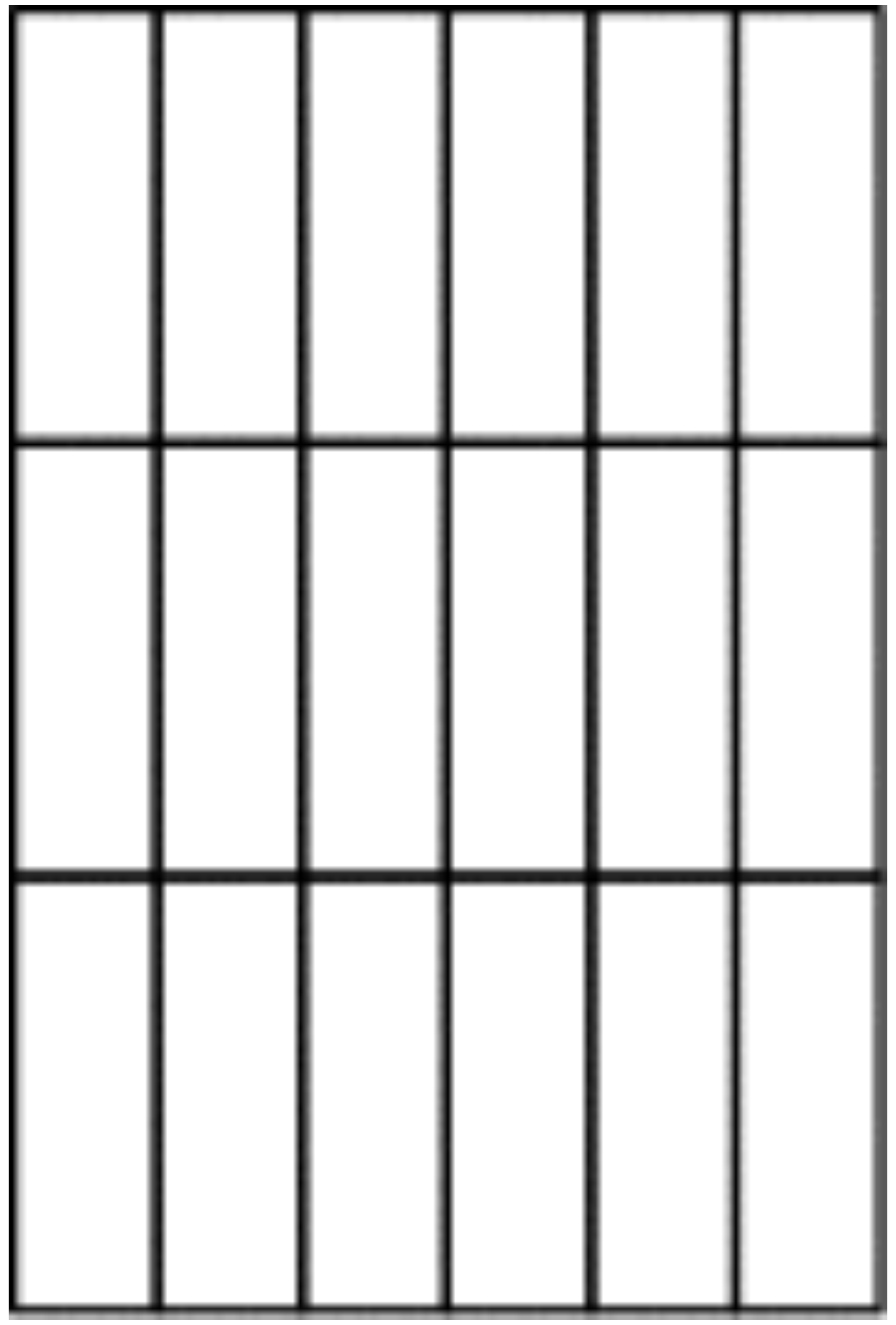


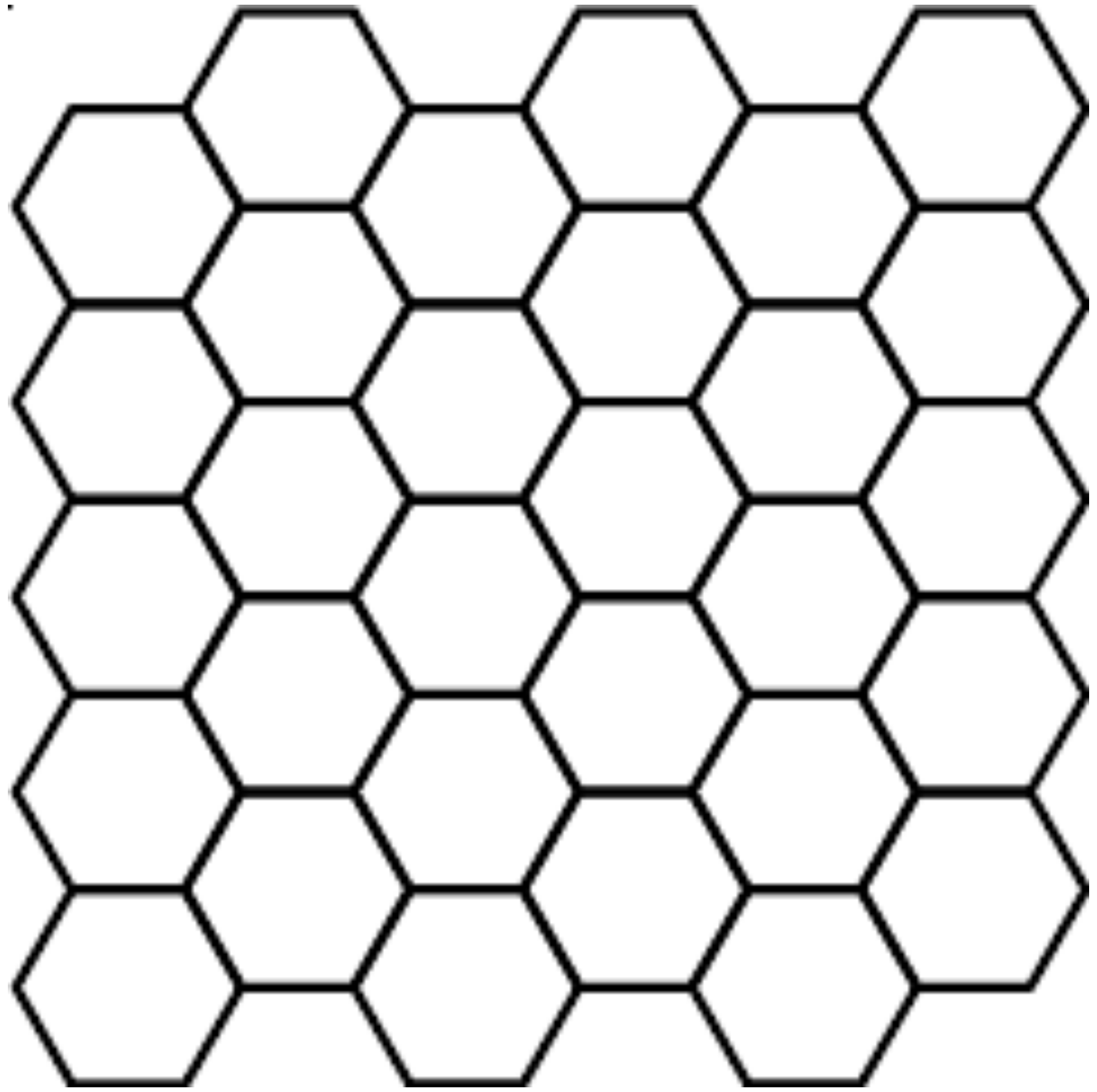
Histograms in 1D

```
In [1]: counts, bins, patches = plt.hist(x, bins=25)

In [2]: plt.show()
```

Bins in 2D

- Different shapes available for binning points
- Common choices: rectangles & hexagons

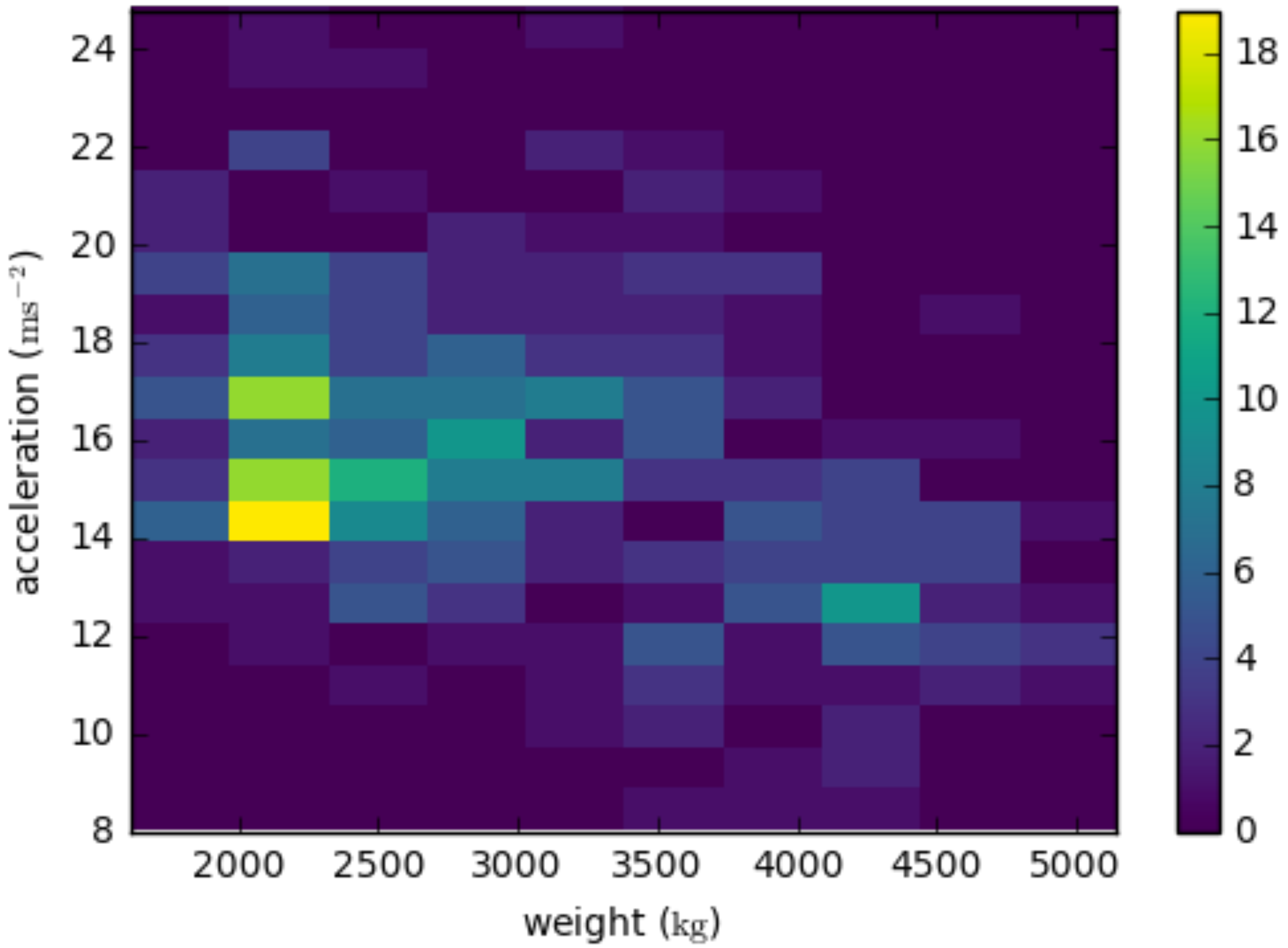




hist2d(): Rectangular binning

```
In [1]: plt.hist2d(x, y, bins=(10, 20)) # x & y are 1D arrays of
   ...: same length

In [2]: plt.colorbar()

In [3]: plt.xlabel('weight ($\mathrm{kg}$)')

In [4]: plt.ylabel('acceleration ($\mathrm{ms}^{-2}$)}')

In [5]: plt.show()
```

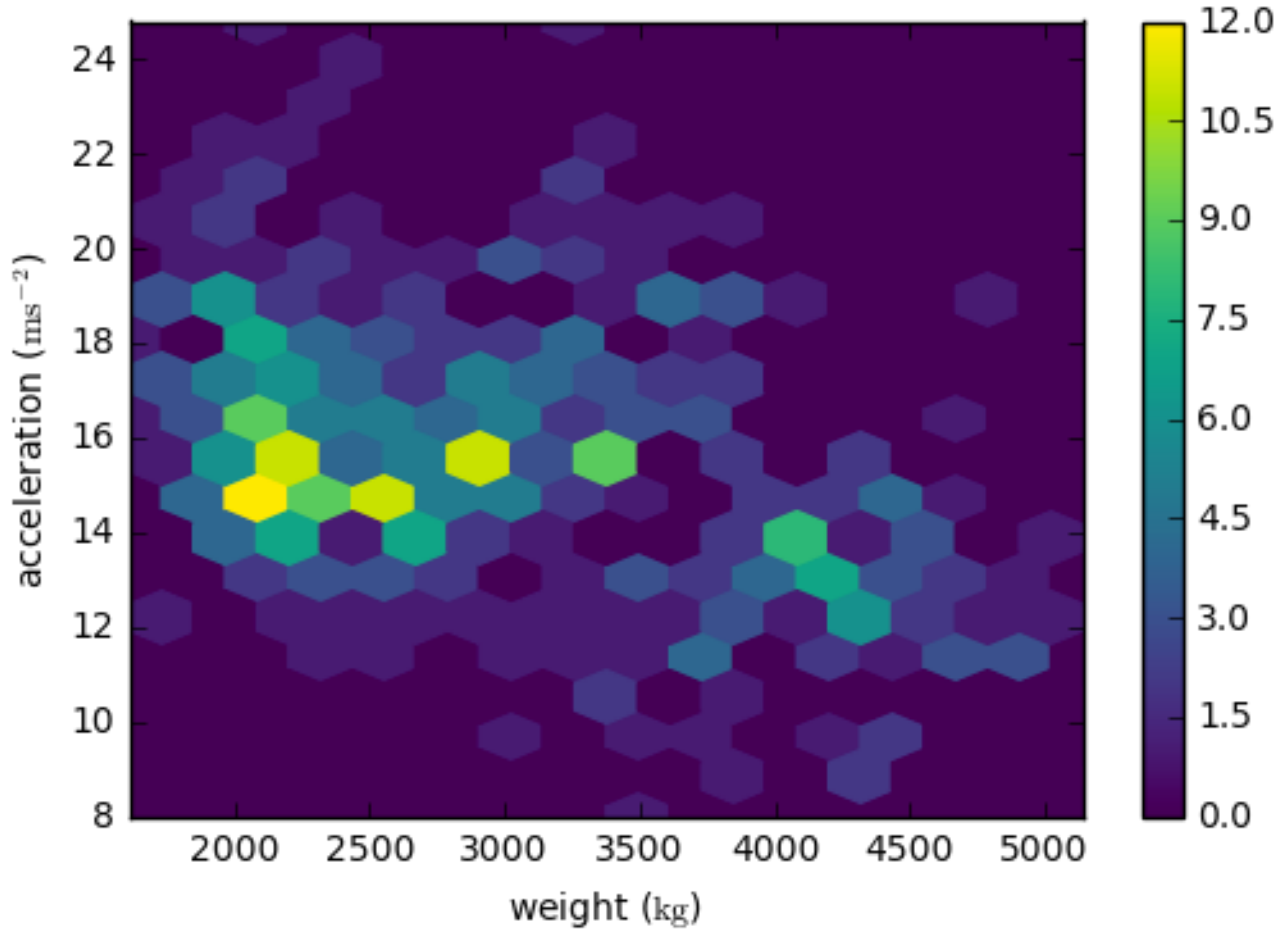
hist2d(): Rectangular binning



hexbin(): Hexagonal binning

```
In [1]: plt.hexbin(x, y, gridsize=(15,10))

In [2]: plt.colorbar()

In [3]: plt.xlabel('weight ($\mathrm{kg}$)')

In [4]: plt.ylabel('acceleration ($\mathrm{ms}^{-2}$)}')

In [5]: plt.show()
```

hexbin(): Hexagonal binning



Let's practice!

Working with images

Images

- Grayscale images: rectangular 2D arrays
- Color images: typically three 2D arrays (channels)
    - RGB (Red-Green-Blue)
- Channel values:
    - 0 to 1 (floating-point numbers)
    - 0 to 255 (8 bit integers)

Loading images

```
In [1]: img = plt.imread('sunflower.jpg')

In [2]: print(img.shape)
(480, 640, 3)

In [3]: plt.imshow(img)

In [4]: plt.axis('off')

In [5]: plt.show()
```

Loading images

Reduction to gray-scale image

```
In [6]: collapsed = img.mean(axis=2)

In [7]: print(collapsed.shape)
(480, 640)

In [8]: plt.set_cmap('gray')

In [9]: plt.imshow(collapsed, cmap='gray')

In [10]: plt.axis('off')

In [11]: plt.show()
```

Reduction to gray-scale image

Uneven samples

```
In [12]: uneven = collapsed[::4,::2] # nonuniform subsampling

In [13]: print(uneven.shape)
(120, 320)

In [14]: plt.imshow(uneven)

In [15]: plt.axis('off')

In [16]: plt.show()
```

Uneven samples

Adjusting aspect ratio

```
In [17]: plt.imshow(uneven, aspect=2.0)

In [18]: plt.axis('off')

In [19]: plt.show()
```

Adjusting aspect ratio

Adjusting extent

```
In [20]: plt.imshow(uneven, cmap='gray', extent=(0,640,0,480))

In [21]: plt.axis('off')

In [22]: plt.show()
```

Adjusting extent

Let's practice!