Computer Vision

Software that can see

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Introduction

The Terminator

Terminator Vision

- Reddish colour
- Foreground object segmented
- White boundary traced around object

What is Image Processing? Some examples...

- Image enhancement (sharpening, smoothing, brightening, ...)
- Image analysis
- Image segmentation
- Image structure detection (skeletonization)
- $\Rightarrow$ Improve the image for **humans**

What is Computer Vision? Some examples...

- Object component detection (edge & region detection)
- Object classification
- Object recognition
- Face detection
- Face recognition
- $\Rightarrow$ Analyse the image for **software**

Python packages we will use

- **Numpy**: efficient multi-dimensional arrays
- **Scipy**: scientific computing (like Matlab toolboxes)
  (image processing, statistics, spatial algorithms, signal processing, Fourier transforms, linear algebra, equation solvers, ...)
- **Skimage** (*a.k.a.* **scikit-image**): image-processing
- **Matplotlib**: graph plotting (like Matlab plotting)

Also maybe of interest:

- **OpenCV**: A comprehensive collection of CV algorithms

Maths that's useful for image processing & CV

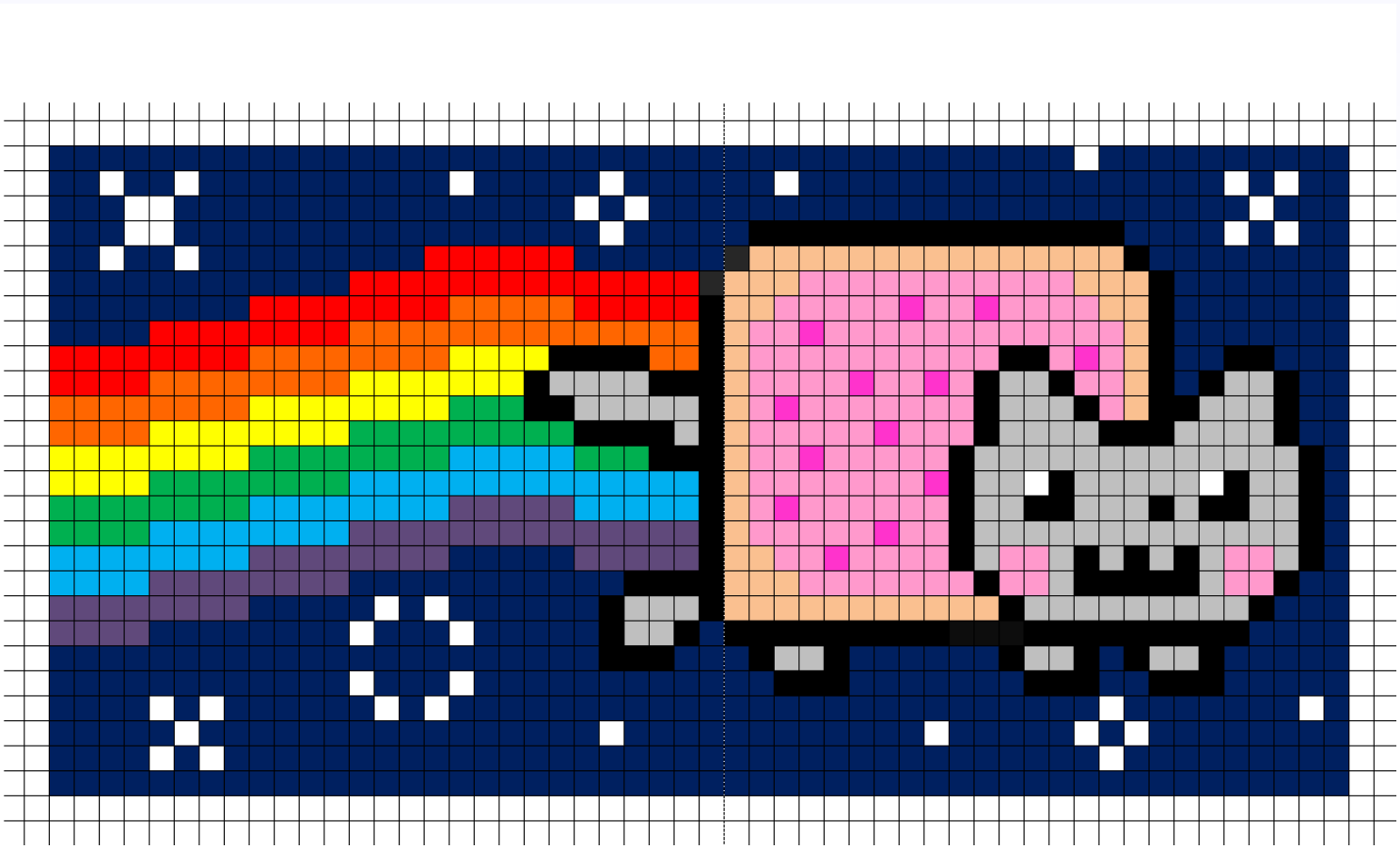
- Calculus (*esp.* differentiation) (in highschool)
- Trigonometry (in highschool)
- Linear Algebra (*esp.* matrices)
- Vector maths (*esp.* in 2-D & 3-D)
- 2nd-year Linear Algebra (*esp.* "eigenvalues & eigenvectors")
- Fourier Analysis
- Graph Theory algorithms

Today: 3x 40-min mini-tutorials: lecture then practical

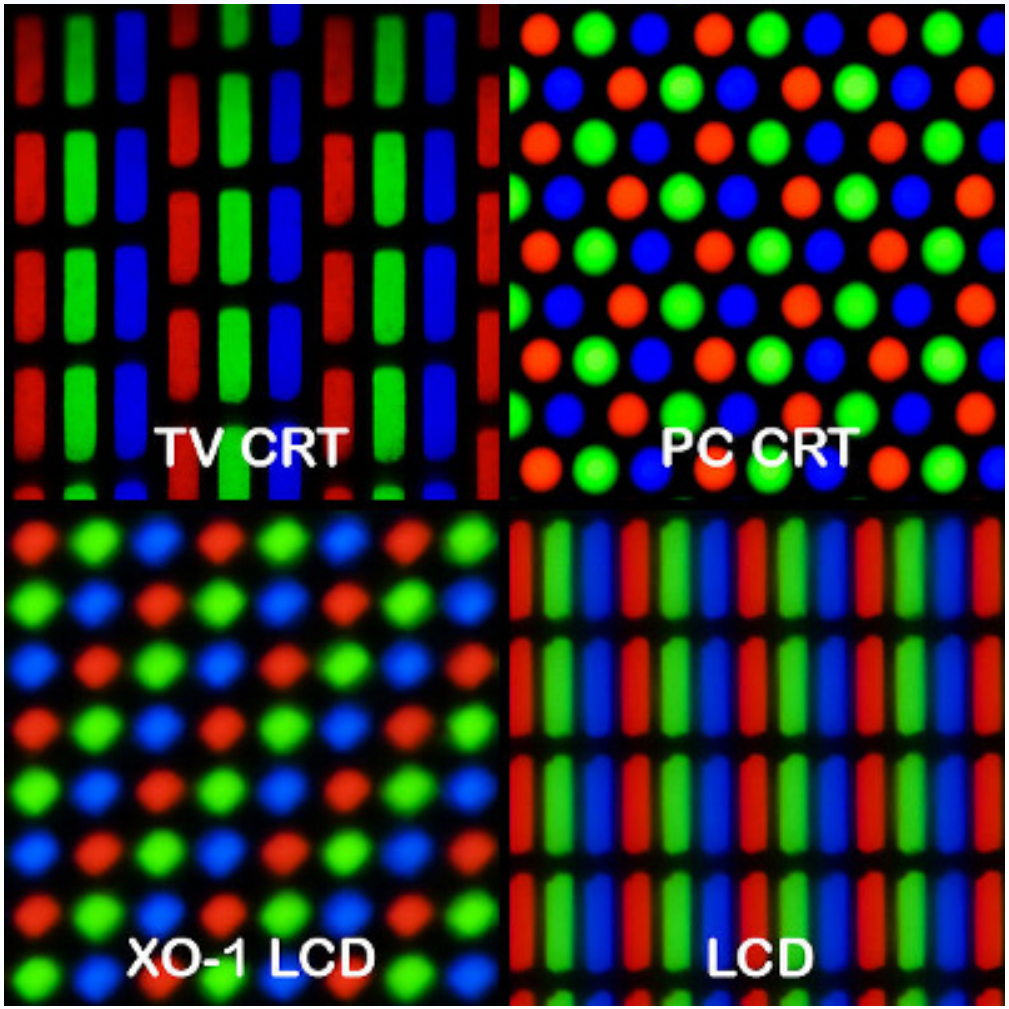
1. Images & colour
2. Numpy arrays
3. Filters, edges, histograms, regions

Images & colour

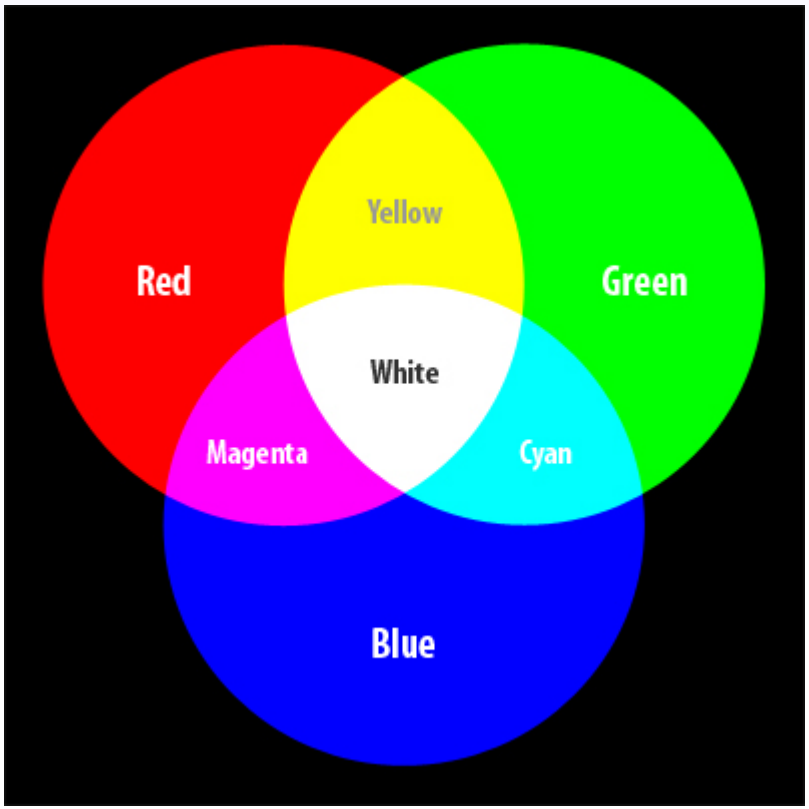
A “raster image” is a grid of coloured pixels

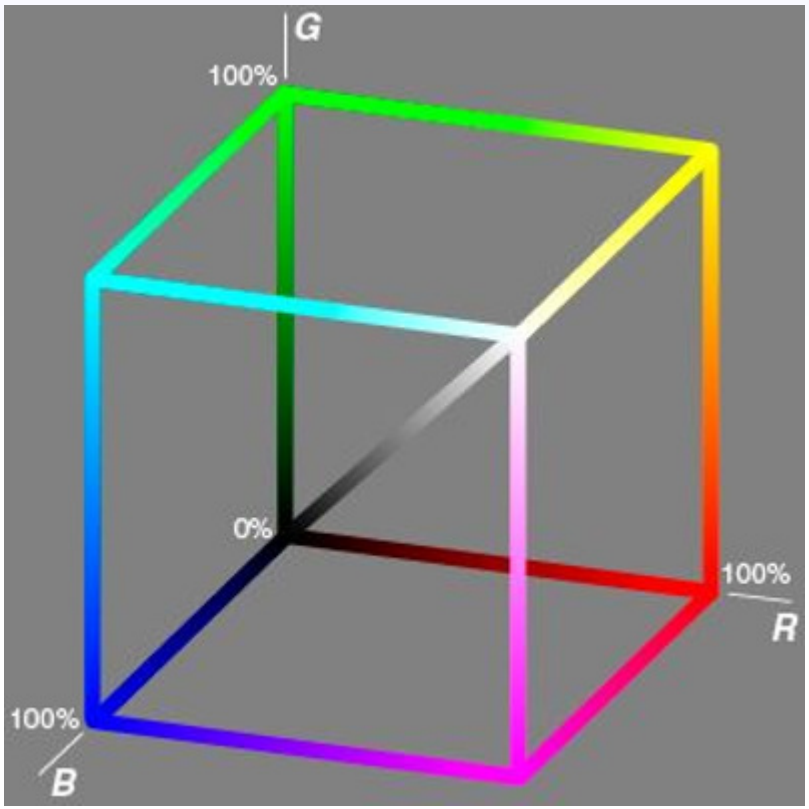


Pixels consist of Red, Green, Blue (RGB) components

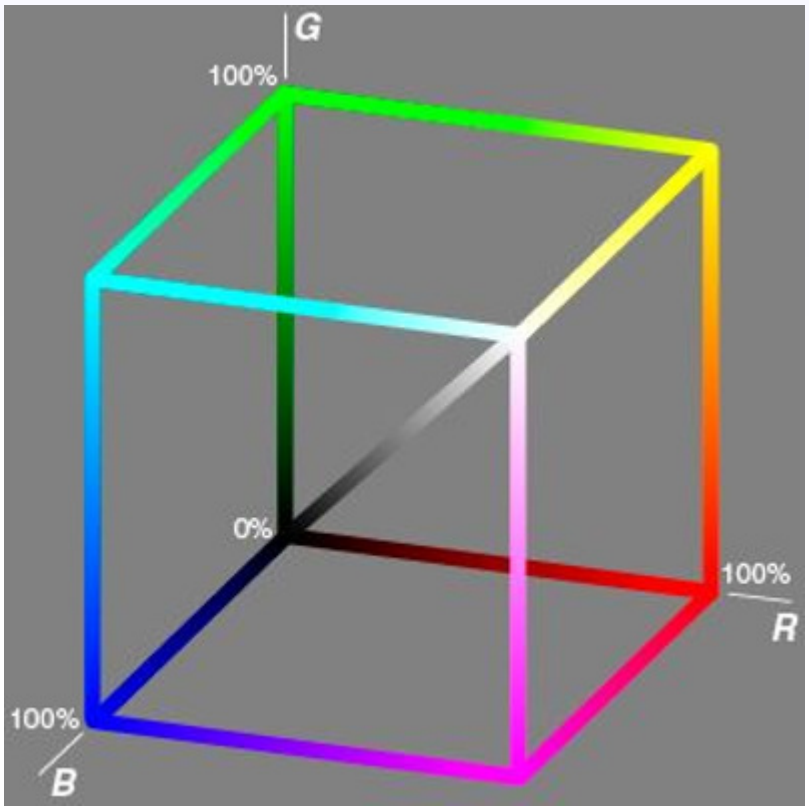


Combine RGB colour components in different amounts ...

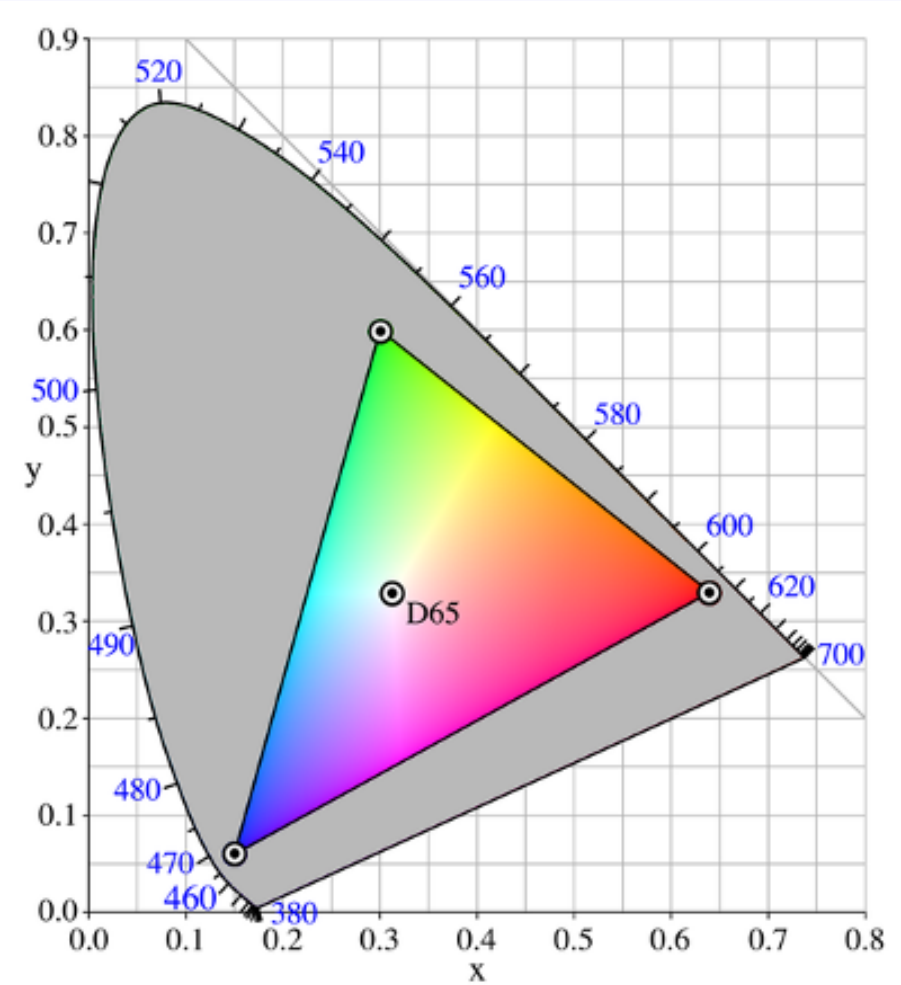




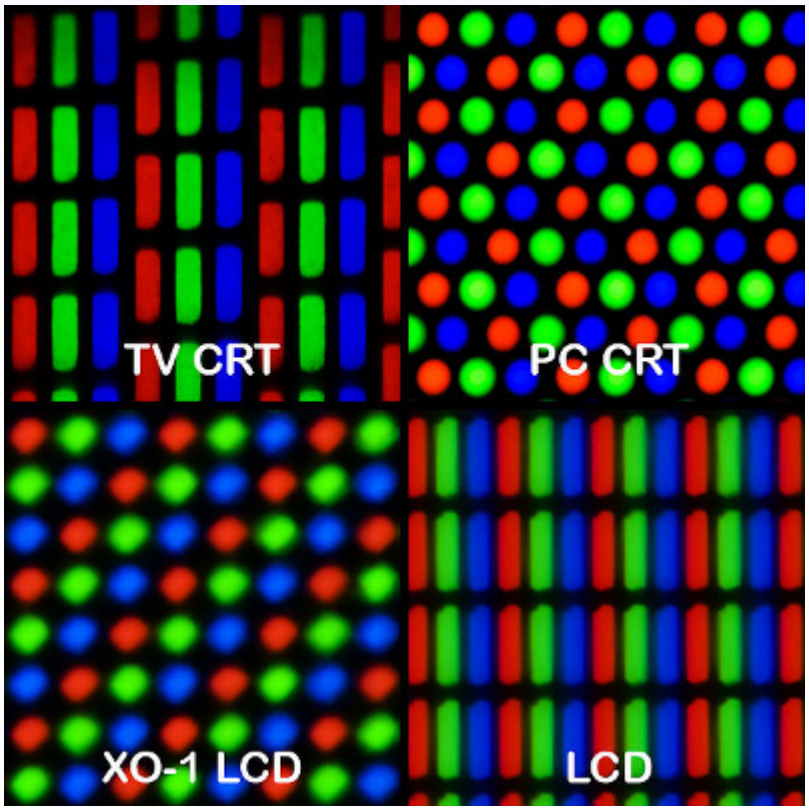
... to create (almost) any colour

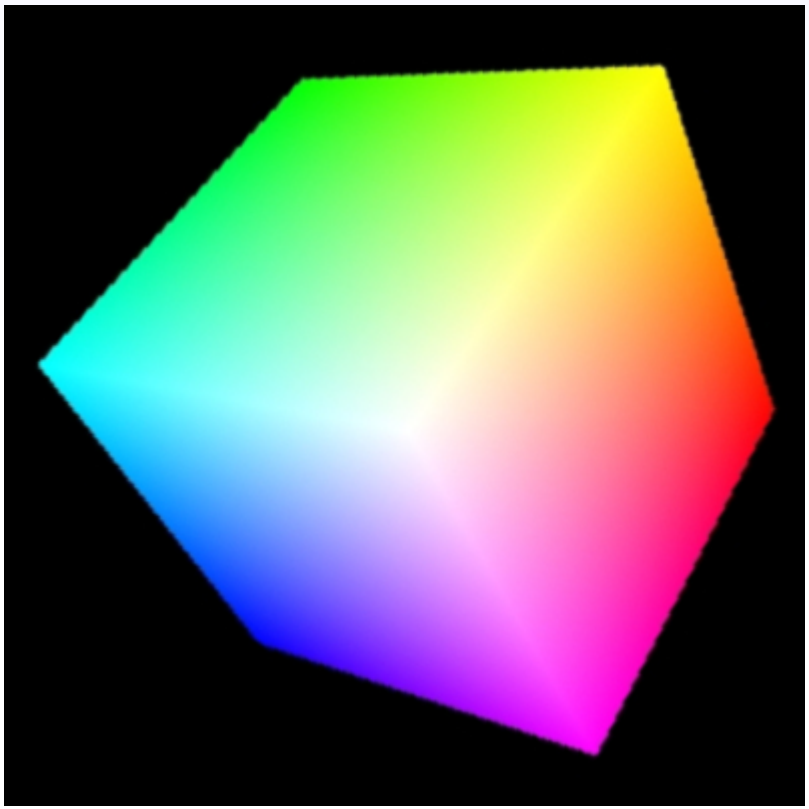


RGB can represent most of the colours visible to humans



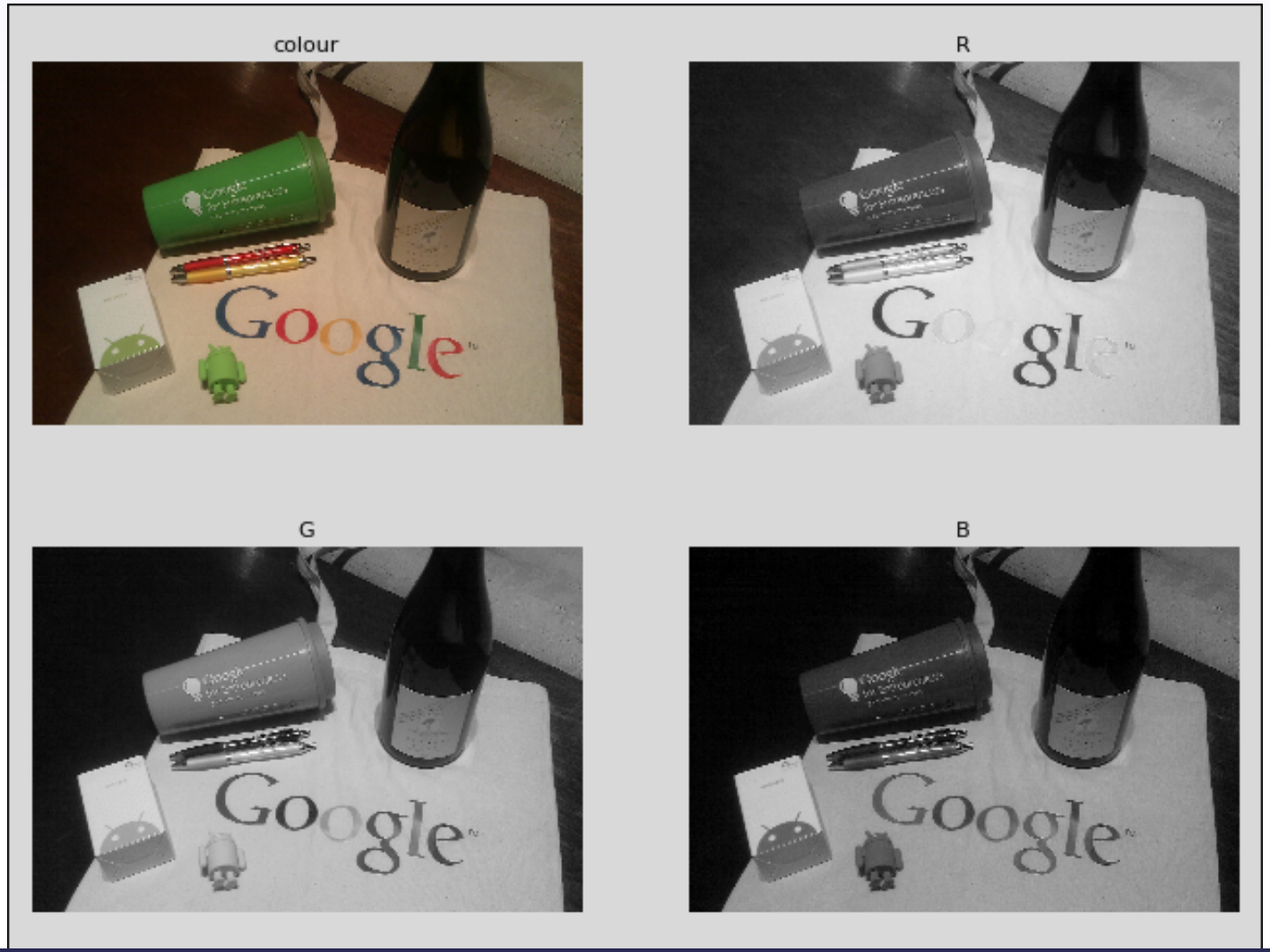
So, each pixel displays some combination of R, G, B



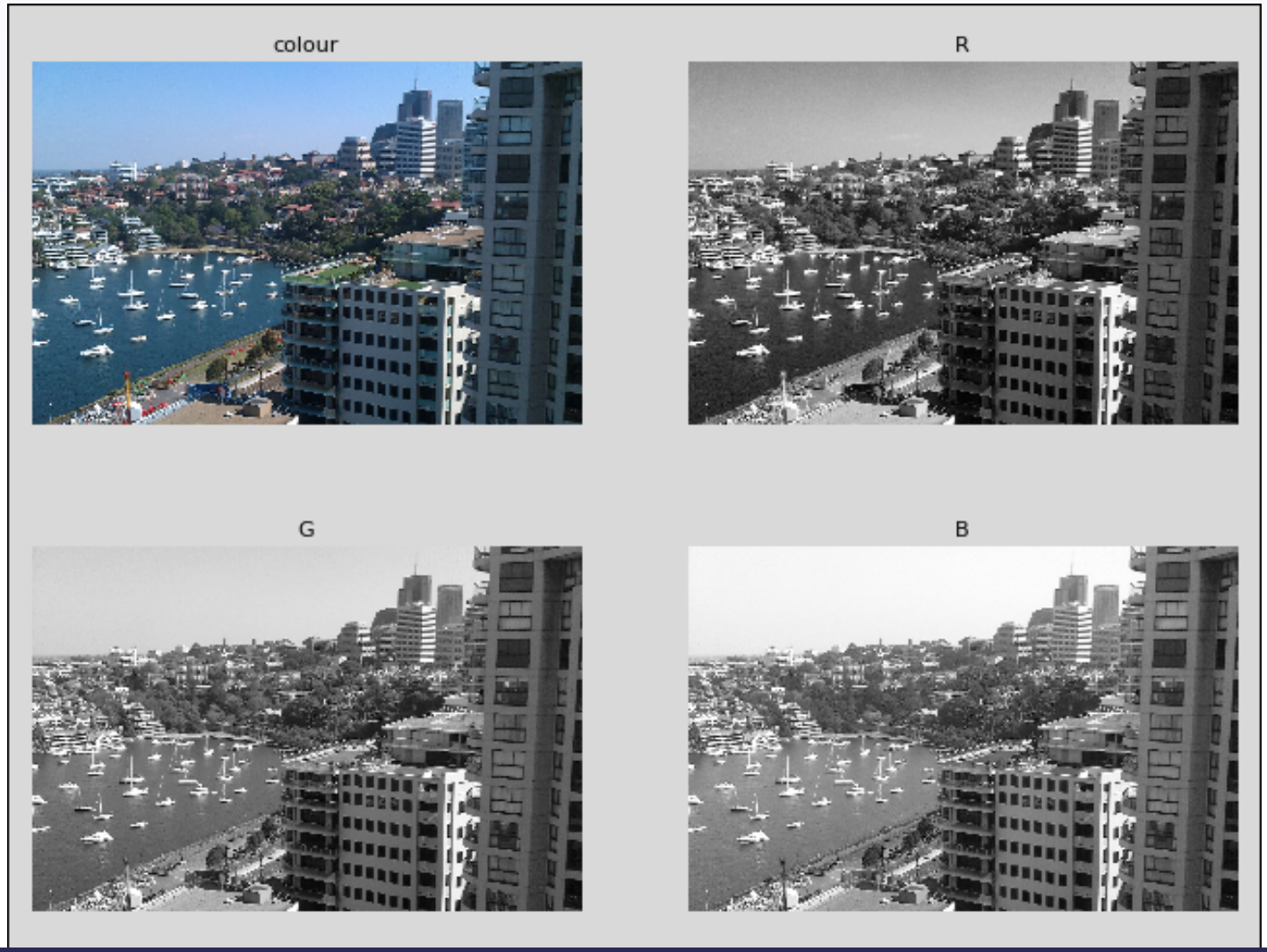


A single-colour slice of R, G or B is called a “channel”

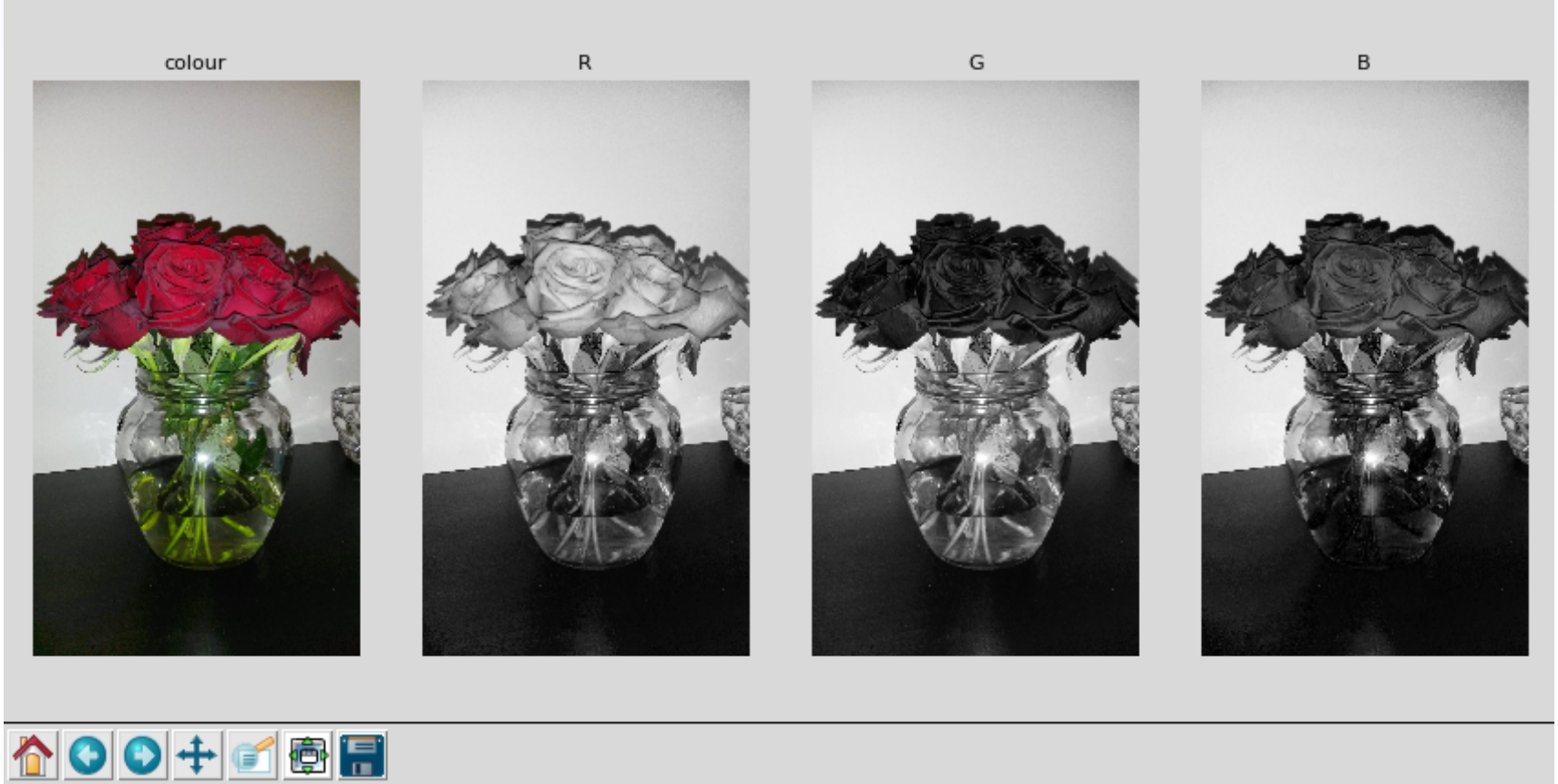
Each channel represents the “intensity” of R, G, B ...



... where the maximum intensity appears white ...



... and the minimum intensity appears black



There are also single-channel “greyscale” images

And “binary” images of just black and white

Different image types have different pixel types

- **binary image**: just a “boolean” value (True or False)
- **greyscale**: 1 numeric value (a greyscale intensity)
- **colour** (RGB): 3 numeric values (the R, G, B intensities)

A numeric value is generally either:

- an integer in the range 0–255 (**uint8**)
- a floating-point number in the range 0.0–1.0 (**float64**)

A bit of code to get you started...

```
>>> # To load an image in Numpy & Scipy:
>>> from scipy.misc import imread
>>> img = imread("some-image.jpg")

>>> # To display an image using Matplotlib:
>>> from matplotlib import pyplot as plt
>>> plt.imshow(img)
>>> plt.show()

>>> # To show the pixels as "pixelated" rather than smooth:
>>> plt.imshow(img, interpolation="none")
>>> plt.show()
```

A bit of code to get you started...

```
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>>> plt.imshow(img, interpolation="none")
>>> plt.show()

# Test images & more code at https://github.com/jboy/ncss2016/images
# and https://github.com/jboy/ncss2016/part1
```

Numpy arrays

Python list: Pros

- A very convenient general-purpose collection
- Simple, convenient syntax:
  `[5, 4, 0, 1, 9, 5, 2]`
- Able to contain multiple different data types at once:
  `[5, "hello", 2.2]`
- Just a few easy-to-remember methods:
  append, count, extend, index, insert, pop, remove, reverse, sort
- Indexing & slicing are intuitive

Python list examples: Access an element at an index

```
>>> my_list = [5, 4, 0, 1, 9, 5, 2]
>>> len(my_list)
7

# Index an element:
# Indices run from 0 to (len-1),
# inclusive.
>>> my_list[0]
5
>>> my_list[1]
4
>>> my_list[6]
2
```

```
# Negative indices count backwards
from the end of the list.
# -1 is the index of the last
element in the list.
>>> my_list[-1]
2
>>> my_list[-2]
5
```

Python list examples: “Slice” to obtain a sub-list

```
>>> my_list = [5, 4, 0, 1, 9, 5, 2]

# Slice a range of elements:  [start:stop]
>>> my_list[1:5]
[4, 0, 1, 9]
```

```
Index from rear:    -6  -5  -4  -3  -2  -1
Index from front:    0   1   2   3   4   5
                   +---+---+---+---+---+---+
                   | a | b | c | d | e | f |
                   +---+---+---+---+---+---+
Slice from front:  :   1   2   3   4   5   :
Slice from rear:   :  -5  -4  -3  -2  -1   :
```

Python list examples: “Slice” to obtain a sub-list

```
>>> my_list = [5, 4, 0, 1, 9, 5, 2]

# Slice a range of elements:
>>> my_list[1:5]
[4, 0, 1, 9]
```

```
# Slice from the start:
>>> my_list[:5]
[5, 4, 0, 1, 9]

# Slice to the end:
>>> my_list[1:]
[4, 0, 1, 9, 5, 2]

# Slice "the whole list":
>>> my_list[:]
[5, 4, 0, 1, 9, 5, 2]
```

Python list: Cons (for image processing)

- Python lists use “indirect” storage of Python objects
- This takes up more memory (a problem for large images)
- This also makes loops slower

- No numerical methods or functions beyond `max`, `min`, `sum`
- So you have to write your own basic functions...

- Not easy to create a list of an arbitrary length
- Especially not easy to create a desired 2-D shape

- In fact, there’s **no way** to tell a list to “be 2-D”

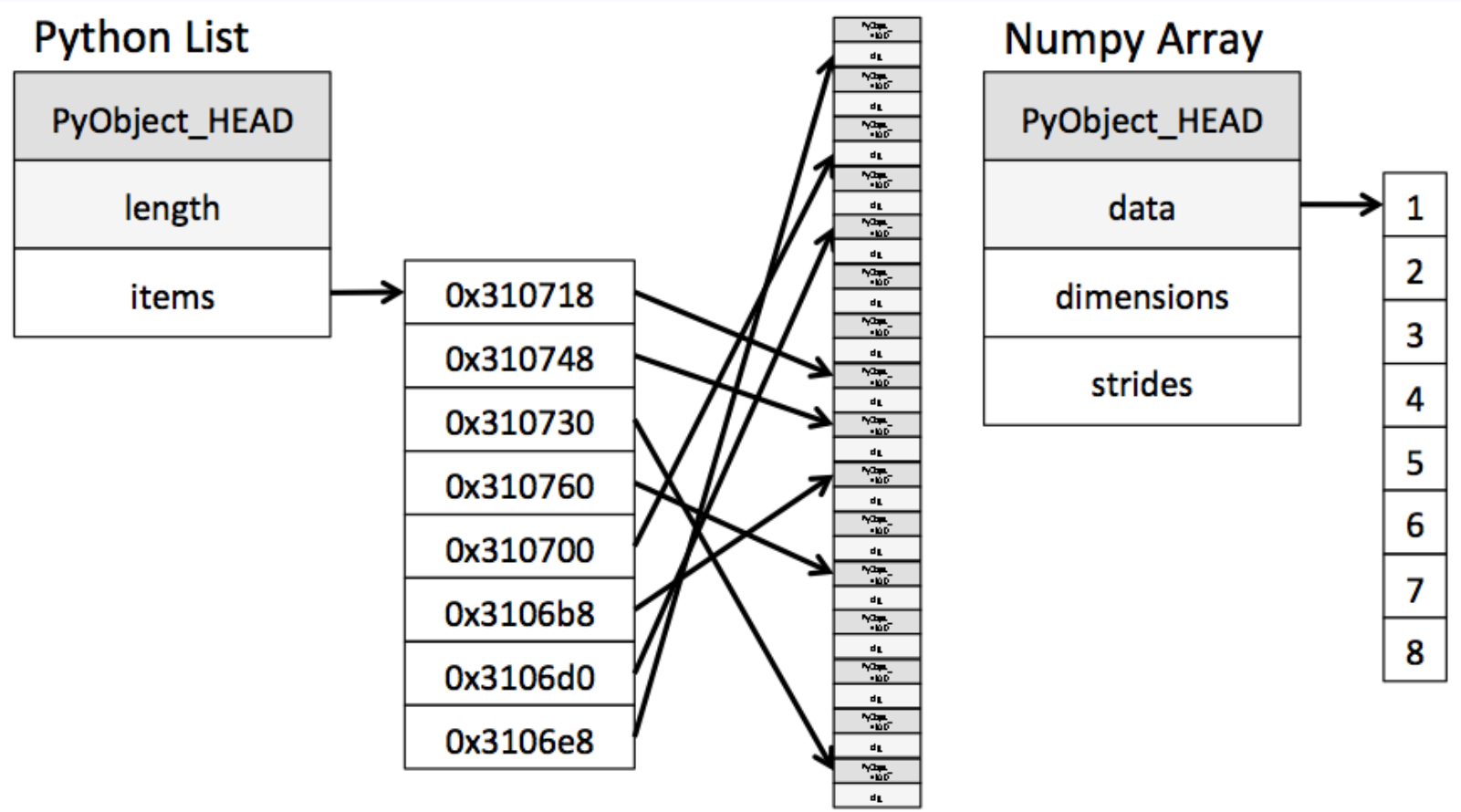
Numpy arrays

- A single Numpy array holds only **one specified data type**
- Benefit: The data can be held compactly in memory
- Benifit: It takes up less memory, and makes loops faster

- Numpy arrays have many numerical methods and functions:
  `max`, `mean`, `min`, `sum`, `argmax`, `argmin`, `clip`, `round`
- And many more!

- It's very easy to tell the Numpy array what shape you want

Python lists *vs.* Numpy arrays in memory



Creating a Numpy array

```
>>> import numpy as np  # ("np" is short for "numeric python")

>>> my_arr = np.array([5, 4, 0, 1, 9, 5, 2])
>>> my_arr
array([5, 4, 0, 1, 9, 5, 2])

>>> my_arr.dtype
dtype('int64')
# ∧ data type is 64-bit integer

>>> my_arr.shape
(7,)
# ∧ 1-D, of length 7
```

Creating a specific length: lists *vs.* Numpy arrays

```
# Python list
```

```
# Numpy array
>>> import numpy as np
```

```
# A range
>>> range(6)
[0, 1, 2, 3, 4, 5]
```

```
# A range
>>> np.arange(6)
array([0, 1, 2, 3, 4, 5])
```

```
# All zeros
>>> [0] * 6
[0, 0, 0, 0, 0, 0]
```

```
# All zeros (floating-point by default)
>>> np.zeros(6)
array([ 0.,  0.,  0.,  0.,  0.,  0.])
```

```
# All ones
>>> [1] * 6
[1, 1, 1, 1, 1, 1]
```

```
# All ones (floating-point by default)
>>> np.ones(6)
array([ 1.,  1.,  1.,  1.,  1.,  1.])
```

Specify a desired data type using the `dtype` parameter

```
>>> import numpy as np
```

```
# A range
>>> range(6)
[0, 1, 2, 3, 4, 5]
```

```
# A range
>>> np.arange(6)
array([0, 1, 2, 3, 4, 5])
```

```
# All zeros
>>> [0] * 6
[0, 0, 0, 0, 0, 0]
```

```
# All zeros (now int32 type)
>>> np.zeros(6, dtype=np.int32)
array([0, 0, 0, 0, 0, 0], dtype=int32)
```

```
# All ones
>>> [1] * 6
[1, 1, 1, 1, 1, 1]
```

```
# All ones (now int32 type)
>>> np.ones(6, dtype=np.int32)
array([1, 1, 1, 1, 1, 1], dtype=int32)
```

Specify a desired data type using the `dtype` parameter

```
>>> import numpy as np
```

```
# All False (for binary images)
>>> [False] * 4
[False, False, False, False]
```

```
# All False (for binary images)
>>> np.zeros(4, dtype=np.bool)
array([False, False, False, False],
dtype=bool)
```

```
# All True (for binary images)
>>> [True] * 4
[True, True, True, True]
```

```
# All True (for binary images)
>>> np.ones(4, dtype=np.bool)
array([ True,  True,  True,  True],
dtype=bool)
```

Specify a desired 2-D shape using a `shape` tuple

```
# We want a shape of 4 rows x 7 columns.
>>> my_arr = np.zeros((4, 7), dtype=np.int32)
>>> my_arr
array([[0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0],
       [0, 0, 0, 0, 0, 0, 0]], dtype=int32)
>>> my_arr.shape
(4, 7)
```

Or reshape an existing array

```
>>> my_long_array = np.arange(28)  # 'arange' creates a 1-D array.
>>> my_long_array
array([ 0,  1,  2,  3,  4,  5,  6,  7,  8,  9, 10, 11, 12, 13, 14, 15,
        16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27])
>>> my_long_array.shape
(28,)

# Note that 4*7 == 28, so total number of elements is unchanged.
>>> my_arr2 = my_long_array.reshape((4, 7))  # Reshape to 2-D.
>>> my_arr2
array([[ 0,  1,  2,  3,  4,  5,  6],
       [ 7,  8,  9, 10, 11, 12, 13],
       [14, 15, 16, 17, 18, 19, 20],
       [21, 22, 23, 24, 25, 26, 27]])
>>> my_arr2.shape
(4, 7)
```

We can index the array in 2-D to access an element

```
>>> my_long_array = np.arange(28)
>>> my_arr2 = my_long_array.reshape((4, 7))
>>> my_arr2
array([[ 0,  1,  2,  3,  4,  5,  6],
       [ 7,  8,  9, 10, 11, 12, 13],
       [14, 15, 16, 17, 18, 19, 20],
       [21, 22, 23, 24, 25, 26, 27]])
>>> my_arr2.shape
(4, 7)
```

```
>>> my_arr2[0,0]
0
>>> my_arr2[1,1]
8
>>> my_arr2[0,6]
6
>>> my_arr2[1,6]
13
>>> my_arr2[3,1]
22
>>> my_arr2[3,6]
27
>>> my_arr2[-1,-1]
27
```

Shapes and indexing in 2-D arrays

- `[0, 0]` (the origin) is always in the top-left.
- `[-1, -1]` is always in the bottom-right.
- **Tip: Don't** think of the coordinates as *(x, y)*.
- Instead, think of the coordinates as *(row, column)*.
- To specify a shape: `(num_rows, num_cols)`
- To index an array: `arr[row_idx, col_idx]`

`num_cols == 4`

`num_rows == 3`

	Column 0	*Column 1*	*Column 2*	*Column 3*
Row 0	`arr[0, 0]`	`arr[0, 1]`	`arr[0, 2]`	`arr[0, 3]`
Row 1	`arr[1, 0]`	`arr[1, 1]`	`arr[1, 2]`	`arr[1, 3]`
Row 2	`arr[2, 0]`	`arr[2, 1]`	`arr[2, 2]`	`arr[2, 3]`

We can create a single-channel (greyscale) image

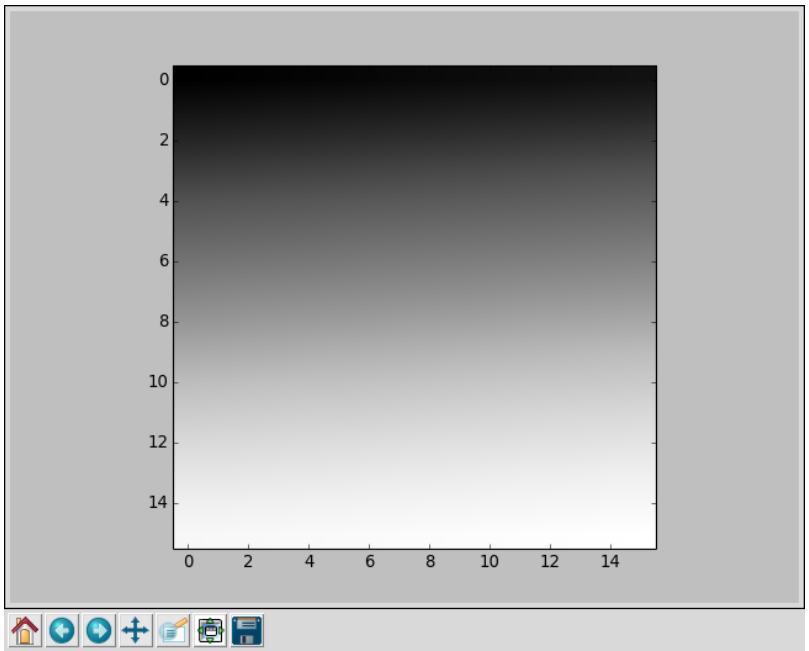
```
>>> arr_256 = np.arange(256, dtype=np.uint8)
>>> arr_256.shape
(256,)
>>> arr_1616 = arr_256.reshape((16, 16))
>>> arr_1616.shape
(16, 16)

# This is a valid greyscale image:
# dtype == uint8, values are in the range [0, 255]
>>> arr_1616.dtype
dtype('uint8')
>>> arr_1616.min()
0
>>> arr_1616.max()
255
```

We can create a single-channel (greyscale) image

```
array([[  0,   1,   2,   3,   4,   5,   6,   7,   8,   9,  10,  11,  12, 13,  14,  15],
       [ 16,  17,  18,  19,  20,  21,  22,  23,  24,  25,  26,  27,  28, 29,  30,  31],
       [ 32,  33,  34,  35,  36,  37,  38,  39,  40,  41,  42,  43,  44, 45,  46,  47],
       [ 48,  49,  50,  51,  52,  53,  54,  55,  56,  57,  58,  59,  60, 61,  62,  63],
       [ 64,  65,  66,  67,  68,  69,  70,  71,  72,  73,  74,  75,  76, 77,  78,  79],
       [ 80,  81,  82,  83,  84,  85,  86,  87,  88,  89,  90,  91,  92, 93,  94,  95],
       [ 96,  97,  98,  99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111],
       [112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127],
       [128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143],
       [144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159],
       [160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175],
       [176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191],
       [192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207],
       [208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223],
       [224, 225, 226, 227, 228, 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 239],
       [240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255]],
```

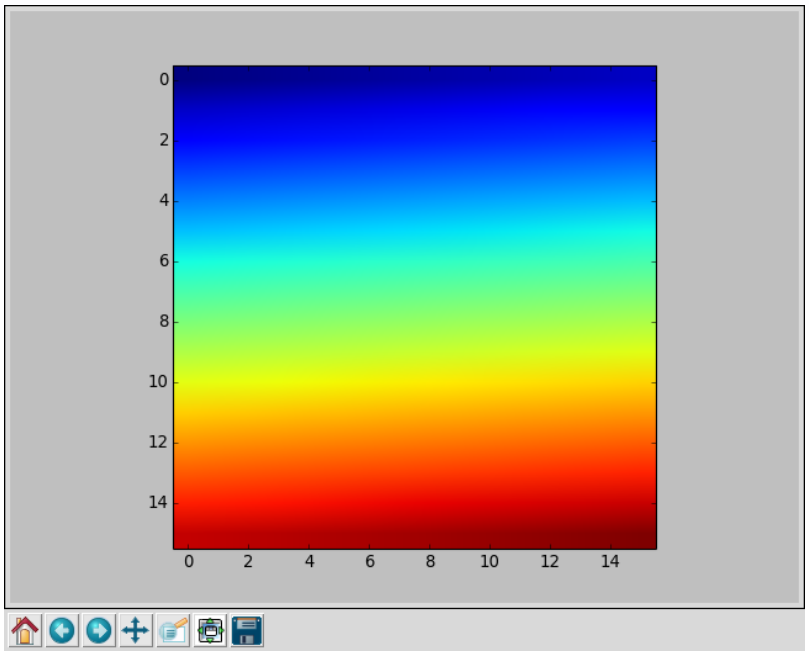
Display the image using Matplotlib

```
>>> import matplotlib.pyplot as plt
# Note that we specify a greyscale colourmap.
>>> plt.imshow(arr_1616, cmap=plt.cm.Greys_r)
>>> plt.show()
```



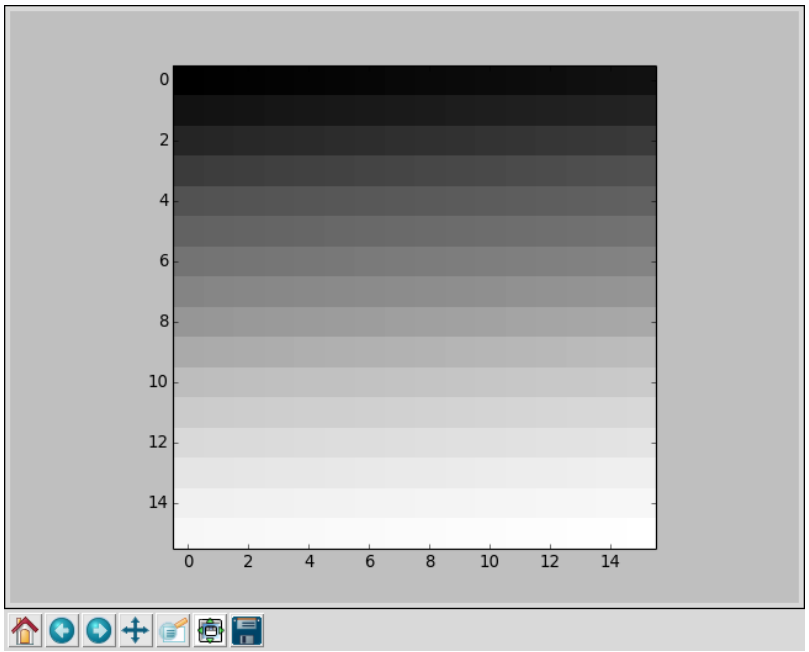
By default, Matplotlib displays greyscale images in colour

```
# If we don't specify a colourmap, Matplotlib uses false colour:
#  black -> blue, white -> red, with a rainbow in-between.
>>> plt.imshow(arr_1616)
>>> plt.show()
```



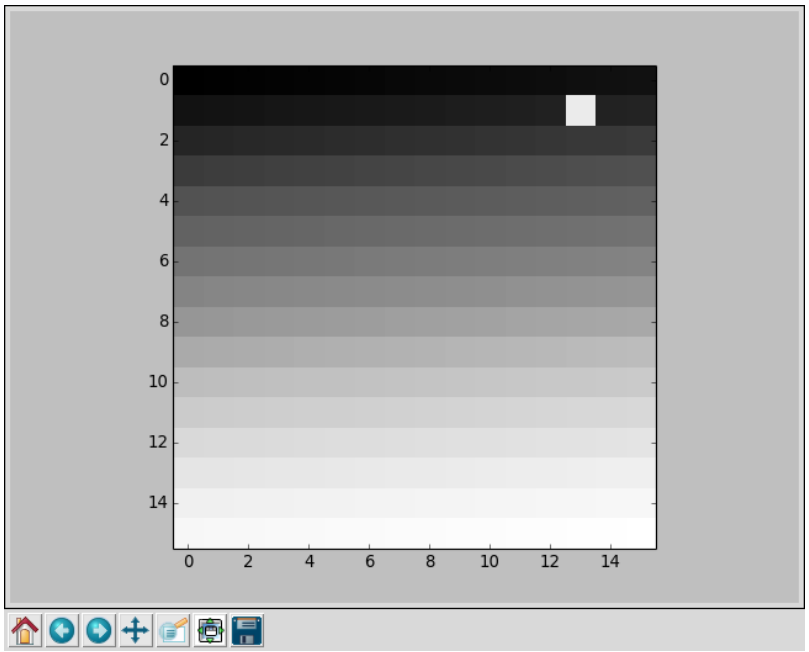
Switch off smoothing to see individual image pixels

```
# Use interpolation="none" to switch off the colour smoothing.
>>> plt.imshow(arr_1616, cmap=plt.cm.Greys_r,
          interpolation="none")
>>> plt.show()
```



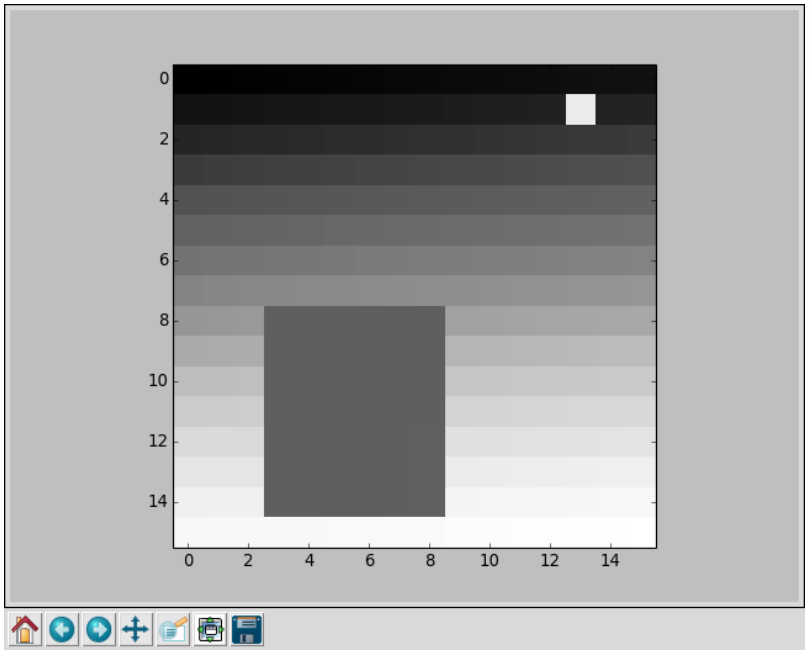
We can modify individual pixels using indexing...

```
>>> arr_1616[1, 13] = 220  # 220 == light grey, almost 255 (white)
>>> plt.imshow(arr_1616, cmap=plt.cm.Greys_r,
          interpolation="none")
>>> plt.show()
```



... or modify larger rectangles using slicing

```
>>> arr_1616[8:15, 3:9] = 77  # rows == [8:15], columns == [3:9]
>>> plt.imshow(arr_1616, cmap=plt.cm.Greys_r,
          interpolation="none")
>>> plt.show()
```



Load colour images using scipy.misc.imread

```
>>> from scipy.misc import imread
>>> img = imread("20141226_222803.jpg")
# Test images at https://github.com/jboy/ncss2016/images

>>> img.shape
(1836, 3264, 3)
# ∧ Note:  1836 rows x 3264 columns x 3 colour channels (RGB)

>>> img.dtype
dtype('uint8')
>>> img.min(), img.max()
(0, 255)

# No need to specify a colourmap for a colour image.
>>> plt.imshow(img)
>>> plt.show()
```

Some image-processing functions only operate on greyscale

```
# You can access individual channels by indexing in the 3rd dimension
# (the colour-channel dimension).
# An individual channel is like a greyscale image.

# The 1st ':'  is for "all rows"; the 2nd ':'  is for "all columns".
>>> red_chan = rgb_img[:,:,0]
>>> red_chan.shape
(1836, 3264)

# The ellipsis ("...") means "fill in as many ':'  as necessary",
# so rgb_img[...,0] is equivalent to rgb_img[:,:,0]

green_chan = rgb_img[...,1]
blue_chan = rgb_img[...,2]
```

Some image-processing functions only operate on greyscale

```
# You can also convert a colour image entirely to greyscale.
# See http://scikit-image.org/docs/dev/api/skimage.color.html#rgb2grey
>>> from skimage.color import rgb2grey
>>> rgb_img.shape
(1836, 3264, 3)
>>> greyscale_img = rgb2grey(rgb_img)
>>> greyscale_img.shape
(1836, 3264)
```

You can change the overall image tint by editing a channel

```
>>> import matplotlib.pyplot as plt
>>> from scipy.misc import imread
>>> img = imread("IMAG0537.jpg")
>>> img[...,0] = 255  # set red channel to max
>>> plt.imshow(img) ; plt.axis("off") ; plt.show()
```

Here are some short scripts to save you some typing...

- Scripts are at https://github.com/jboy/ncss2016/part1

  `useful.py`

  `display_rgb_colour.py`

  `display_rgb_grey.py`

- Slides are at https://github.com/jboy/ncss2016/part2

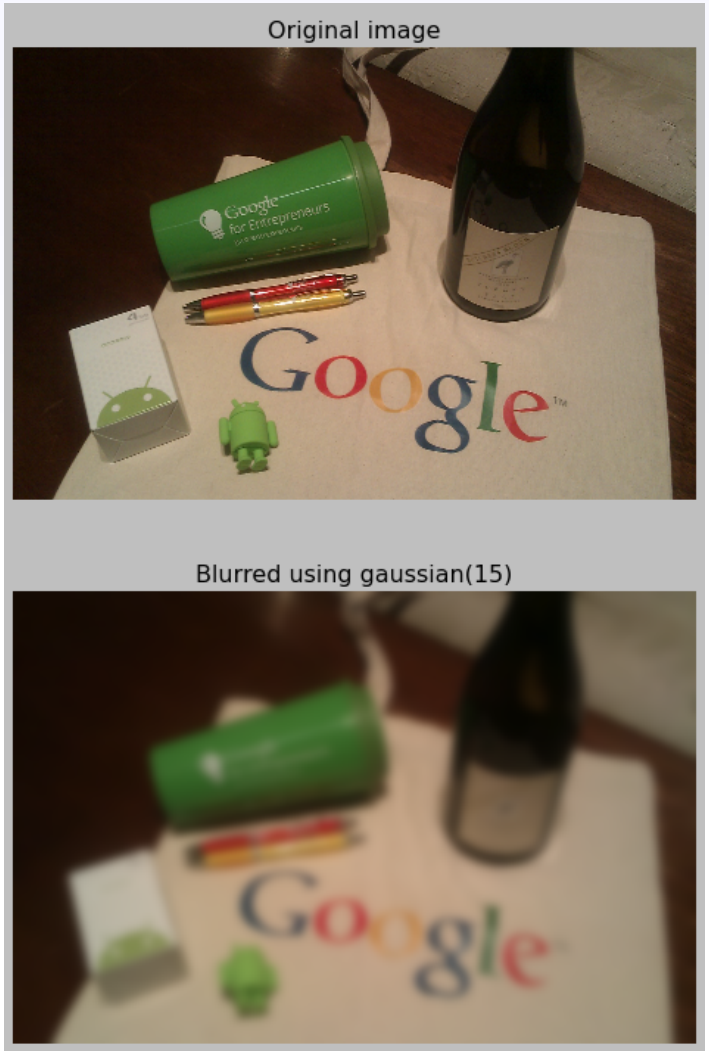
Filters, edges, histograms, regions

Filters

- A **filter** applies the same operation to every pixel in an image.
- Filters can be used for image enhancement (smoothing, sharpening)
- or for edge detection (part of image segmentation)

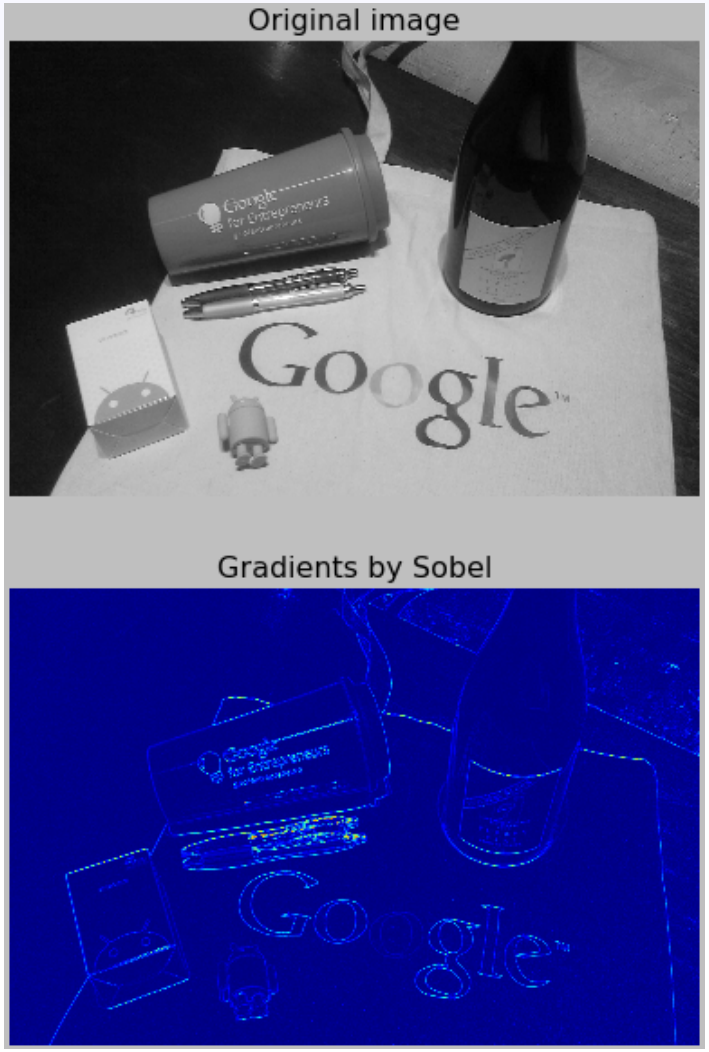
Gaussian filter blurs the image

```
>>> import matplotlib.pyplot as plt
>>> from scipy.misc import imread
>>> img = imread("IMAG0537.jpg")

>>> from skimage.filters import gaussian
>>> blurred15 = gaussian(img, 15)

>>> fig, (ax0, ax1) = plt.subplots(nrows=2)
>>> ax0.imshow(img)
>>> ax0.set_title("Original image")
>>> ax0.axis("off")
>>> ax1.imshow(blurred15)
>>> ax1.set_title("Gaussian(15) blur")
>>> ax1.axis("off")
>>> plt.show()
```



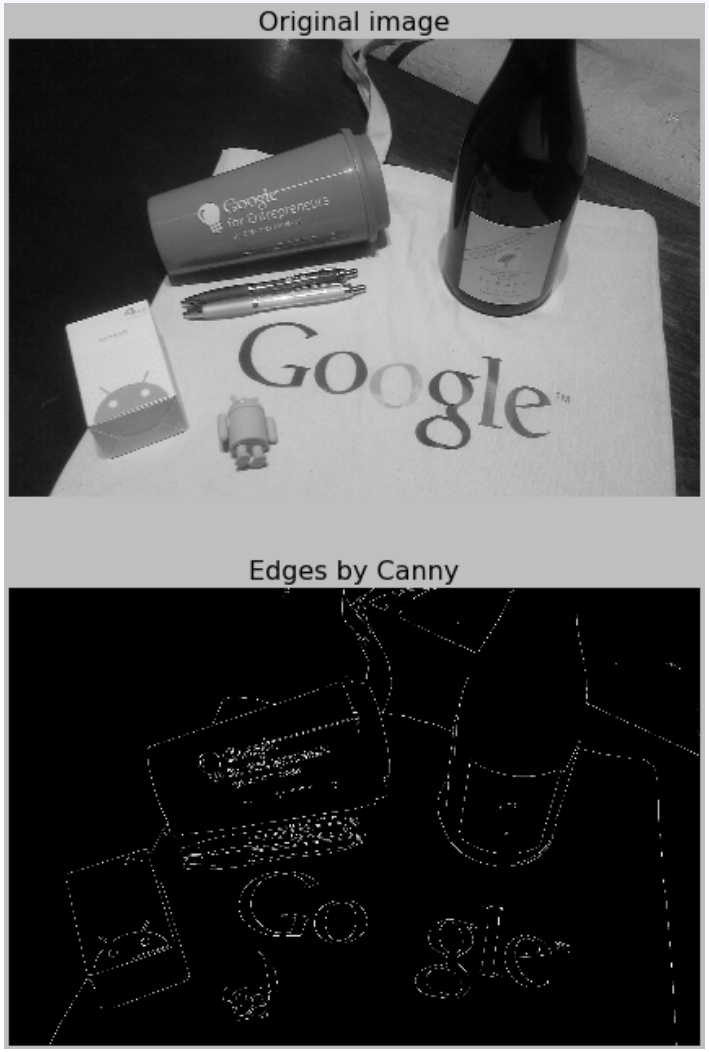
Sobel filter calculates greyscale gradient magnitude

```
>>> from skimage.color import rgb2grey
>>> from skimage.filters import sobel
# Sobel only accepts greyscale images.
>>> img_g = rgb2grey(img)
>>> gradients = sobel(img_g)

>>> fig, (ax0, ax1) = plt.subplots(nrows=2)
>>> ax0.imshow(img_g, cmap=plt.cm.Greys_r)
>>> ax0.set_title("Original image")
>>> ax0.axis("off")
>>> ax1.imshow(gradients)
>>> ax1.set_title("Gradients by Sobel")
>>> ax1.axis("off")
>>> plt.show()
```



Canny edge detector finds binary edges in greyscale

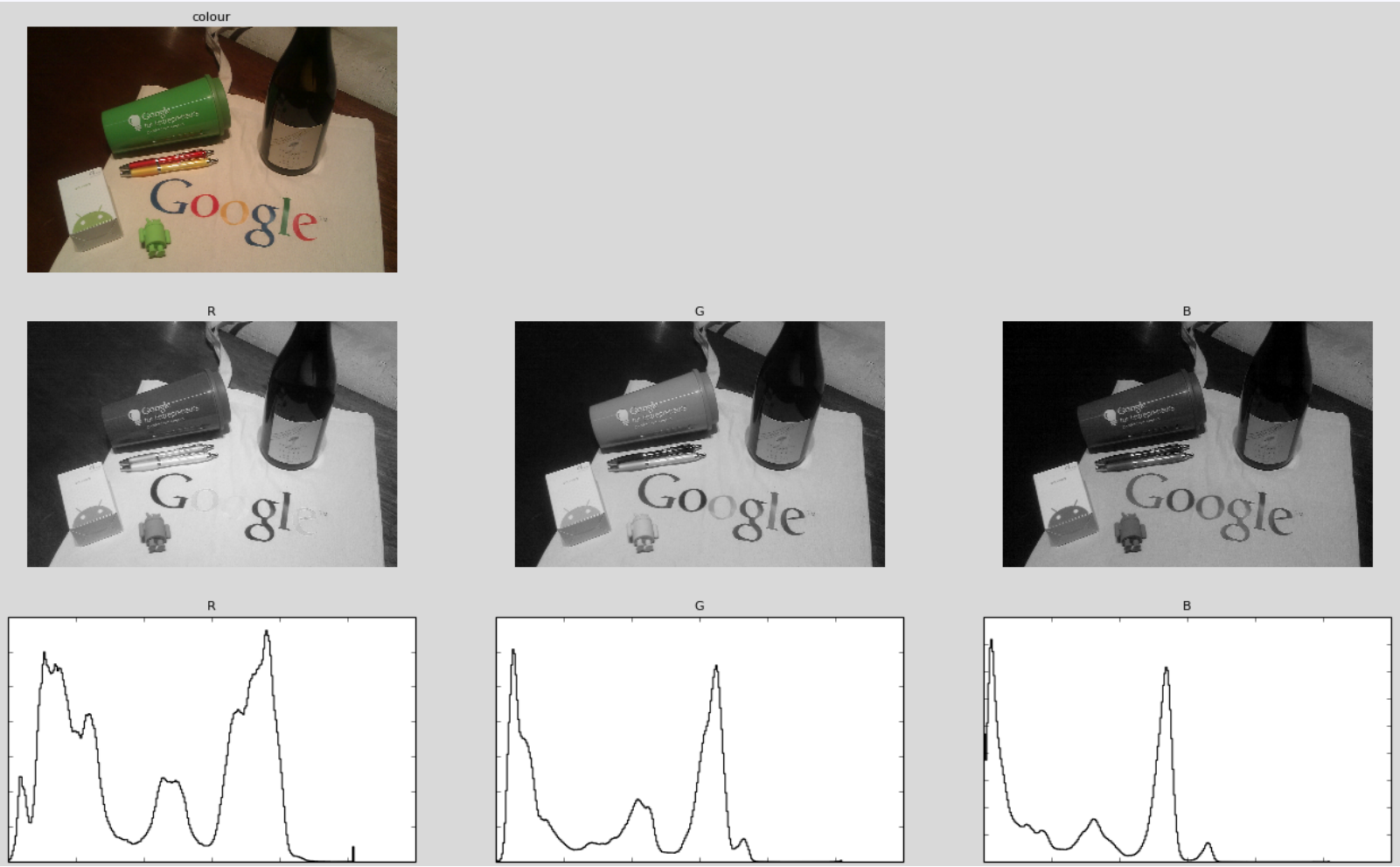
```
>>> from skimage.color import rgb2grey
>>> from skimage.filters import canny
# Canny only accepts greyscale images.
>>> img_g = rgb2grey(img)
>>> edges = canny(img_g)

>>> fig, (ax0, ax1) = plt.subplots(nrows=2)
>>> ax0.imshow(img_g, cmap=plt.cm.Greys_r)
>>> ax0.set_title("Original image")
>>> ax0.axis("off")
>>> ax1.imshow(edges, cmap=plt.cm.Greys_r)
>>> ax1.set_title("Edges by Canny")
>>> ax1.axis("off")
>>> plt.show()
```



Detected edges usually don’t form closed boundaries

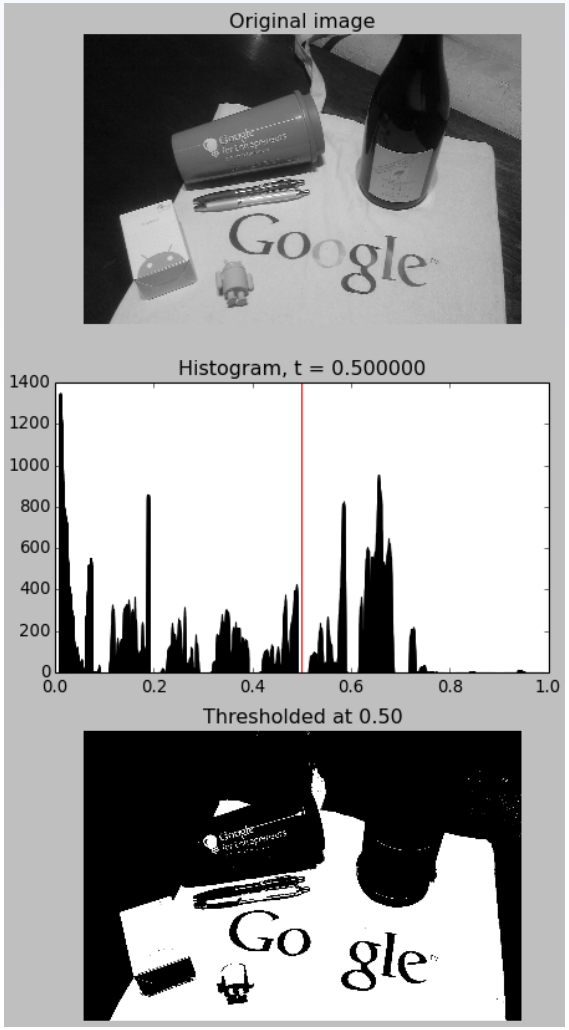
- **Problem:** If detected edges don’t form into closed loops, they won’t segment the image into regions.
- But we want to find image regions that correspond to objects.
- Hence, we consider **region-based image segmentation**.

Histograms show the counts of light & dark grey pixels



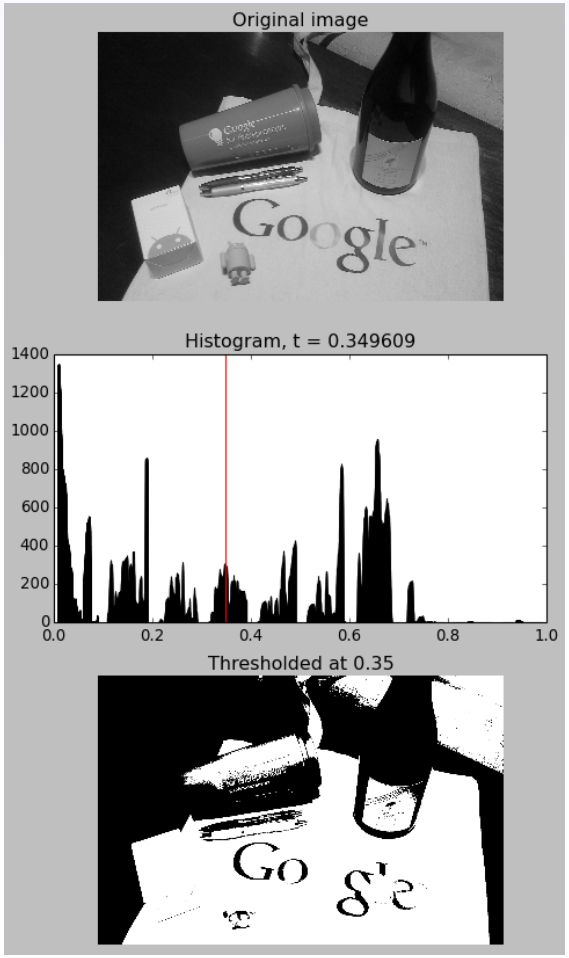
You can “threshold” a greyscale image to binary

```
# We just take a guess:  half the max.
>>> t = img_g.max() / 2.0
>>> thresh = img_g > t

>>> fig, (ax0, ax1, ax2) =
plt.subplots(nrows=3)
>>> ax0.imshow(img_g, cmap=plt.cm.Greys_r)
>>> ax0.set_title("Original image")
>>> ax0.axis("off")
>>> ax1.hist(img_g)
>>> ax1.set_title("Histogram, t=%2f"%t)
>>> ax1.axvline(t, color="r")
>>> ax2.imshow(thresh, cmap=plt.cm.Greys_r)
>>> ax2.set_title("Thresholded by
guesstimate")
>>> ax2.axis("off")
>>> plt.show()
```



Otsu's method chooses an "optimal" threshold automatically

```
>>> from skimage.filters import
threshold_otsu
>>> # Otsu determines "optimal" threshold.
>>> t = threshold_otsu(img_g)
>>> thresh = img_g > t

>>> fig, (ax0, ax1, ax2) =
plt.subplots(nrows=3)
>>> ax0.imshow(img_g, cmap=plt.cm.Greys_r)
>>> ax0.set_title("Original image")
>>> ax0.axis("off")
>>> ax1.hist(img_g)
>>> ax1.set_title("Histogram, t=%2f"%t)
>>> ax1.axvline(t, color="r")
>>> ax2.imshow(thresh, cmap=plt.cm.Greys_r)
>>> ax2.set_title("Thresholded by Otsu")
>>> ax2.axis("off")
```



Further reading (if you're interested)

- Watershed image segmentation

Thanks for your time!

- If you have any more questions about image processing or computer vision, please ask!
- (whether in person today, or by email in the future)

Some more short scripts to save you some typing...

- At https://github.com/jboy/ncss2016/part3