


浙江大学爱丁堡大学联合学院

ZJU-UoE Institute

Image histogram

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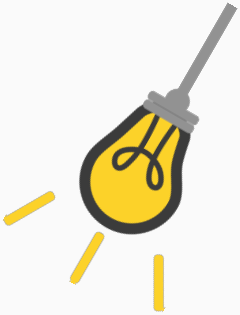
Learning objectives

- Define and produce an image histogram
- Use histograms to interpret image quality
- Apply point operations to manipulate image histograms



Outline

What is a histogram?

"A histogram is an approximate representation of the distribution of numerical data." (Wikipedia)

Given a variable x, in the interval $[x_{min}; x_{max}]$, we divide this interval (or a suitably larger one) into non-overlapping **bins** and count the number of values of x falling into each bin.
Generally, we choose bins to be of equal size.

Histogram example

Given $x = 5, 7, 10, 22, 35, 88, 26, 74, 22, 95$

We can choose the interval $[0; 99]$, and divide it into bins of size 10 $[0 : 9][10; 19] \ldots [90 : 99]$

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We now count the occurrences of x in each bin.

$$[0 : 9] \rightarrow 2$$

$$[1 : 10] \rightarrow 1$$

...and so on

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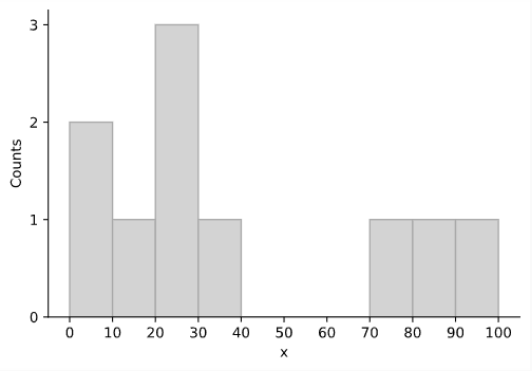


x =	5	7	10	22	35	88	26	74	22	95

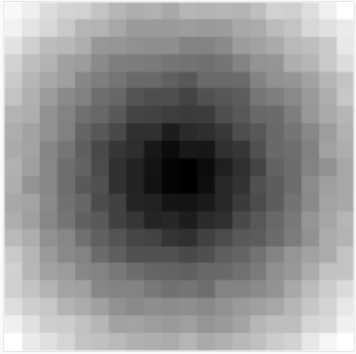
Histogram of an image

Images are just matrices, so we can count the occurrences of each pixel value in the image.

Example

An 8-bit image, 20 x 20

```
> print(img.shape)
(20, 20)
>print(np.min(img))
0
>print(np.max(img))
100
```



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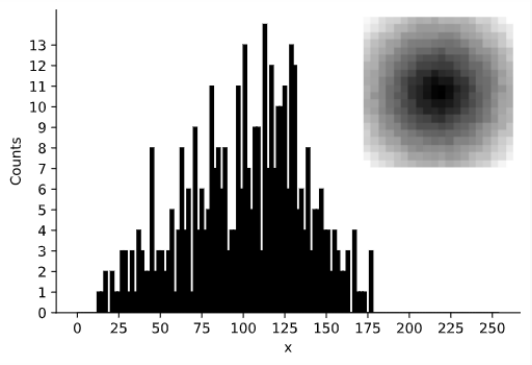
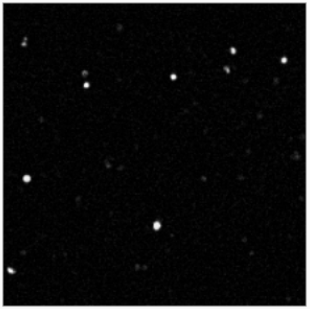
Maximum dynamic range [0, 255]
We count the occurrences of each pixel with intensity between 0 and 255.

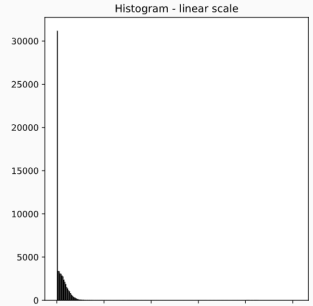


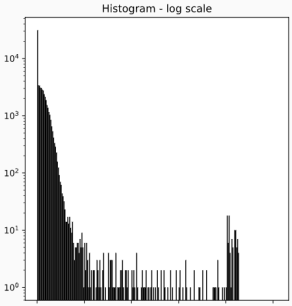
What can you tell about the image from looking at the histogram?

Logarithmic scale

We can plot the histogram on a logarithmic scale. Useful when images contain many pixels of a specific intensity (e.g. cells on a black background).

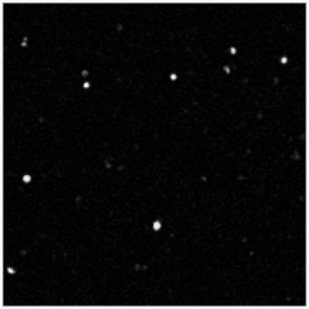


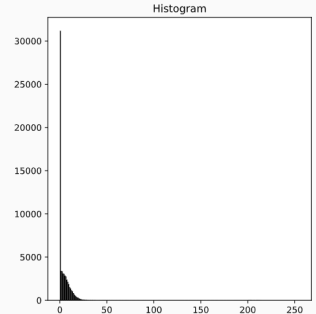


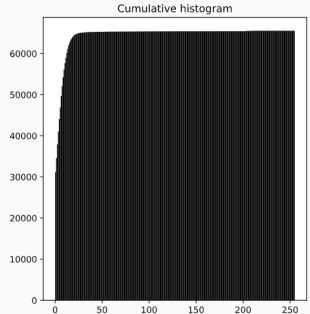


Cumulative histogram

Alternatively, we can plot a cumulative histogram (see later for uses). Each bar is the count of pixels with intensity between 0 and the corresponding bin.

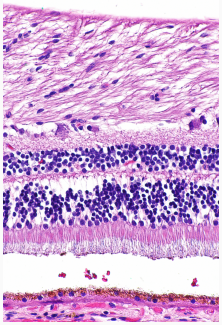




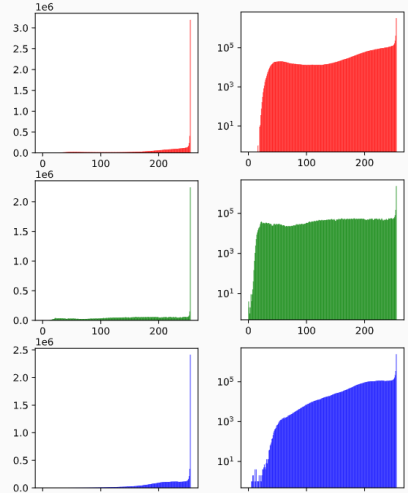


Histograms of RGB images

For RGB (or multi-channel) images, it makes sense to have a single histogram per channel



H&E staining of retina (cell nuclei stained blue-purple and extracellular material stained pink)
Librepath - CC BY-SA 3.0



RGB histogram - left linear, right logarithmic.

Histograms are destructive

It is important to remember that producing a histogram is a destructive operation. We can generate a histogram from an image, but cannot recreate the image from the histogram.

These three images have the same histogram!

Drawing a histogram using Matplotlib

The Matplotlib `hist` function makes it very easy to plot a histogram

```
import matplotlib.pyplot as plt
img = io.imread("cells.tif")

fig, ax = plt.subplots(1, 2, figsize=(12, 6))
# Linear
ax[0].hist(img.ravel(), bins=range(255), color="black")
ax[0].set_title("Histogram - linear scale")
```

The `bins` parameter accepts either a sequence defining the bins edges, or a single value with the number of desired bins.

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# Linear
ax[0].hist(img.ravel(), bins=range(255), color="black")
ax[0].set_title("Histogram - linear scale")
# Log
ax[1].hist(img.ravel(), bins=range(255), color="black", log=True)
ax[1].set_title("Histogram - log scale")
plt.show()
```

The `bins` parameter accepts either a sequence defining the bins edges, or a single value with the number of desired bins.

Outline

Brightness

The **brightness** of an image is the average intensity of all its pixels

$$B(I) = \frac{1}{w * h} \sum_{r=1}^{h} \sum_{c=1}^{w} I(r, c)$$

Where w and h are the width and height of the image, and $I(r, c)$ is the intensity of the pixel at row r and column c.

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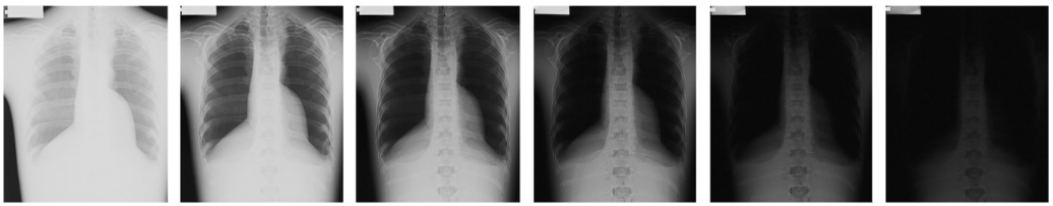
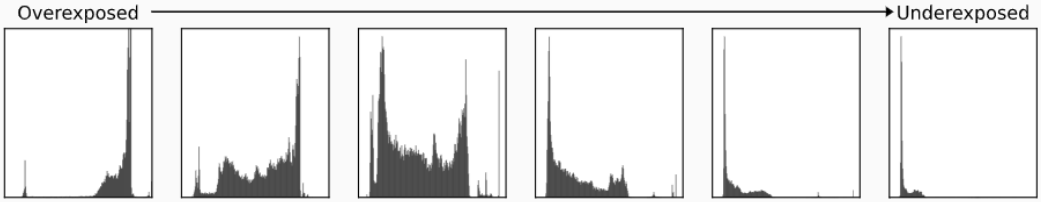
Brightness example



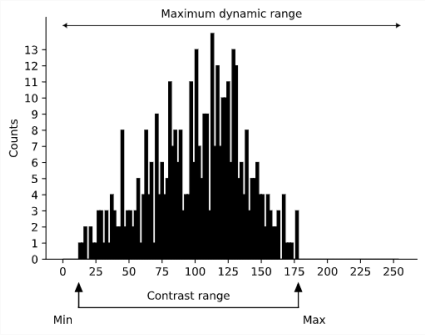
Same X-ray, decreasing brightness - Image from Veldkamp et al., 2009



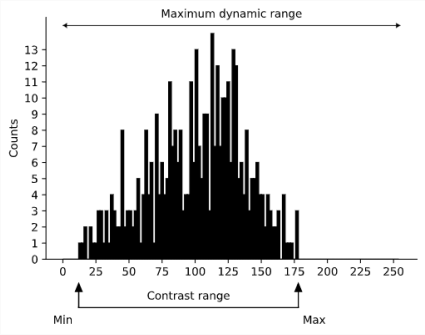
Overexposed

Contrast

Contrast is *the difference in luminance or colour that makes an object distinguishable* (Wikipedia). It measures the relationship between light and dark pixels.



Contrast



Contrast is *the difference in luminance or colour that makes an object distinguishable* (Wikipedia). It measures the relationship between light and dark pixels. Many different definitions in the literature (see Peli, *J. Opt. Soc. Am. A*, 1990)

Weber contrast (range $0 \to \infty$)

$$\frac{I_{obj} - I_{bg}}{I_{bg}}$$

Michelson contrast (range $0 \to 1$)

$$\frac{I_{max} - I_{min}}{I_{max} + I_{min}}$$

RMS contrast

$$\sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

where x is the normalised intensity $0 \leq x \leq 1$

Point operations and neighborhood operations

Manipulating pixel intensities allows enhancement of images.

Two types of operations:

- Point operations - Change pixel intensity based only on its value
- Neighborhood operations - Change pixel intensity based on the intensity of the pixel and its neighbours.

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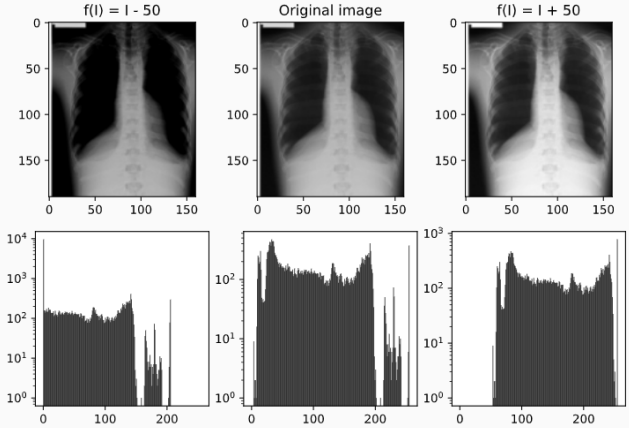
So, the resulting intensity I' of a point operation is $I'_{(x,y)} = f(I_{x,y})$.

Manipulating brightness

We can easily change an image brightness by using a point operation $f(I_{x,y}) = I_{x,y} + \mathit{offset}$, which shifts the image histogram to the left or to the right.



What is happening to the histograms?

Example code for brightness manipulation

```
from skimage import img_as_float, img_as_ubyte

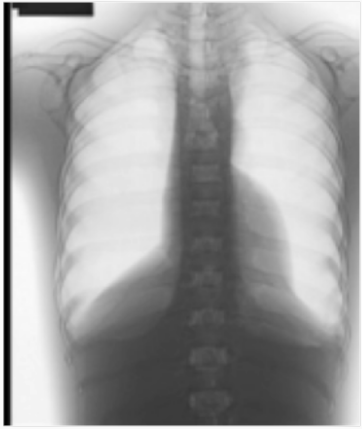
def change_brightness(img, offset):
   """
   Changes the brightness of an image
   img:  the image
   offset:  the brightness offset to apply
   """

   img2 = img_as_float(img)
   img2 += offset/255
   img2[img2<0]=0
   img2[img2>1]=1
   return (img_as_ubyte(img2))

img_2 = change_brightness(img, 10)
```

Your turn!

Can you think of a point operation to invert an image? What happens to the histogram? Write your own Python function to do this!



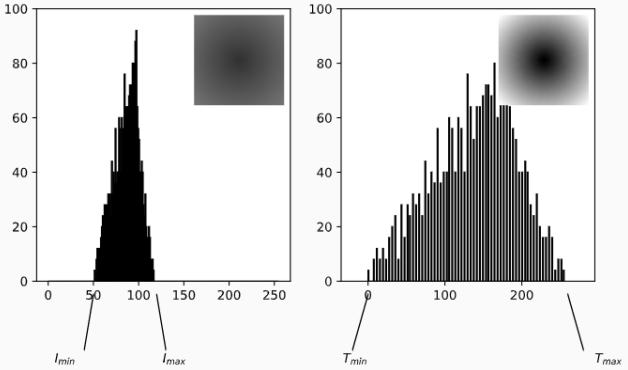
Manipulating contrast - histogram stretching

A simple way of increasing the contrast of an image is to stretch its histogram.

Simplest form:

$$I' = (I - I_{min})\frac{T_{max} - T_{min}}{I_{max} - I_{min}} + max$$

Where I_{min} and I_{max} are the minimum and maximum intensity of the image, and T_{min} and T_{max} are the minimum and maximum intensity of the target histogram.



This can easily be skewed by a few values, so we can use the 2^{nd} and 98^{th} percentiles instead of the I_{min} and I_{max} values.

Histogram stretching in Python

```
import numpy as np
from skimage.exposure import rescale_intensity

img_rescale = rescale_intensity(img, in_range=(0, 100), out_range=(0, 255))
```

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from skimage.exposure import rescale_intensity

img_rescale = rescale_intensity(img, in_range=(0, 100), out_range=(0, 255))
# Or, use the percentile version:
# Calculate the 2nd and 98th percentiles
p2, p98 = np.percentile(img, (2, 98))
img_rescale = rescale_intensity(img, in_range=(p2, p98), out_range=(0, 255))
```

Histogram equalization

Histogram matching