Lab 2

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Autumn 2024-25

Review

Sampling affects spatial resolution by determining the density of pixels and, consequently, the level of detail captured in the image.

Quantization affects intensity resolution by determining how many different intensity values can be represented, impacting the image's tonal richness.

Aliasing: Occurs when the sampling rate is too low to capture the detail in the image, leading to distortion.

Quantization Error: The difference between the actual continuous intensity and the quantized value.

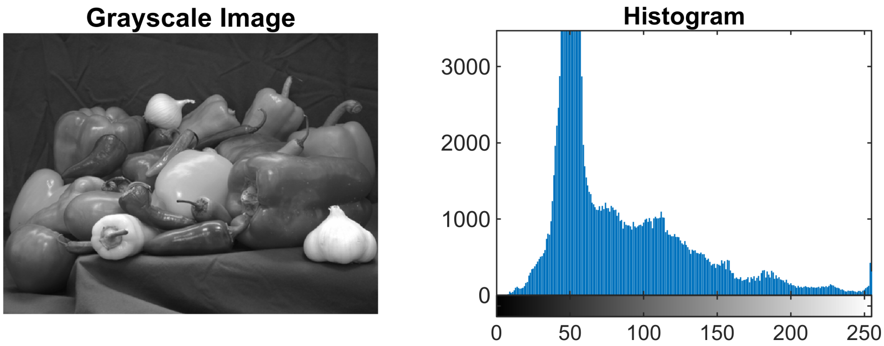
Histograms

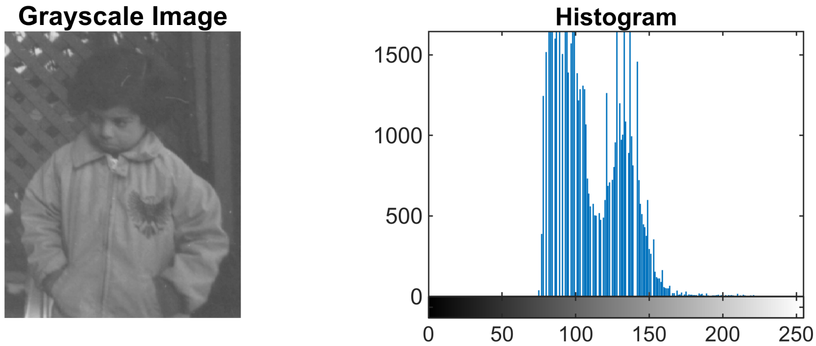
An image histogram is a *graphical* representation that shows the distribution of pixel intensity values in an image.

Applications: [Contrast enhancement, Thresholding, Analysis]

Example 1: Create and Interpret Histogram

```
% read the image
img = imread('peppers.png');
img_2 = imread('pout.tif');

% for simplicity, convert rgb images into grayscale
gray_img = rgb2gray(img);

figure;
subplot(2,2,1)
imshow(gray_img);
title('Grayscale Image');
% show its histogram
subplot(2,2,2)
imhist(gray_img);
title('Histogram');
subplot(2,2,3)
imshow(img_2);
title('Grayscale Image');
% show its histogram
subplot(2,2,4)
imhist(img_2);
title('Histogram');
```





Interpret the histogram

Dark Image: Histogram peaks at lower intensity values.

Bright Image: Histogram peaks at higher intensity values.

Low Contrast: Histogram is narrow and concentrated.

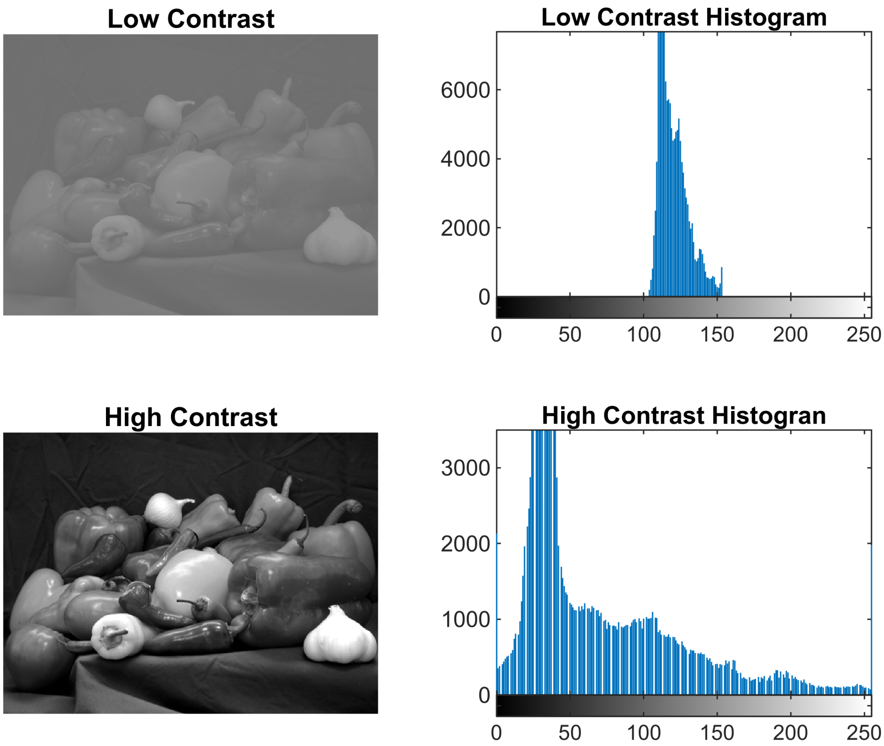
High Contrast: Histogram spans a wide range of intensity values.

Example 2: Adjusting Contrast

Contrast refers to the difference in luminance or color that makes an object distinguishable.

```
% Create low contrast image from the grayscale version
low_contrast = imadjust(gray_img, [0 1], [0.4 0.6]);

% Create high contrast image from the grayscale version
high_contrast = imadjust(gray_img, stretchlim(gray_img), [0 1]);

% Plotting
figure;
subplot(2,2,1);
imshow(low_contrast);
title('Low Contrast');

subplot(2,2,3);
imshow(high_contrast);
title('High Contrast');
```

```
subplot(2,2,2);
imhist(low_contrast);
title('Low Contrast Histogram')

subplot(2,2,4);
imhist(high_contrast);
title('High Contrast Histogran');
```



Example 3: Histogram Equalization (Mathematically)

Histogram equalization is a **contrast enhancement** technique used in digital image processing. It improves the *global* contrast of an image by redistributing the intensity values so that they span the entire range of possible values.

In this example, we'll perform histogram equalization on a simple grayscale image with 8 intensity levels (0 to 7). We'll walk through each step mathematically to demonstrate how the process works.

Intensity Level r_k	**Number of Pixels** n_k
0	0
1	0
2	10
3	10
4	20
5	20

6	4
7	0
Total N	64

Solution

Step 1: Compute the Probability Density Function (PDF) using the formula: $p_k = \frac{n_k}{N}$

Step 2: The CDF accumulates the probabilities up to each intensity level using the formula: $s_k = \sum_{j=0}^{k} p_j$

Step 3: Compute the transformation function using the formula: $s_k^{'} = \lfloor (L-1) \times s_k \rfloor$, where L is the number of intensity levels)

Step 4: Perform mapping to get the new frequencies.

r_k	n_k	p_k	s_k	$s_k^{'}$	$n_k^{'}$
0	0	$\frac{0}{64} = 0$	0	$\lfloor (8-1) \times 0 \rfloor = 0$	0
1	0	$\frac{0}{64} = 0$	0	$\lfloor 7 \times 0 \rfloor = 0$	10
2	10	$\frac{10}{64} = 0.1562$	0.1562	$\lfloor 7 \times 0.1562 \rfloor \approx 1$	10
3	10	$\frac{10}{64} = 0.1562$	0.3124	$\lfloor 7 \times 0.3124 \rfloor \approx 2$	0
4	20	$\frac{20}{64} = 0.3125$	0.6248	$\lfloor 7 \times 0.6284 \rfloor \approx 4$	20
5	20	$\frac{20}{64} = 0.3125$	0.9373	$\lfloor 7 \times 0.9373 \rfloor \approx 6$	0
6	4	$\frac{4}{64} = 0.0625$	0.9998 ($\approx$1)	$\lfloor 7 \times 0.9998 \rfloor \approx 7$	20
7	0	$\frac{0}{64} = 0$	0.9998 ($\approx$1)	$\lfloor 7 \times 0.9998 \rfloor \approx 7$	4

> The commands below are to help you check your calculations manually, next we'll perform histogram equalization with `histeq()` ***function in MATLAB***

```
% Create 8 intensity levels
r_k = 0:7
```

```
r_k = 1×8
     0     1     2     3     4     5     6     7
```

```
% Initialize the original frequencies
```

```
n_k = [0, 0, 10, 10, 20, 20, 4, 0]
```

```
n_k = 1×8
     0     0    10    10    20    20     4     0
```

```
N = sum(n_k)
```

```
N = 64
```

```
% Calculate the PDF
p_k = n_k / N
```

```
p_k = 1×8
         0         0    0.1562    0.1562    0.3125    0.3125    0.0625         0
```

```
% Calculate the CDF
s_k = cumsum(p_k)
```

```
s_k = 1×8
         0         0    0.1562    0.3125    0.6250    0.9375    1.0000    1.0000
```

```
L = 8
```

```
L = 8
```

```
% Apply transfotmation
s_k_new = floor((L-1) * s_k)
```

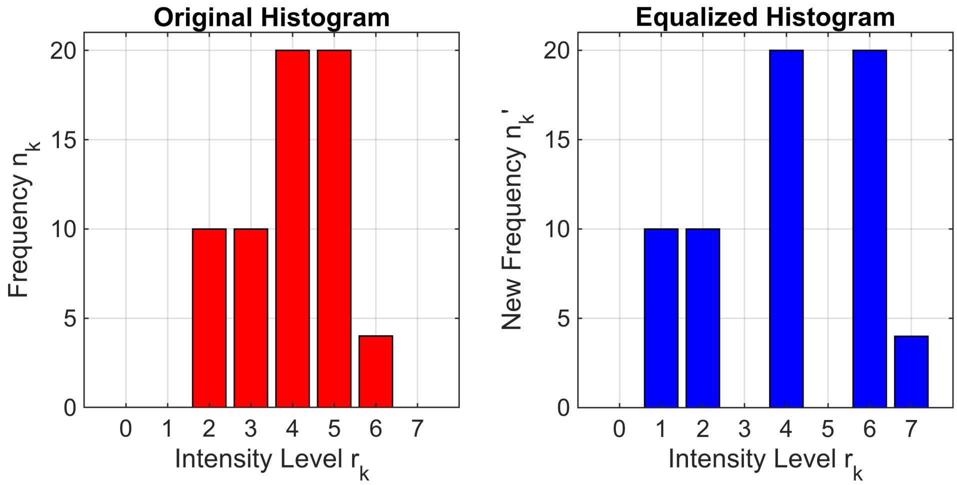
```
s_k_new = 1×8
     0     0     1     2     4     6     7     7
```

```
% If your calculations are right, these are the new frequencies after
% mapping.
n_k_new = [0, 10, 10, 0, 20, 0, 20, 4]
```

```
n_k_new = 1×8
     0    10    10     0    20     0    20     4
```

```
figure;
% Plot the original histogram
subplot(1,2,1)
bar(r_k, n_k, 'FaceColor', [1.0 0.0 0.0]);
title('Original Histogram');
xlabel('Intensity Level r_k');
ylabel('Frequency n_k');
xlim([-1.0 L]);
xticks(0:L-1);
ylim([0 max(n_k)+1]);
grid on
axis square
% Plot the equalized histogram
subplot(1,2,2)
bar(r_k, n_k_new, 'FaceColor', [0.0 0.0 1.0]);
title('Equalized Histogram');
xlabel('Intensity Level r_k');
ylabel("New Frequency n_k'");
xlim([-1.0 L]);
xticks(0:L-1);
ylim([0 max(n_k)+1]);
```

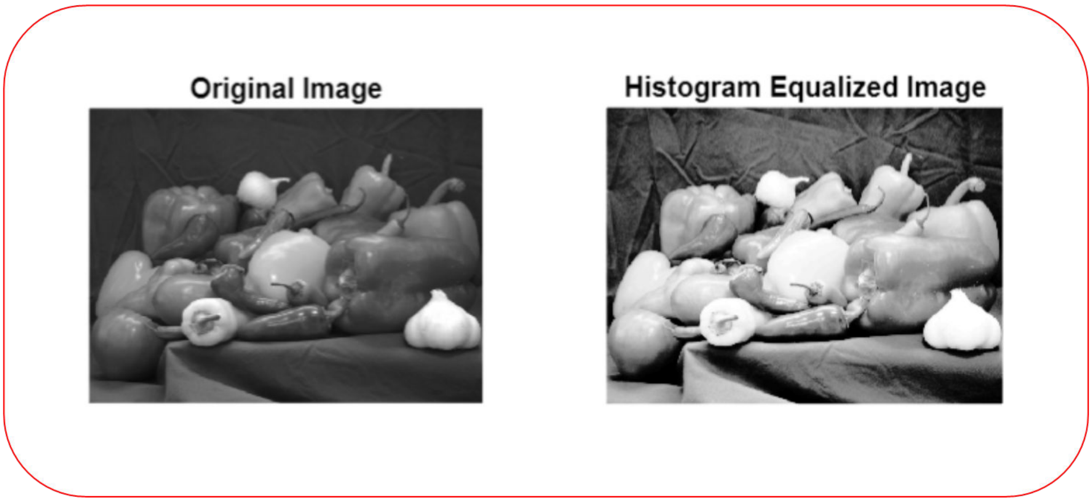
```
grid on
axis square
```



Example 4: Histogram Equalization with `histeq()`

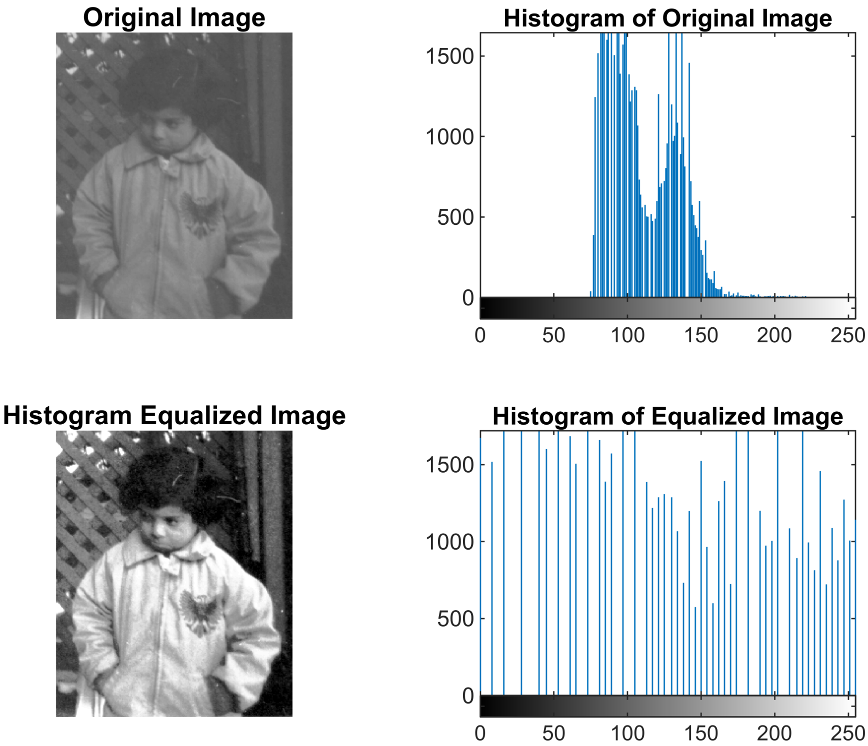
In this example we will use a new image other than the `peppers.png`. This is because it has a good contrast and applying histogram equalization on it will result in **unwanted over enhancement**. If you replaced the `pout.tif` image in the code below with the `peppers.png` you will get the following results:

```
% replace the first line in the code with this one.
org_img = rgb2gray(imread('peppers.png'));
```




```
% Import the image with bad contrast
org_img = imread('pout.tif');

% Apply histogram equalization
```

```
equalized_image = histeq(org_img);

% Display the original image
figure;
subplot(2, 2, 1);
imshow(org_img);
title('Original Image');

% Display the equalized image
subplot(2,2,3);
imshow(equalized_image)
title('Histogram Equalized Image');

% Display the histogram of the original image
subplot(2,2,2);
imhist(org_img);
title('Histogram of Original Image');

% Display the histogram of the equalized image
subplot(2,2,4);
imhist(equalized_image);
title('Histogram of Equalized Image');
```



Becareful when using Histogram Equaliztion as it has the followin limitations:

1. **Over-enhancement:** May amplify noise in homogeneous regions.
2. **Global Adjustment:** Affects the entire image uniformly, which might not be ideal for images with localized contrast issues.

3. **Loss of Original Intensity Relationships:** The process can alter the original intensity relationships, which might be important in some applications.