Image Processing

Image Enhancement in the Spatial Domain

PhD, Associate Professor Leyla Muradkhanli

Spatial Domain

What is spatial domain?

The spatial domain refers to the space in which the image is represented by its pixels.

An image in the spatial domain is represented as a 2D function (f(x, y)), where (x) and (y) are spatial coordinates (pixels) and the function value corresponds to the intensity or color value at that point.

When we talk about image processing in the spatial domain, it means directly manipulating the pixel values of an image to improve it or extract information.

Spatial Domain

Spatial domain techniques operate by modifying the pixel values directly.

Common spatial domain operations include:

- Brightness adjustment
- Contrast enhancement
- Image smoothing or sharpening
- Thresholding

Types of Image Enhancement in the Spatial Domain

Spatial Domain Techniques

- These operate directly on pixel values.
- Used to modify contrast, brightness, sharpness, etc.

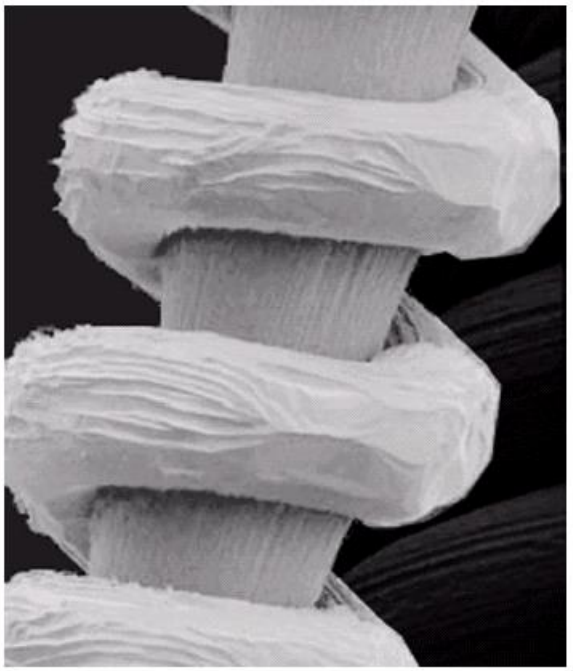
Common Spatial Techniques:

Method	Description
Contrast Adjustment	Stretch or compress the range of intensity values.
Histogram Equalization	Distributes pixel intensities more uniformly.
Smoothing (Blurring)	Reduces image noise and detail.
Sharpening	Highlights edges and fine details.
Image Negatives	Inverts brightness to emphasize features.
Thresholding	Converts grayscale to binary image for segmentation.

Image Enhancement

Image Enhancement means improvement of images to be suitable for specific applications.

Example:



Note: each image enhancement technique that is suitable for one application may not be suitable for other applications.

Image Enhancement Example

Original image

Enhanced image using
Gamma correction

Image Enhancement in the Spatial Domain

Image enhancement using processes performed in the Spatial domain results in images in the Spatial domain.

We can write it as $g(x,y) = T[f(x,y)]$

where f(x,y) is an original image, g(x,y) is an output and T[ ] is a function defined in the area around (x,y)

Note: T[ ] may have one input as a pixel value at (x,y) only or multiple inputs as pixels in neighbors of (x,y) depending in each function.

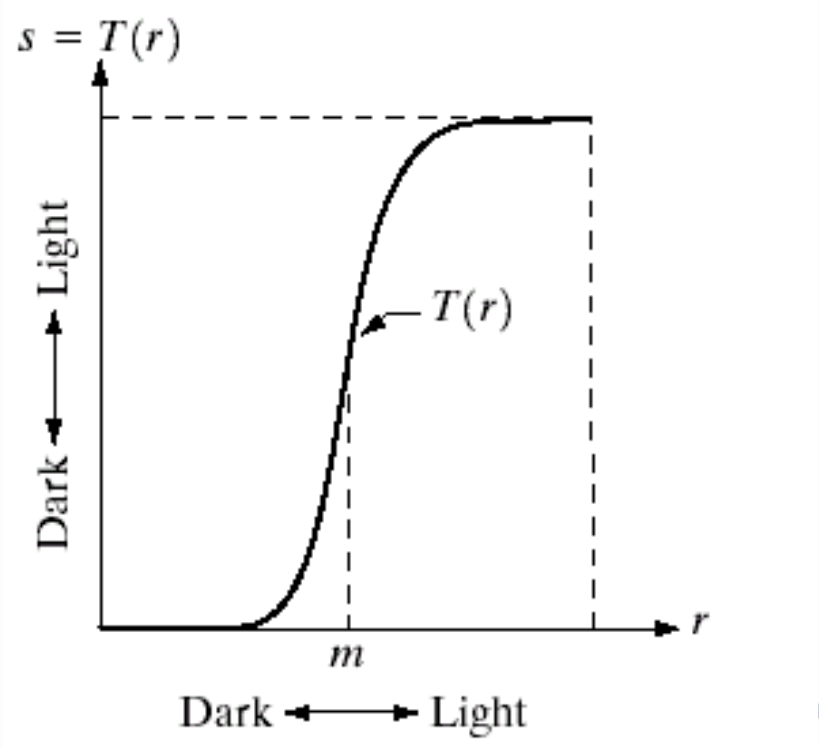
Ex. Contrast enhancement uses a pixel value at (x,y) only for an input while smoothing filter use several pixels around (x,y) as inputs.

Gray Level Transformation

Transforms intensity of an original image into intensity of an output image using a function:

$$s = T(r)$$

where r = input intensity and s = output intensity



Example:
Contrast enhancement

Histogram

Histograms are a way of visualizing the predominant intensities of an image. As a definition, image histograms are a count of the number of pixels that are at a certain intensity. When represented as a plot, the x-axis is the intensity value, and the y-axis is the number of pixels with that intensity value.

Histogram

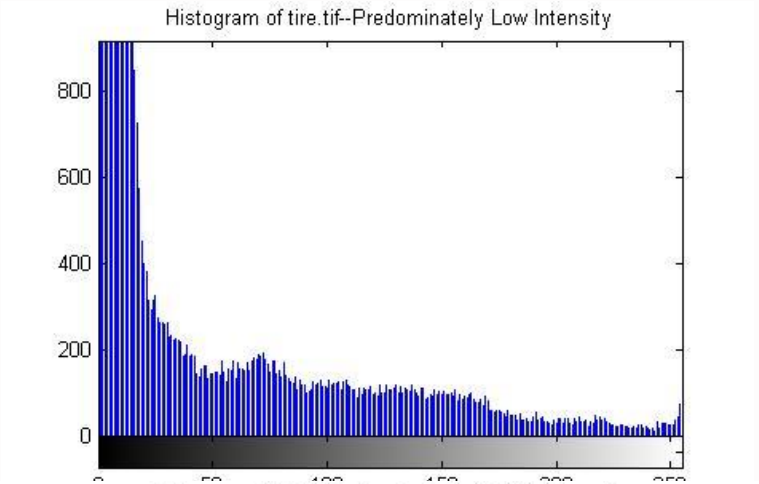
It is a graphical representation of the intensity distribution of an image. It quantifies the number of pixels for each intensity value considered.

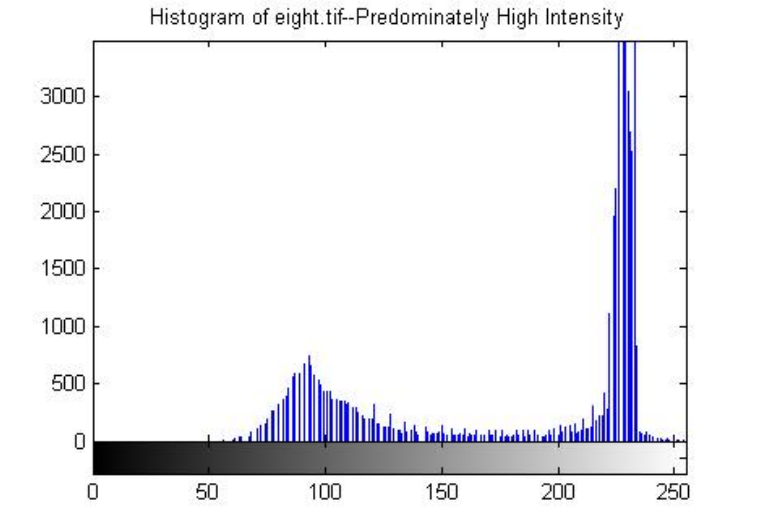
Histogram

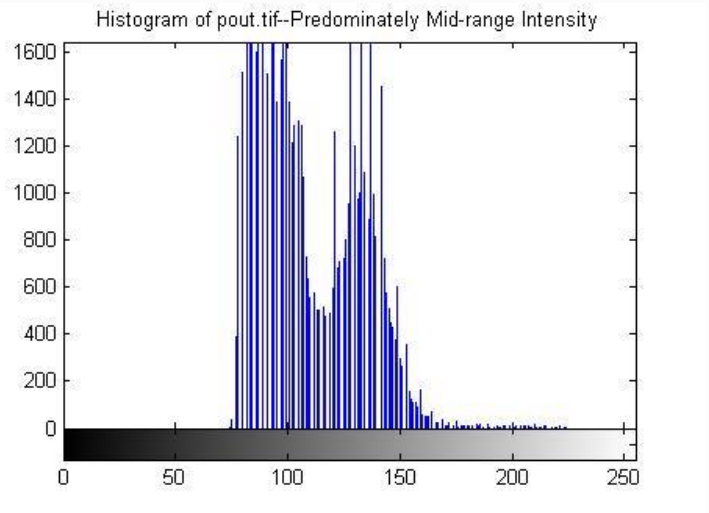
Histogram is considered as a graph or plot which is related to frequency of pixels in an Gray Scale Image with pixel values (ranging from 0 to 255). Grayscale image is an image in which the value of each pixel is a single sample, that is, it carries only intensity information where pixel value varies from 0 to 255. Images of this sort, also known as black-and-white, are composed exclusively of shades of gray, varying from black at the weakest intensity to white at the strongest where Pixel can be considered as a every point in an image.

Histogram

The following are examples of histograms with predominately low, mid and high range intensities.

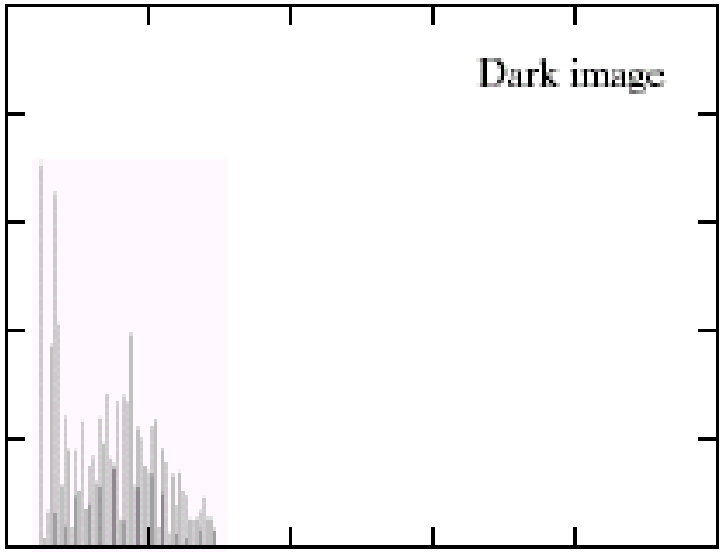






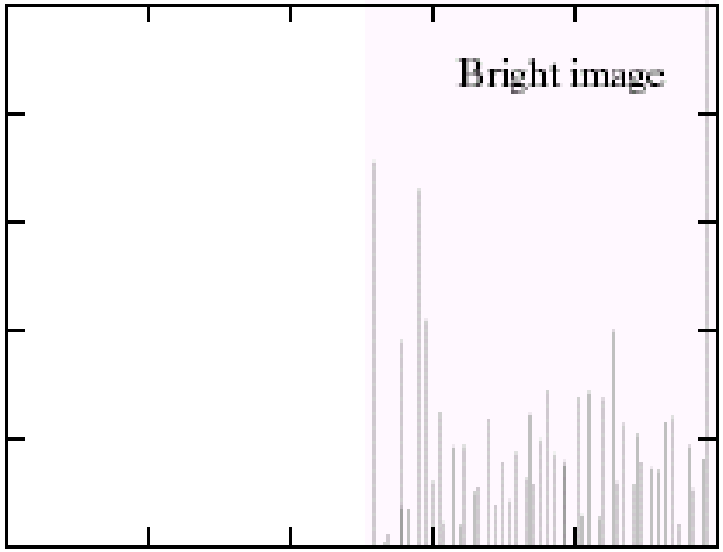
Histogram of an Image

graph of no. of pixels vs intensities



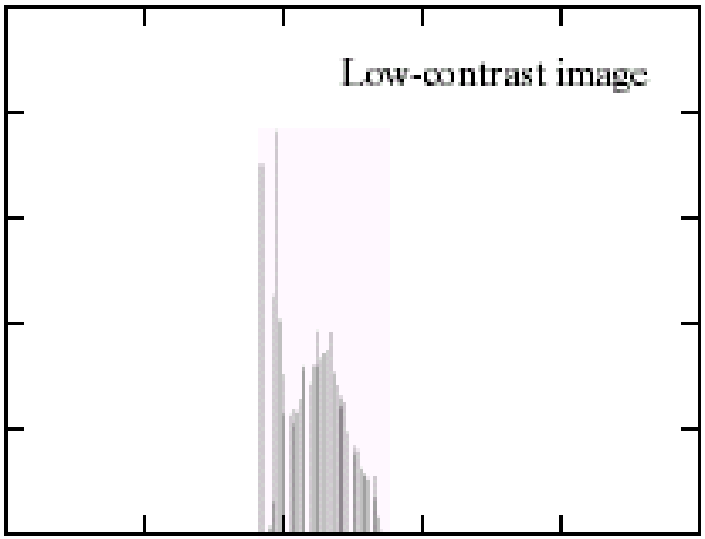
$$h(r_k) = n_k$$

Dark image has histogram on the left

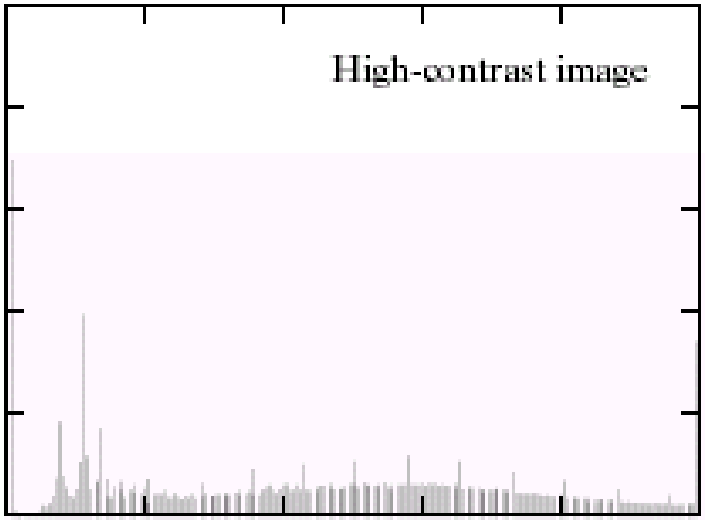


Bright image has histogram on the right

Histogram of an Image



low contrast image
has narrow histogram



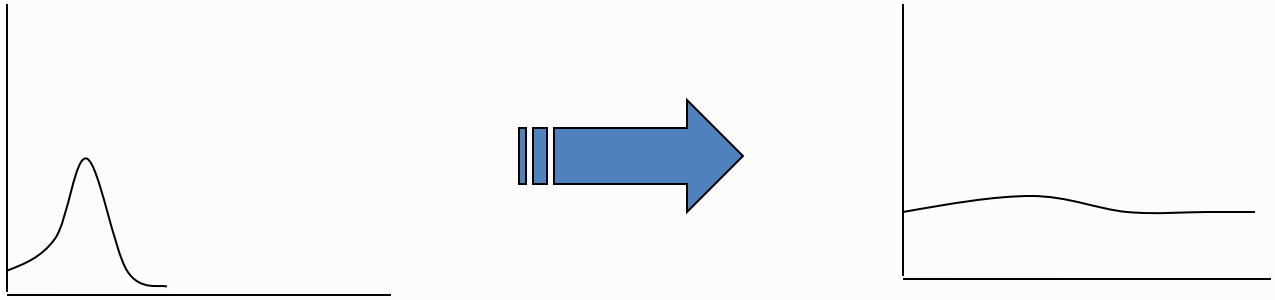
high contrast image
has wide histogram

Histogram Processing

Intensity transformation based on histogram information to yield desired histogram

- Histogram equalization

To make histogram distributed uniformly



- Histogram matching

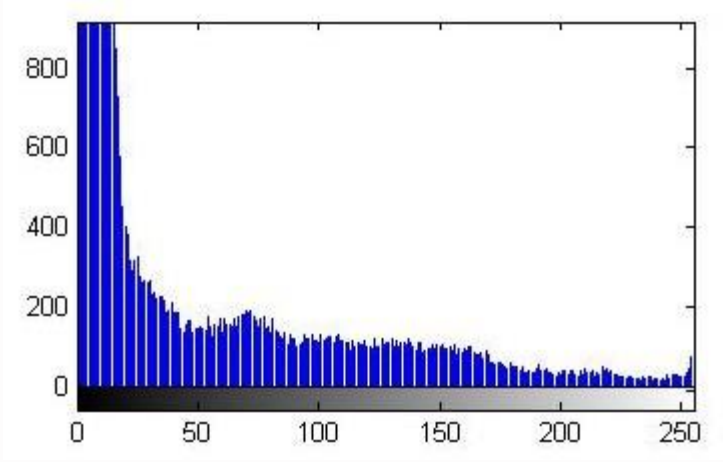
To make histogram as the desire

Histogram Equalization

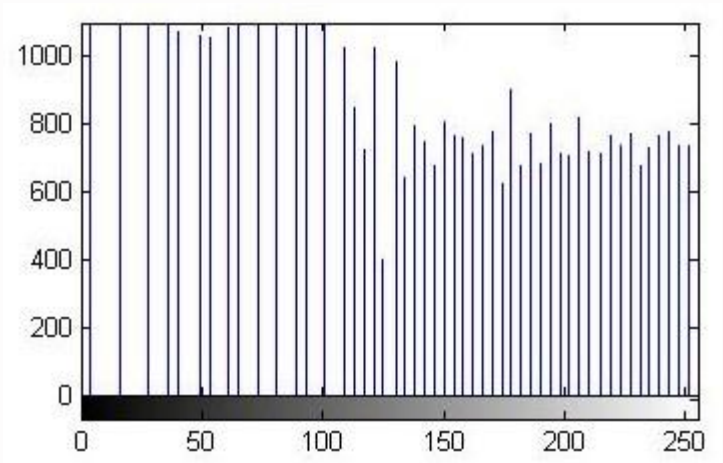
The idea behind **Histogram Equalization** is that we try to evenly distribute the occurrence of pixel intensities so that the entire range of intensities is used more fully. We are trying to give each pixel intensity equal opportunity; thus, equalization. Especially for images with a wide range of values with detail clustered around a few intensities, histograms will improve the contrast in the image.

Histogram Equalization

Original



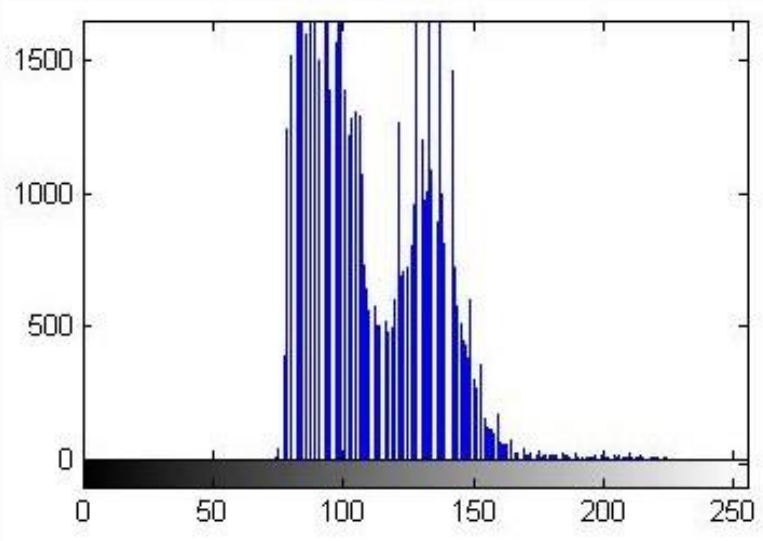
With Histogram Equalization



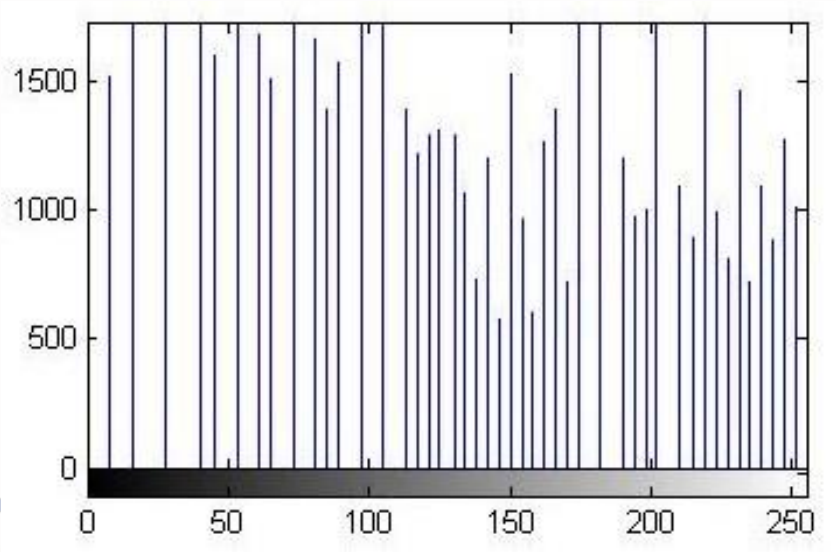
Histogram Equalization

Mid Range Intensities

Original



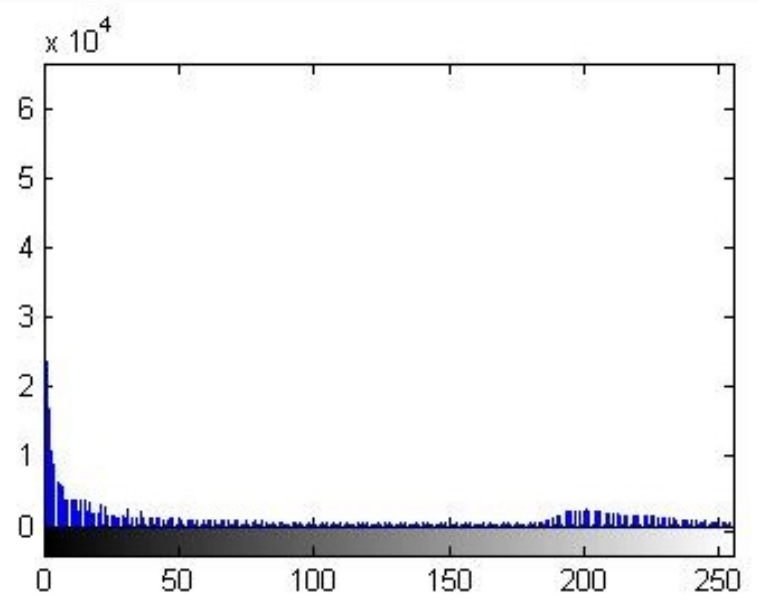
With Histogram Equalization



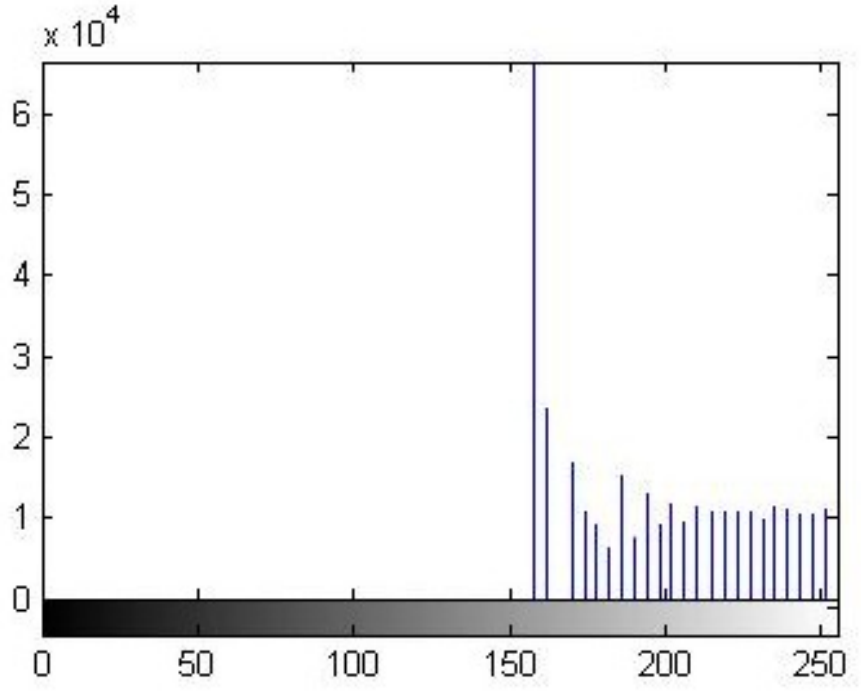
Histogram Matching

Sometimes, histogram equalization does not produce the contrast or results that we expect. Consider the following example

Original



Histogram Matching



With Histogram Equalization

Histogram Matching

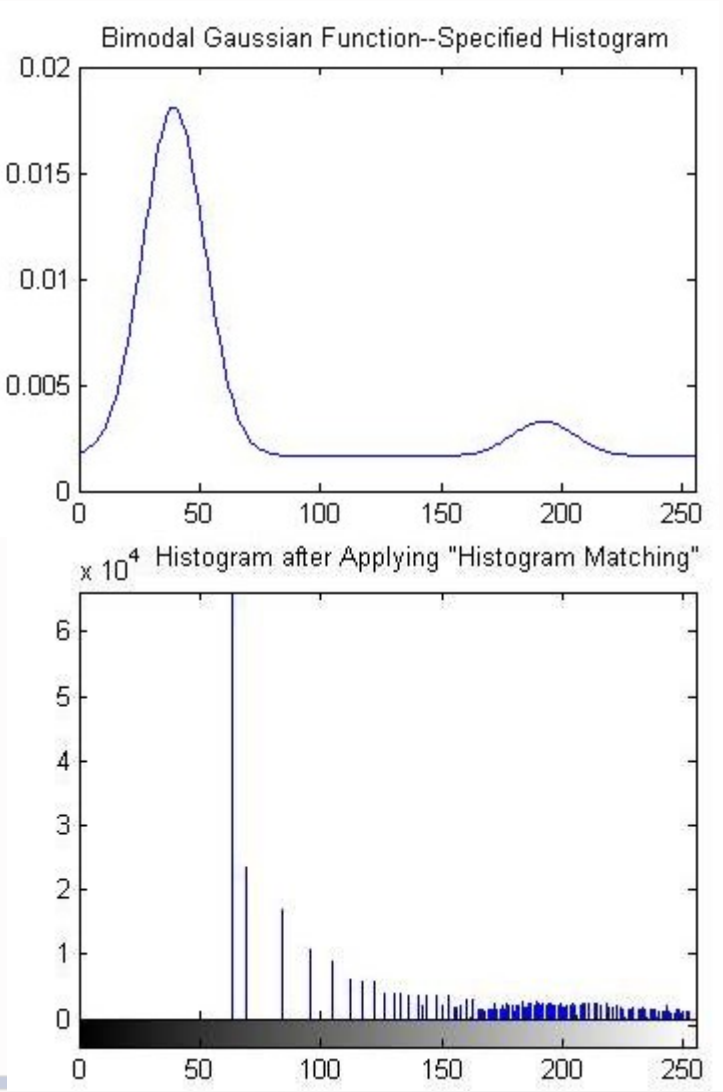
You will notice that there are very few low intensity values in the histogram equalized image above.
To fix this, we will use histogram matching (or histogram specification).
To provide some background, histogram equalization tries to create an equal probability of each intensity occurring. This equal probability is represented by a horizontal line. If you wanted to emulate the results above, you could pass a horizontal line as a second argument to histeq.

Histogram Matching

With histogram matching, we provide a multimodal (multi-peaked) Gaussian function as an argument to histeq. In contrast to the horizontal line of histogram equalization, the Gaussian function specifies that certain intensity ranges will have more probability of occurring than others. To speak intuitively, by passing a multimodal Gaussian function as a second argument to histeq, the modified image histogram will have peaks that approximately match the peaks of the Gaussian function.

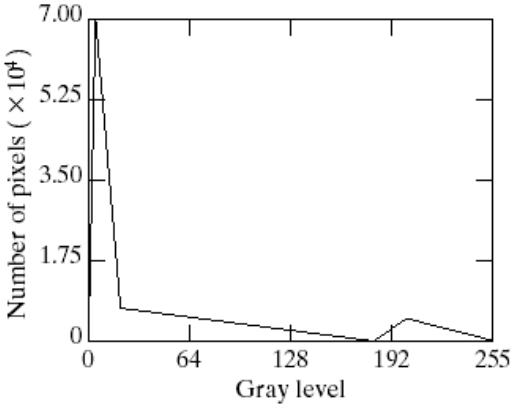
Histogram Matching

Note this approximate match in the moon example below:

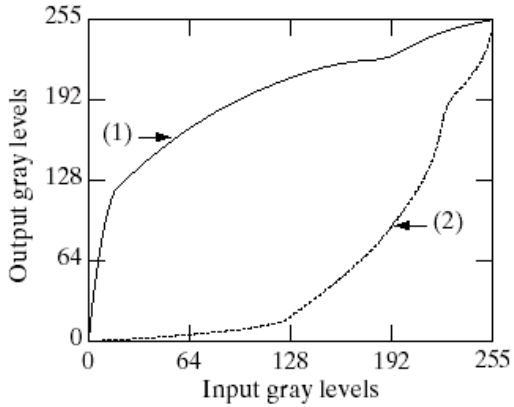


Histogram Matching Example

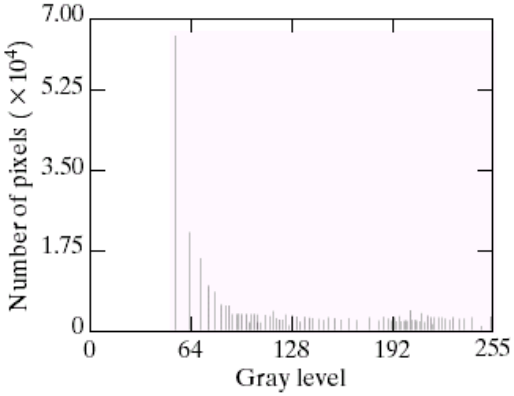
Desired histogram



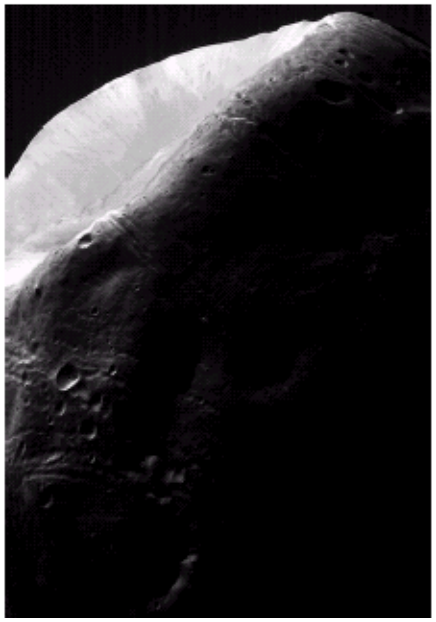
Transfer function

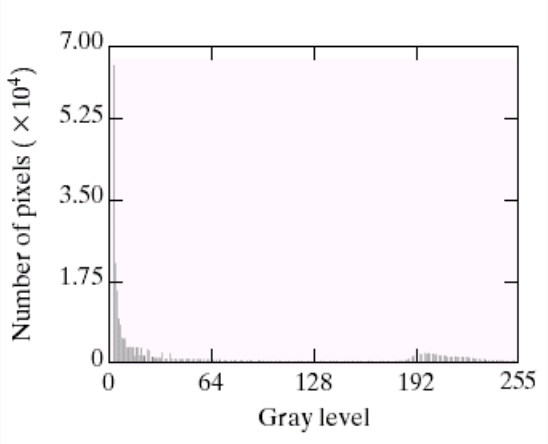


Actual histogram

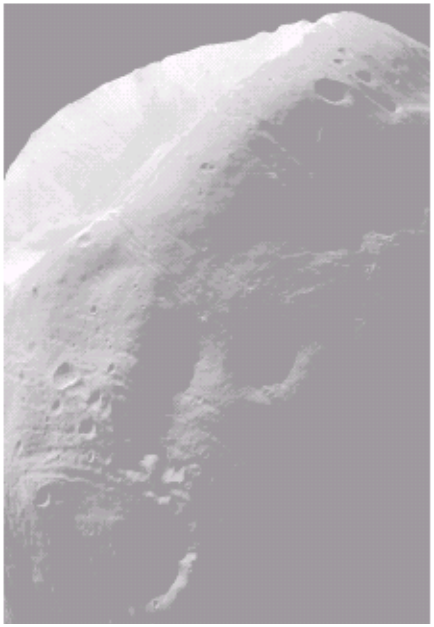


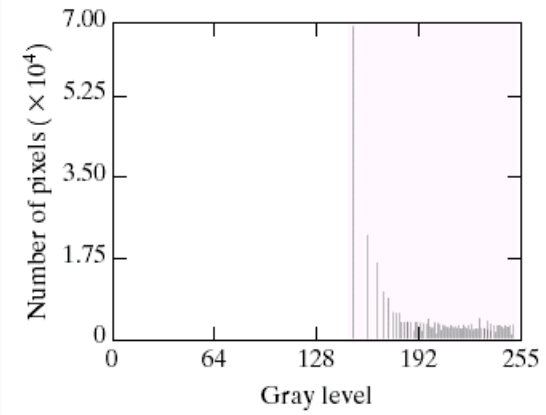
Histogram Matching Example



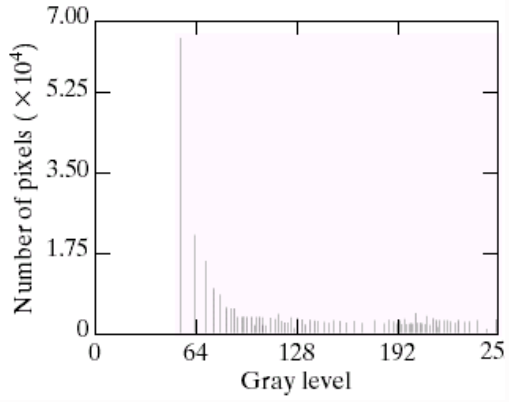


Original image





After histogram equalization



After histogram matching