ICT2403 – Graphics and Image Processing

Intensity Transformation and Spatial Filtering – I
Intensity Transformation and Image Noise

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Learning Outcomes

- At the end of this lecture, you should be able to;
  - describe spatial domain of the digital image.
  - recognize the image enhancement techniques.
  - describe and apply the concept of intensity transformation.
  - express histograms and histogram processing.
  - describe image noise.
  - characterize the types of Noise.
  - describe concept of image restoration.

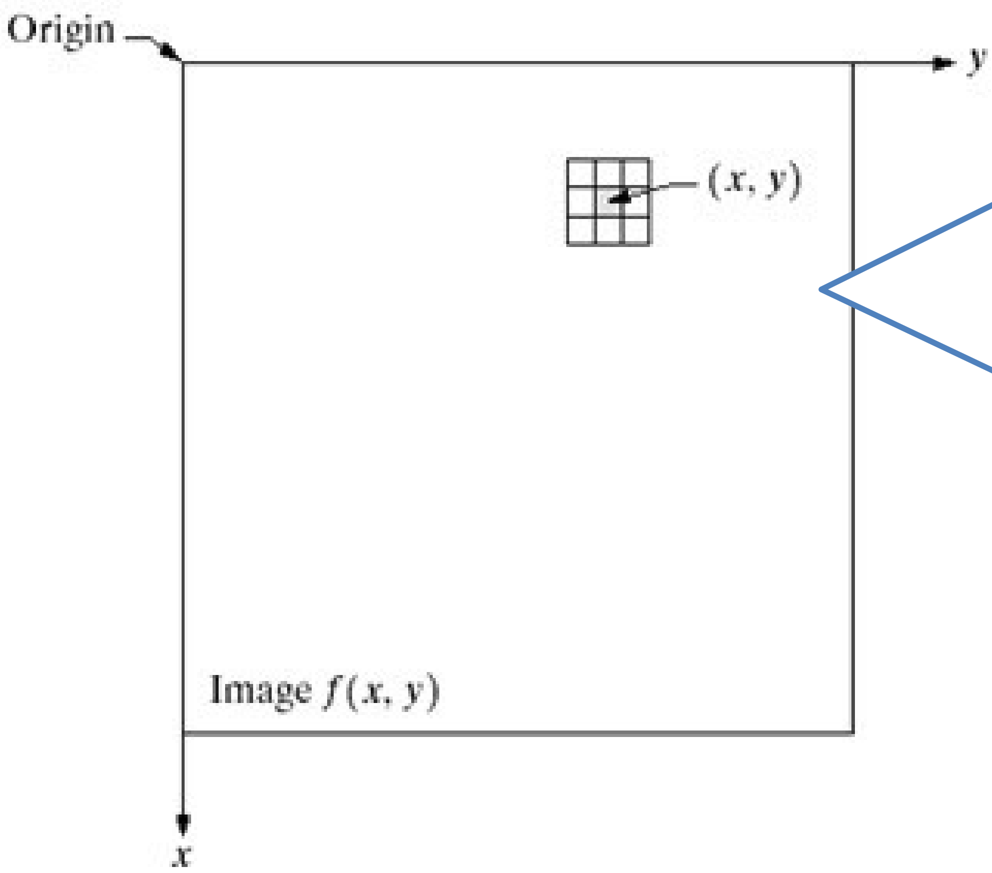
Spatial Domain

- The plain contains the pixels of an image.
- Spatial domain image processing techniques operate directly on the pixels of an image.
- Generally, these techniques are computationally more efficient and require less processing resources to implement.
- The spatial domain process can be express as:

$$\mathbf{G(x, y) = T\ [\ \mathit{f}(x,y)]}$$

Where, f(x, y) is the input image, g(x, y) is the output image, T is an operator on *f* defined over neighborhood of point (x, y)

Spatial Domain (cont….)



The principle approach in defining a neighborhood about a point (x,y) is to use a square or rectangular sub image area centered at (x,y)

Image Enhancement

- It is a process of manipulating an image so that the result is more suitable than the original for specific application.
- Enhancement techniques are problem oriented.

Intensity Transformation

- Intensity transformation can express as:

  $$s = T(r)$$

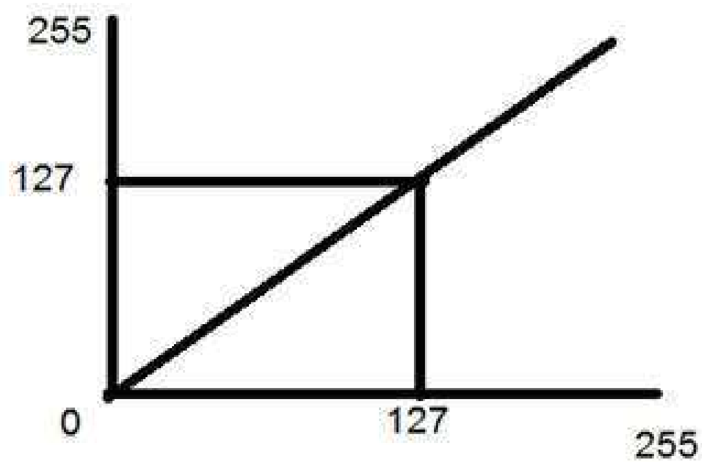
  Where transformation **T** maps a pixel value r into a pixel value s.

  The values of pixels before processing is denoted as **r** and after **s.**
- Image enhancement can be done through gray level transformations and there are three basic gray level transformations.
  - Linear
  - Logarithmic
  - Power – law

Linear transformation

- It includes simple identity and negative transformation.
  - Identity transformation

    $$g(x,y) = f(x,y)$$

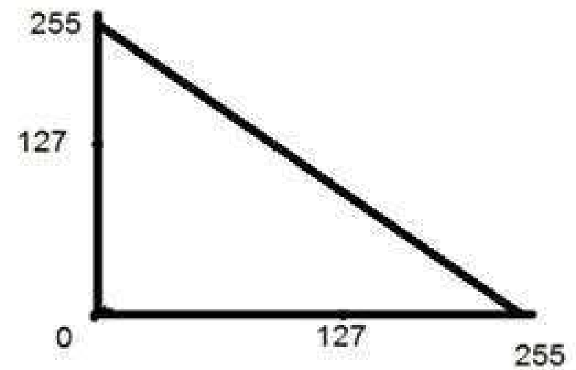


Linear transformation (cont…)

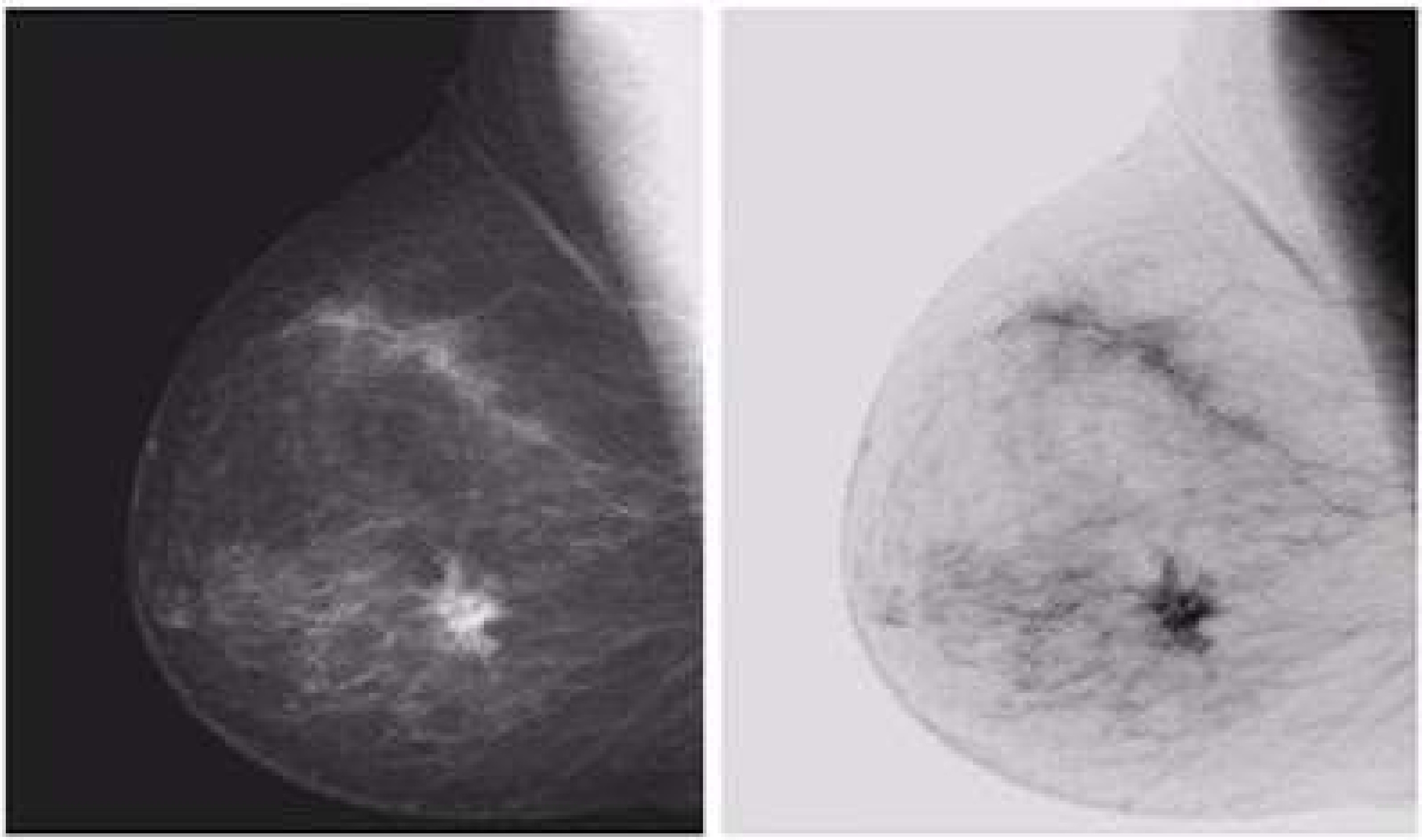
- **<u>Image Negetives</u>**
  - The negative of an image with gray levels in the range, [0, L-1] is obtained by using the negative transformation given by;

$$s = (L-1) - r$$

  - Reversing the intensity levels of an image in this manner produces a equivalent of photographic negative.
  - <u>This type of processing is particularly suitable for enhancing white or gray detail embedded in dark regions of an image, especially when the black areas are dominant in size.</u>



Linear transformation (cont...)



Log Transformation

- Logarithmic transformation further contains two type of transformation.
  - Log transformation
  - Inverse log transformation.
- The general form of log transformation is expressed using the equation given below;

$$s = c \log (1+r);$$

where c is a constant, and it is assumed that $r>=0$.

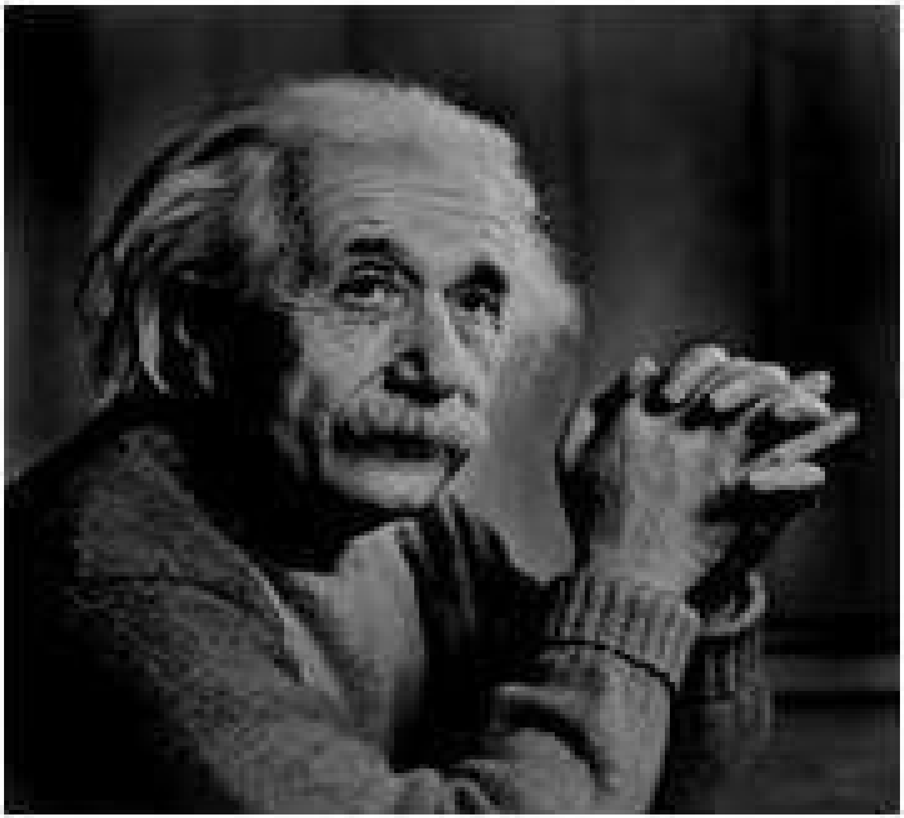
Log Transformation (cont…)

- This transformation maps a narrow range of low gray-level values in the input image into a wider range of output levels.
- We use this type of transformation to expand the values of dark pixels in an image while compressing the higher level values.
- The opposite is true of the inverse log transformation.

  Ex: Fourier spectrum

Log Transformation (cont…)

Input Image



Log Transformed Image

Power-Law (Gamma) Transformation

- The power law transformations have the basic form;

$$\boldsymbol{s = c\, r^{\gamma}}$$

where c and γ are positive constants.

- As in the case of log transformation, power law curves with fractional values of γ map narrow range of dark input values into a wider range of output values

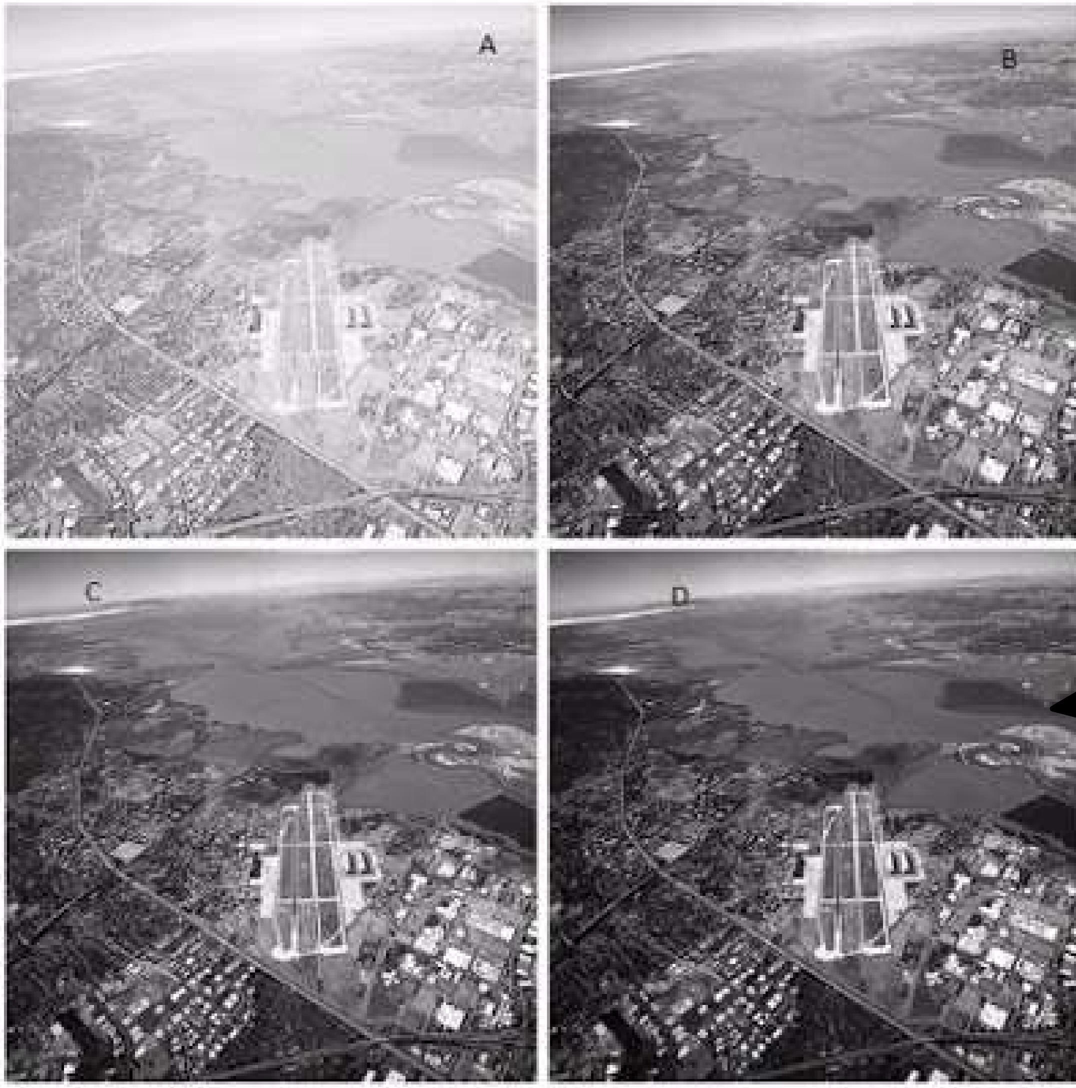
Power-Law (Gamma) Transformation (Cont…)

- A variety of devices used for image capture, printing and image display respond according to the power law.
- By convention, the exponent in the power law equation is referred to as **gamma**.
- The process used to correct this power-law response phenomenon is called **gamma correction.**
- Gamma correction is important if displaying an image accurately on a computer screen of is concern.

Power-Law (Gamma) Transformation (Cont…)

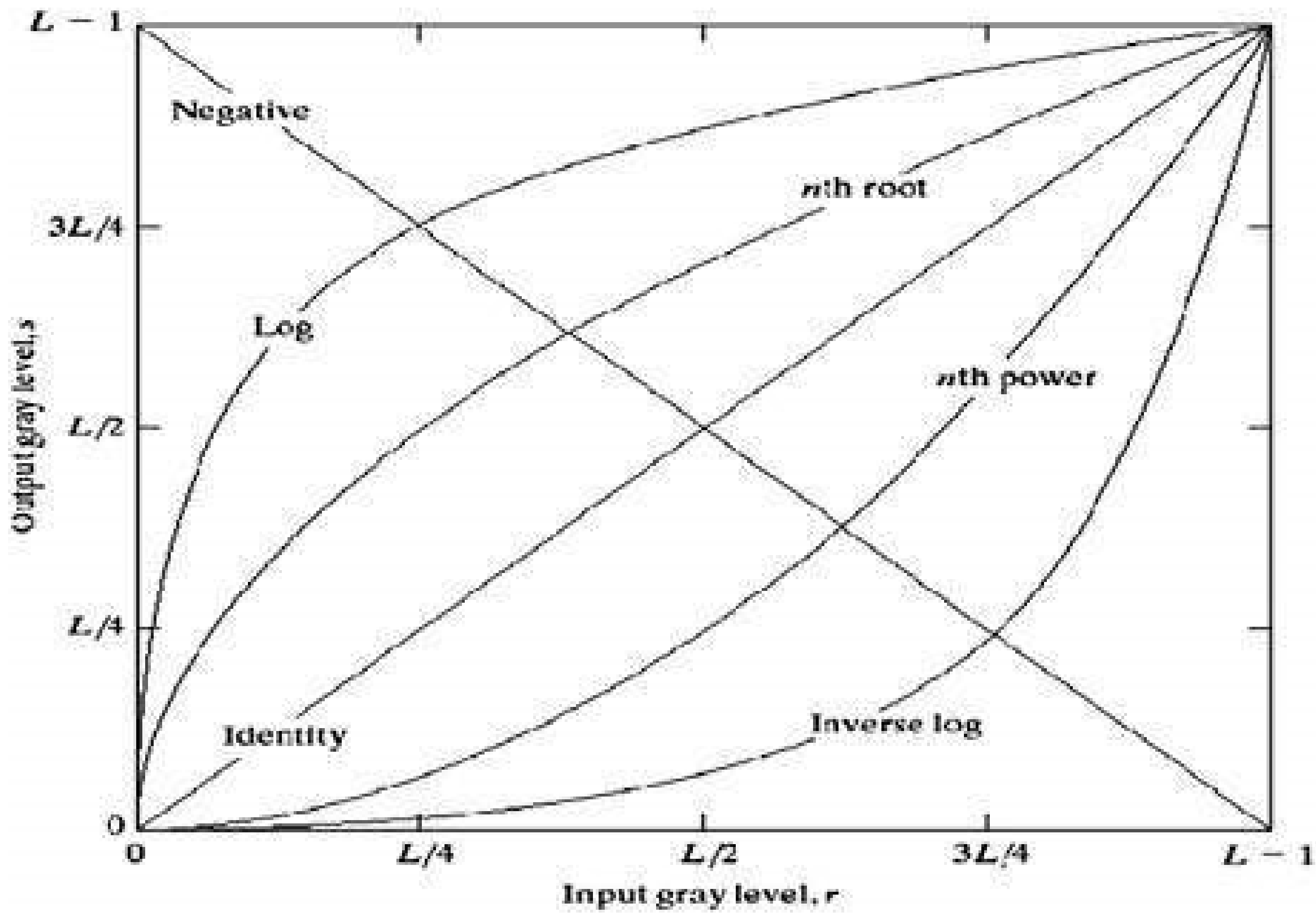
- Images that are not corrected properly can look either bleached out, or what is more likely, too dark.
- Trying to reproduce colors accurately also requires some knowledge of gamma correction because varying the values of gamma correction changes not only brightness, but also the ratio of red to green to blue.

Power-Law (Gamma) Transformation (Cont…)



(A) Areal image and (B)-(D) results of applying the transformation in power law transformation with c=1 and γ=*3.0, 4.0, 5.0* respectively

Intensity Transformation All in One

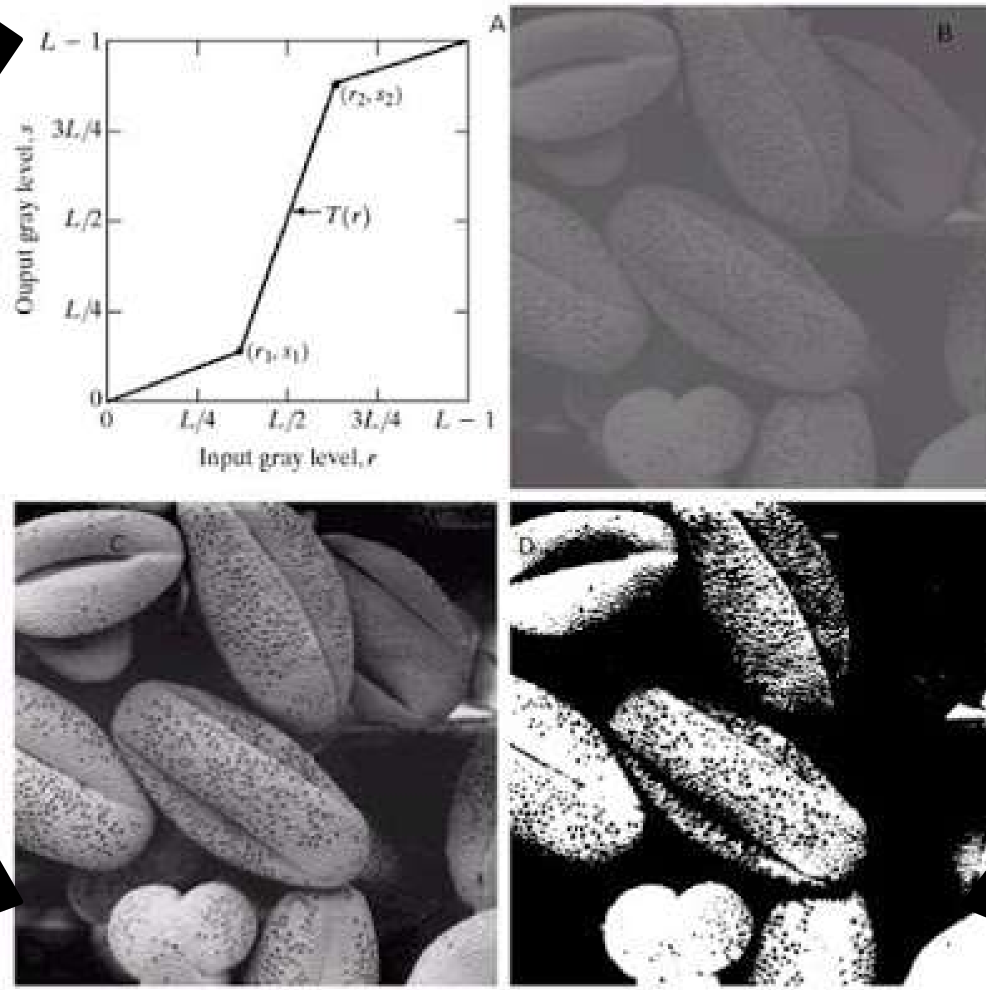


Piece wise Linear Transformation Functions

- ***<u>Contrast Stretching</u>***
  - Low contrast images can results from poor illumination, lack of dynamic range in the imaging sensor, or even wrong setting of a lens aperture during image acquisition.
  - The idea behind contrast stretching is to increase the dynamic range of the gray levels in the image being processed.

Piece wise Linear Transformation Functions (Cont…)

the location of points (r_1, s_1) and (r_2, s_2) control the shape of the transformation function



Result of contrast stretching obtained by setting $(r_1, s_1) = (r_{min}, 0)$ and $(r_2, s_2) = (r_{max}, L-1)$ where r_{min} and r_{max} denotes the min and max intensity levels in image

If $r_1 = r_2$, $s_1 = 0$ and $s_2 = L-1$, the transformation becomes a thresholding function that creates a binary image.

Piece wise Linear Transformation Functions (Cont…)

- ***Gray Level Slicing***
  - Highlighting a specific range of gray levels in an image often is desired.
  - One approach for gray level slicing is to display a high value for all gray levels in the range of interest and low value for all other gray levels. This produces a binary image.
  - Another approach for gray level slicing is brightness the desired range of gray levels but preserves the background and gray level tonalities in the image unchanged.

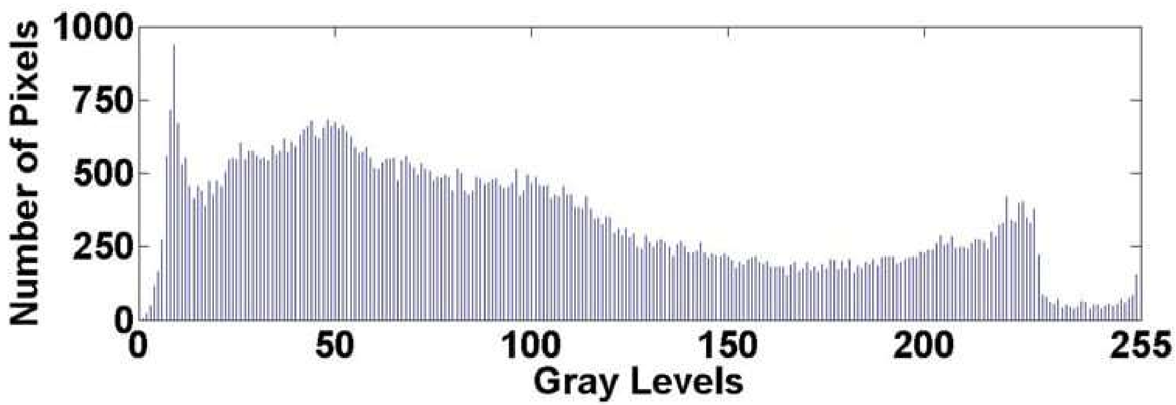
Piece wise Linear Transformation Functions (Cont…)

Result of slicing

Result of transformation

Histogram Processing

- An intensity histogram is a graph showing the number of pixels in an image at each different intensity value found in that image.
- More simply, histogram is a graphical representation of the intensity distribution of an image.



(a)

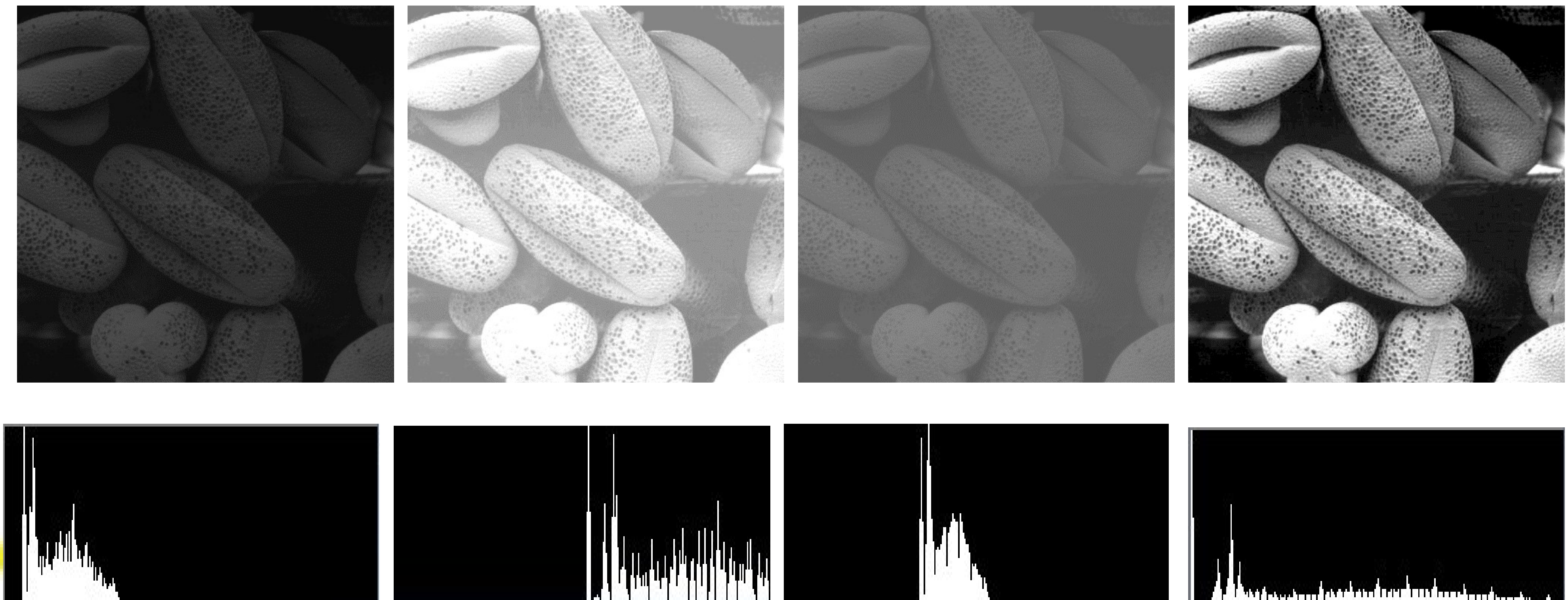
(b)

Histogram Processing

- For an 8 bit gray scale image there are 256 different possible intensities, and so the histogram will graphically display 256 numbers showing the distribution of pixels amongst those gray scale values.
- It is common practice to normalized a histogram by dividing each of its components by the total number of pixels in the image.

Histogram Processing (cont…)

Dark	Light	Low contrast	High contrast



Histogram Equalization

- It is a method that improves the contrast in an image, in order to stretch out the intensity range.
- Equalization implies *mapping* one distribution (the given histogram) to another distribution (a wider and more uniform distribution of intensity values) so the intensity values are spread over the whole range.

Histogram Equalization

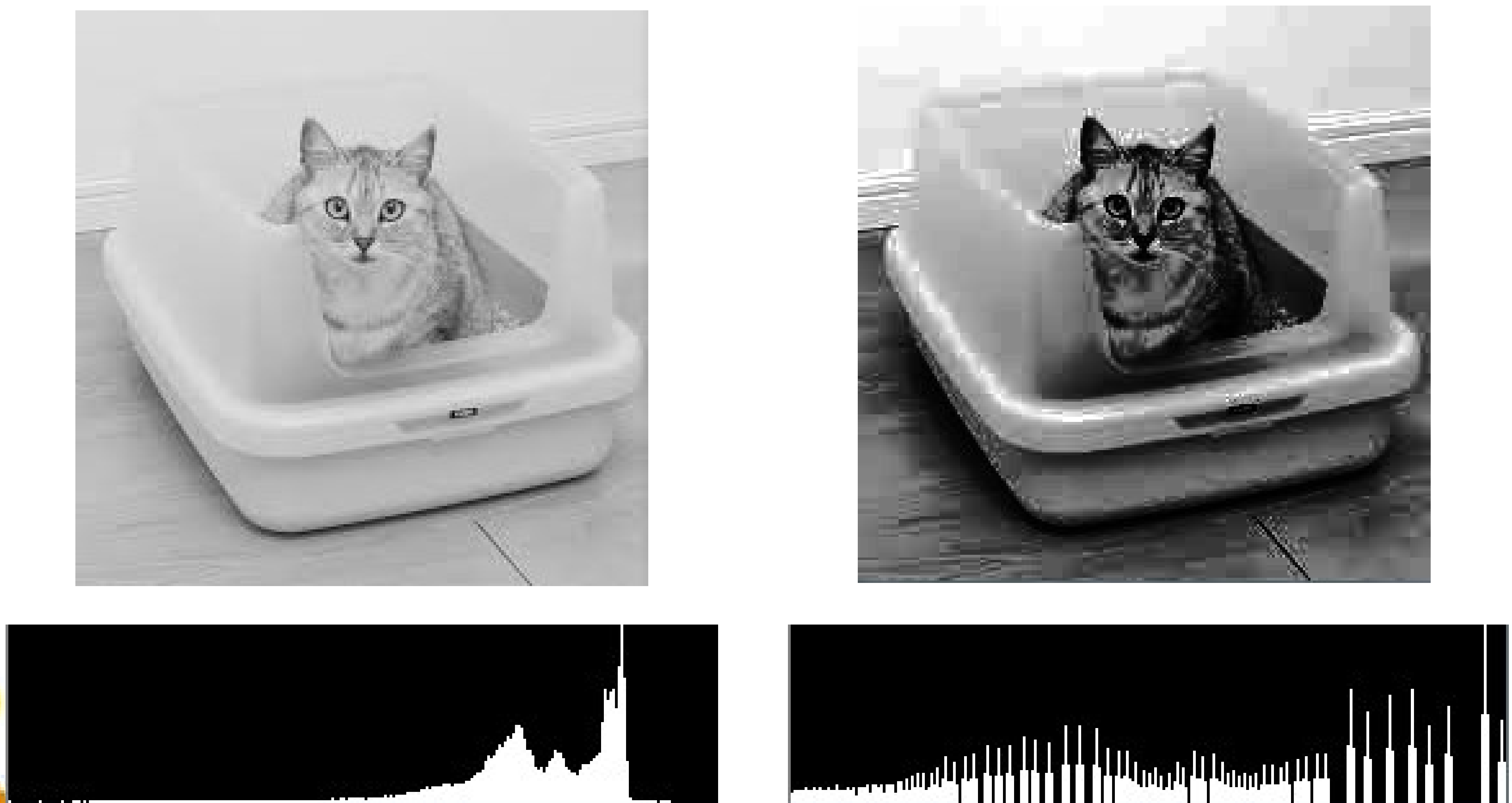
- **<u>How to do Histogram Equalization</u>**
  - Calculate the histogram of the original image. Let $h(r_k)$ denote the number of pixels with intensity r_k .
  - Normalize the histogram by dividing each histogram value by the total number of pixels N, to get the probability distribution function (PDF): $p(r_k) = h(r_k) /N$.
  - Compute the cumulative distribution function (CDF):

$$CDF(r_k) = \sum_{j=0}^{k} p(r_k)$$

  - Map the original pixel values to new values using the CDF to achieve a uniform histogram:

$$s_k = ((L-1).\,CDF(r_k))$$

Histogram Equalization (Cont…)



Contrast Stretching

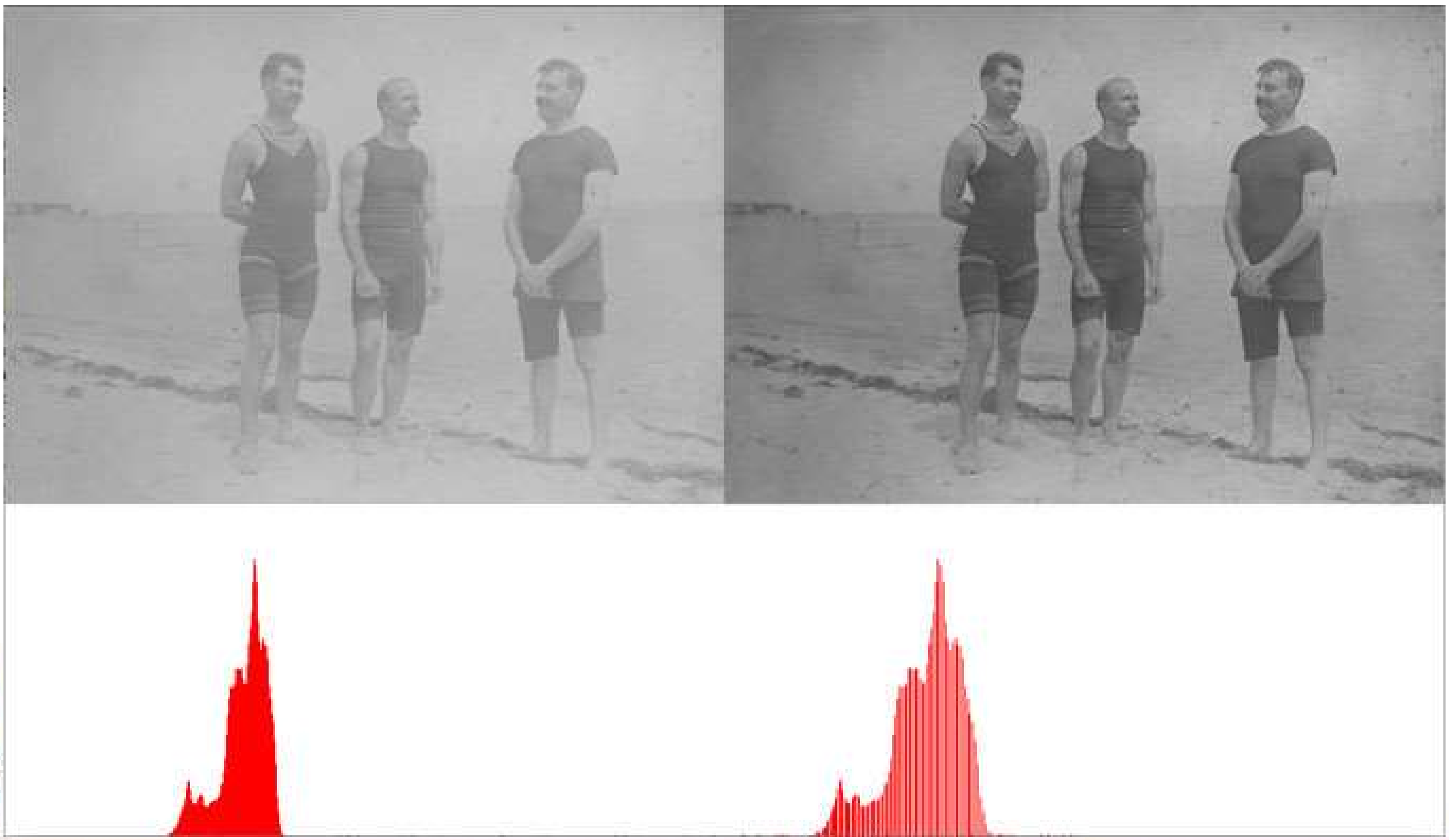
- Contrast stretching, also known as normalization, enhances the contrast in an image by stretching the range of intensity values.

$$s = a + \frac{(r - r_{min})(b - a)}{r_{max} - r_{min}}$$

- Where:
- S is the output pixel value after contrast stretching.
- r is the original pixel value.
- r_{min} and r_{max} are the minimum and maximum pixel values in the original image, respectively.
- a and b are the desired minimum and maximum values for the output image, often 0 and 255 for 8-bit images.
- This formula linearly maps the intensity values from the original range (r_{min}, r_{max}) to the new range (a, b), enhancing the contrast of the image.

Difference between Contrast Stretching and Histogram Equalization

- Contrast Stretching



Difference between Contrast Stretching and Histogram Equalization (cont…)

- Histogram Equalization

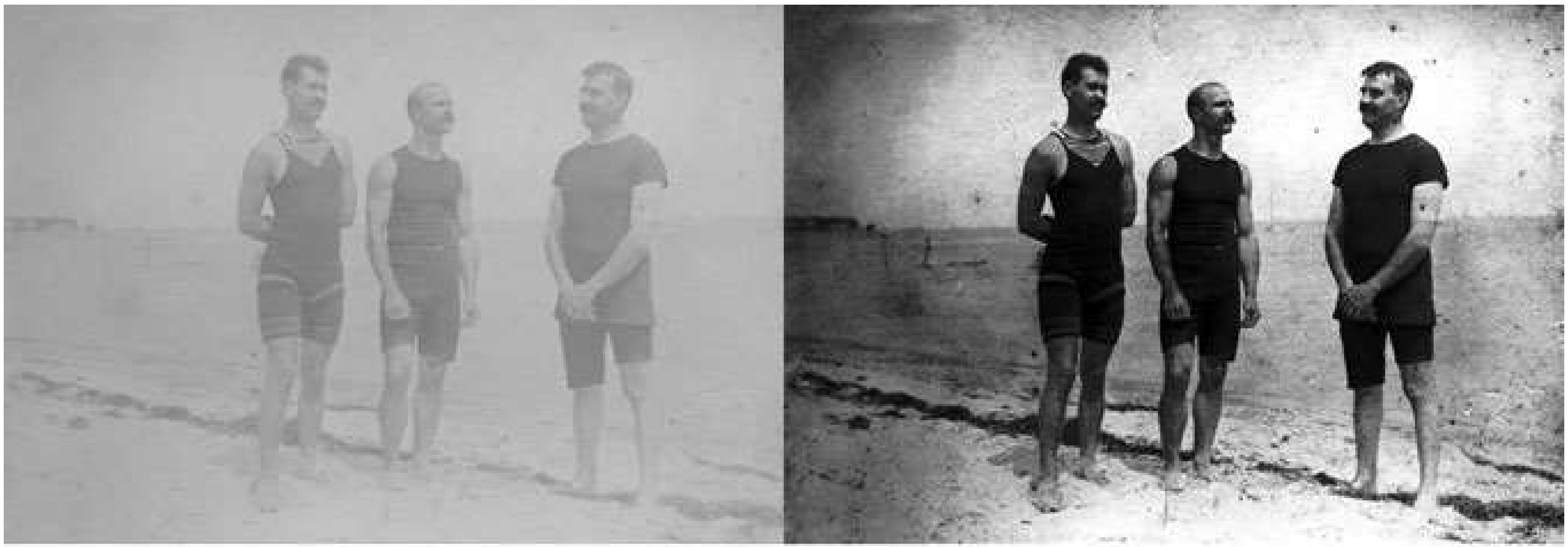
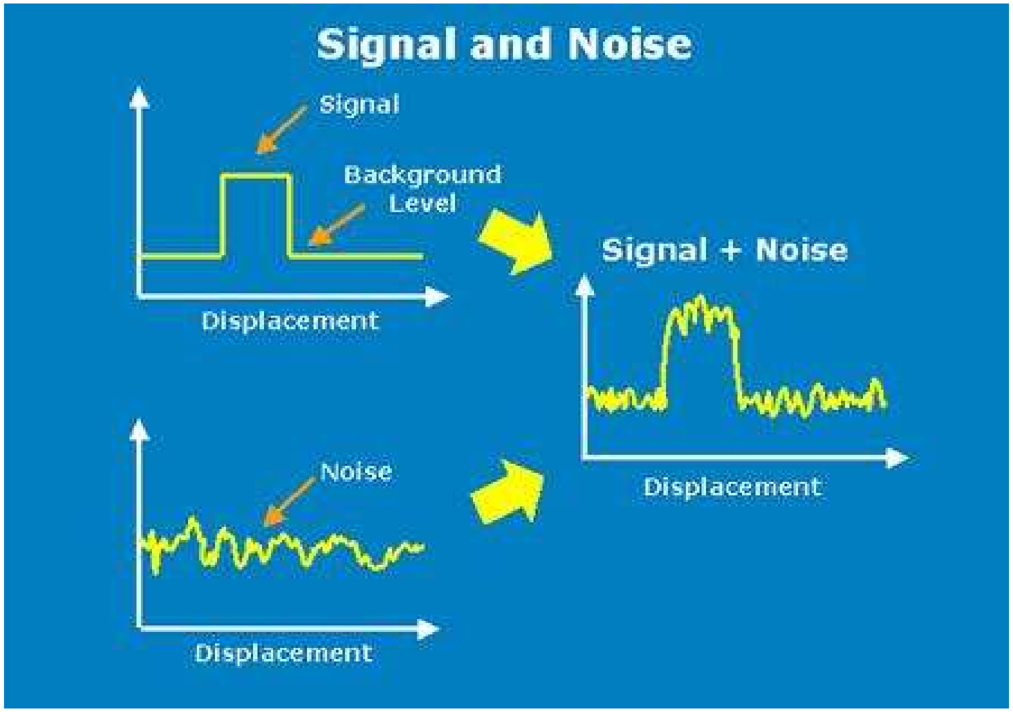


Image Noise

- Noise is a visual distortion in digital images.
- It causes visual degradations in digital images.
- Even though noise is unavoidable, it can become so small relative to the signal that it appears to be nonexistent.
- The signal to noise ratio (SNR) is a useful and universal way of comparing the relative amounts of signal and noise for any electronic system; high ratios will have very little visible noise whereas the opposite is true for low ratios.

Image Noise (Cont…)



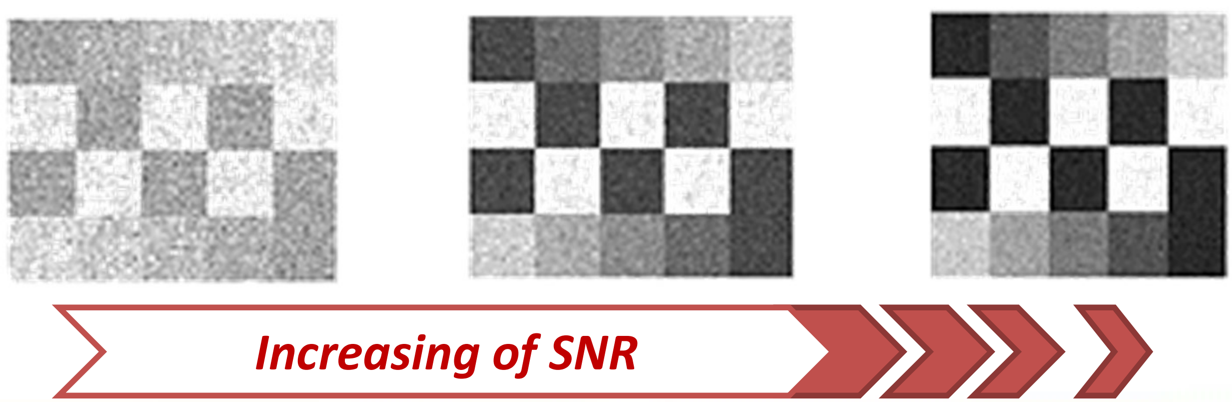


Image Noise (Cont…)

- Noisy image can be modelled as follows:

$$g(x, y) = f(x, y) + \eta(x, y)$$

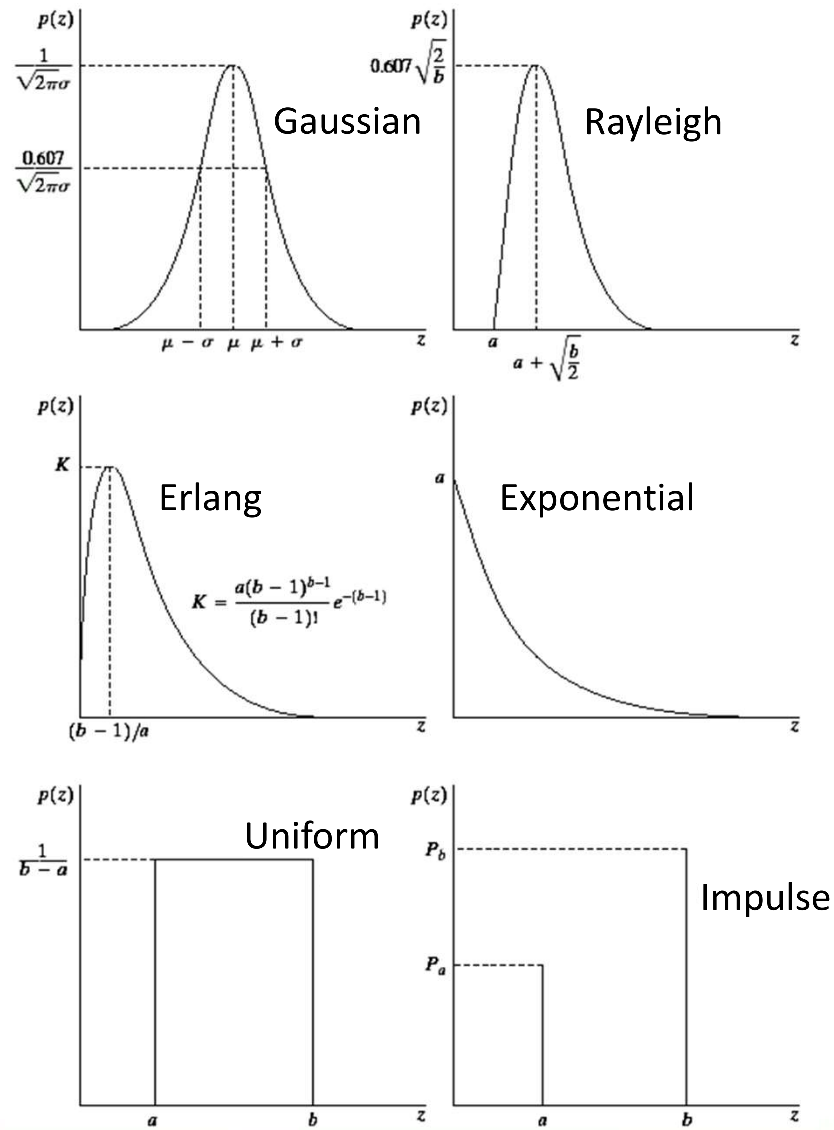
where $f(x, y)$ is the original image pixel, $\eta(x, y)$ is the noise term and $g(x, y)$ is the resulting noisy pixel.

Image Noise (Cont…)

- **Source of image noise**
  - **Error occurs in image signal** :while an image is being sent electronically from one place to another.
  - **Exposure time :** Long exposures can introduce static, which can also be a cause of digital noise. (Lens exposure time, also known as shutter speed, refers to the duration for which the camera's shutter is open to allow light to hit the sensor when taking a photo.)
  - **ISO factor:** ISO number indicates how quickly a camera’s sensor absorbs light (sensitivity to light), higher ISO produce progressively more noise.
  - **Size of the sensor**
  - **Pixel density -** Pixel density refers to the number of pixels per unit area on a sensor or display, often measured in pixels per inch (PPI) for displays or pixels per square millimeter for camera sensors.
  - **Shadows-** Shadows in digital images can lead to noise for several reasons related to the camera's sensor sensitivity, image processing, and the inherent characteristics of how light interacts with the sensor.

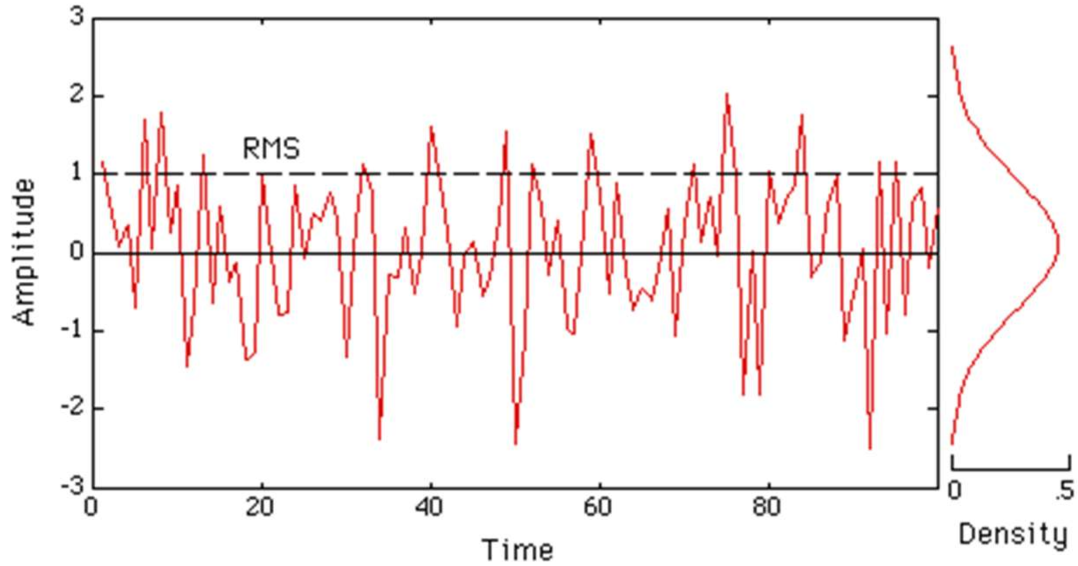
Types of Noise

- The "distribution" of noise is based on probability.
- Hence the model is called a Probability Density Function (PDF).
- Noise types are
  - Gaussian Noise
    - Most common pattern
  - Rayleigh Noise
  - Gamma (Erlang) Noise
  - Exponential Noise
  - Uniform Noise
  - Impulse Noise
    - salt and pepper



Types of Noise (Cont…)

- **Gaussian Noise:**
  - Gaussian noise arises in an image due to factors such as electronic circuited noise and sensor noise due to poor illumination and/ or high temperature.
  - Gaussian noise is noise that has a random and normal distribution of instantaneous amplitudes over time.



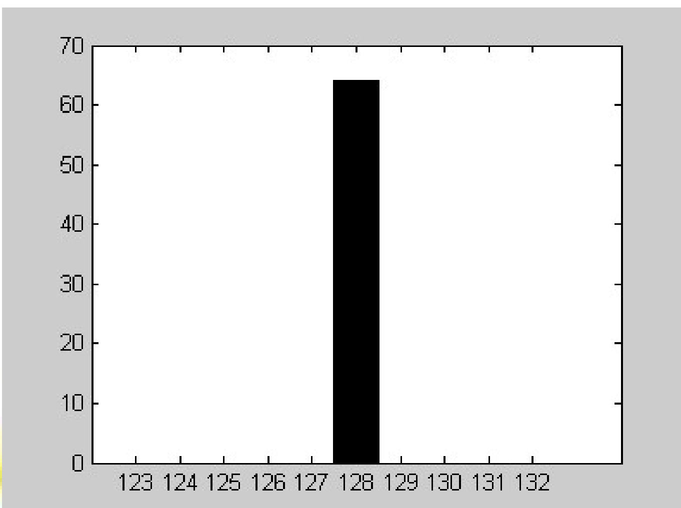
Types of Noise (Cont...)

128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128

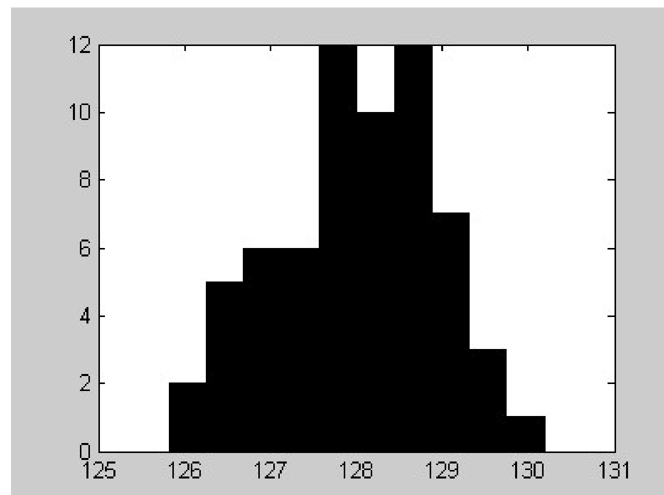
$\sigma^2 = 1$

128	128	129	127	129	126	126	128
126	128	128	129	129	128	128	127
128	128	128	129	129	127	127	128
128	129	127	126	129	129	129	128
127	127	128	127	129	127	129	128
129	130	127	129	127	129	130	128
129	128	129	128	128	128	129	129
128	128	130	129	128	127	127	126

X



Y



Types of Noise (Cont...)

- **Rayleigh Noise:**
  - This type of noise usually occurs in range imaging.
- **Gamma (Erlang) Noise and Exponential Noise:**
  - This can be found in laser imaging.
- **Uniform Noise:**
  - This is not often encountered in real-world imaging systems, but provides a useful comparison with Gaussian noise.

Types of Noise (Cont…)

- **Impulse Noise:**
  - Impulse noise is very common in digital images.
  - Impulse noise is always independent and uncorrelated to the image pixels.
  - Unlike Gaussian noise, for an impulse noise corrupted image all the image pixels are not noisy.
  - **Salt impulse noise:**
    - assumed to have the brightest gray level.
    - Appears as white spot in the image
  - **Pepper impulse noise:**
    - darkest value of the gray level in the image.
    - Appears as black spot in the image

Types of Noise (Cont...)

Definition

Each pixel in an image has the probability of p/2 (0<p<1) being contaminated by either a white dot (salt) or a black dot (pepper)

$$g(x,y)=\begin{cases} 255 & \text{with probability of p/2} \\ 0 & \text{with probability of p/2} \\ f(x,y) & \text{with probability of 1-p} \end{cases}$$

noisy pixels

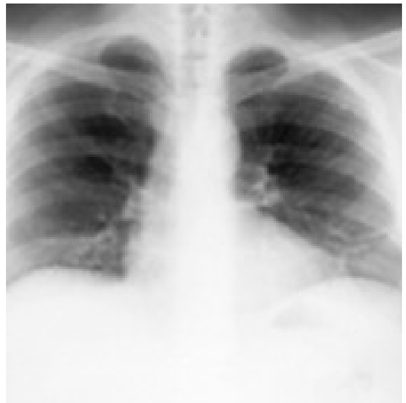
clean pixels

$$1 \le x \le H, 1 \le y \le W$$

f(x,y): noise-free image, g(x,y): noisy image

<u>Note</u>: in some applications, noisy pixels are not simply black or white, which makes the impulse noise removal problem more difficult

Types of Noise (Cont…)



P=0.1

128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128

X

128	128	255	0	128	128	128	128	128	128
128	128	128	128	0	128	128	128	128	0
128	128	128	128	128	128	128	128	128	128
128	128	0	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
128	128	128	128	128	128	128	128	128	128
0	128	128	128	128	255	128	128	128	128
128	128	128	128	128	128	128	128	128	255
128	128	128	128	128	128	128	255	128	128

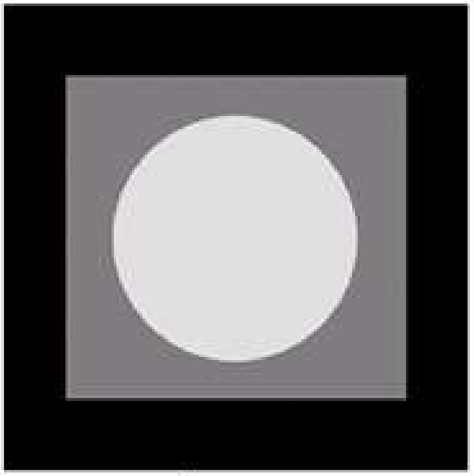
Y

Noise level p=0.1 means that approximately 10% of pixels are contaminated by salt or pepper noise (highlighted by red color)

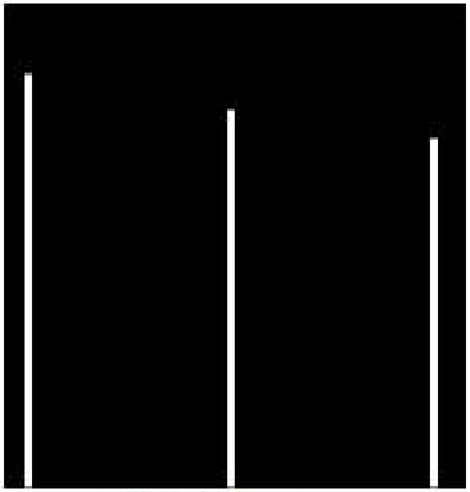
Noise Example

The test pattern to the right is ideal for demonstrating the addition of noise

The following slides will show the result of adding noise based on various models to this image

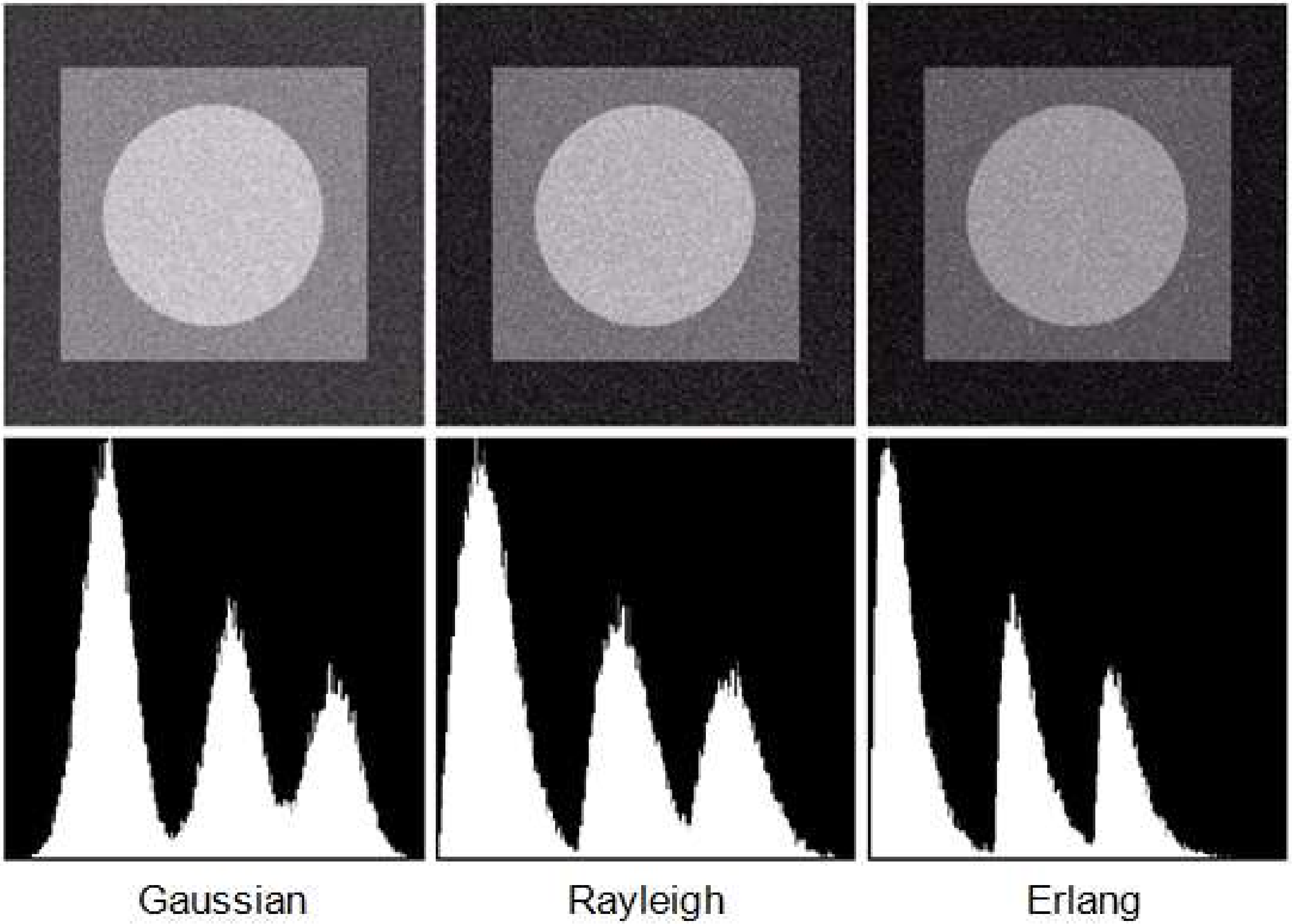


Image

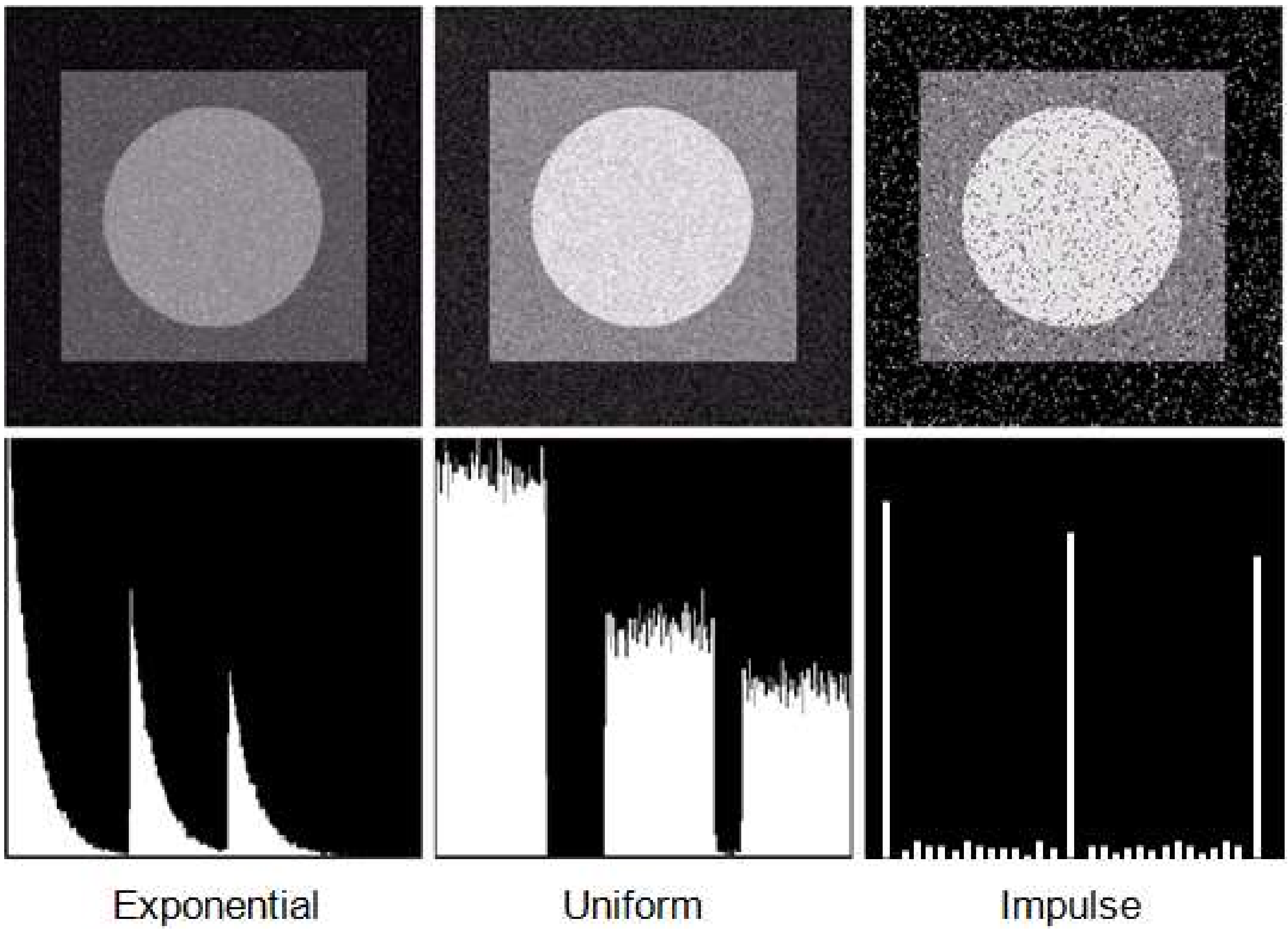


Histogram

Noise Example (Cont...)



Noise Example (Cont…)



Noise Example (Cont…)

- With the exception of slightly different overall intensity, it is difficult to differentiate visually between the first five image of previous example, even though their histograms are significantly different.
- Salt and pepper noise is the only that is visually indicative of the type of noise causing the degradation.

Periodic Noise

- Unlike the types of noise we discussed previously, periodic noise depends on the spatial coordinates.
- It arises typically from <u>electrical or electromechanical interference during the image acquisition.</u>
- It can be reduced through frequency domain filtering.

Periodic Noise (Cont…)

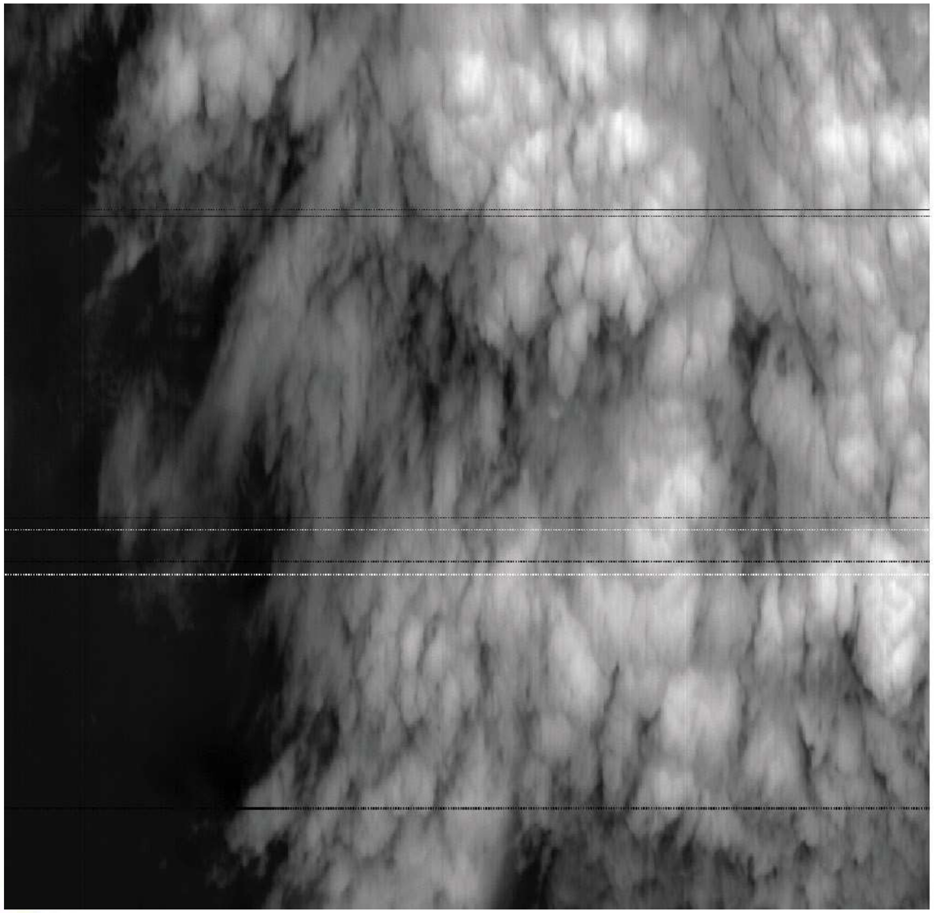


Image Restoration

- There are some artifacts which directly effect to the degradation of image. ex: Noise
- The principle goal of restoration techniques is to improve an image in some predefined sense.
- Unlike image enhancement, most part in image restoration is an objective process.
- Restoration attempts to recover an image that has been degraded by using the priory knowledge of the degradation phenomenon.

Image Restoration (Cont…)

- Restoration techniques are oriented toward modeling the degradation and applying the inverse process in order to recover the original image.
- This approach usually involves formulating a criterion of goodness that will yield an optimal estimate of the desired result.
- Ex: contrast stretching is an image enhancement technique and it is focused to view purpose whereas; removing image blur using deblurring technique is considered as image restoration.

Image Restoration (Cont…)

Contrast Stretching

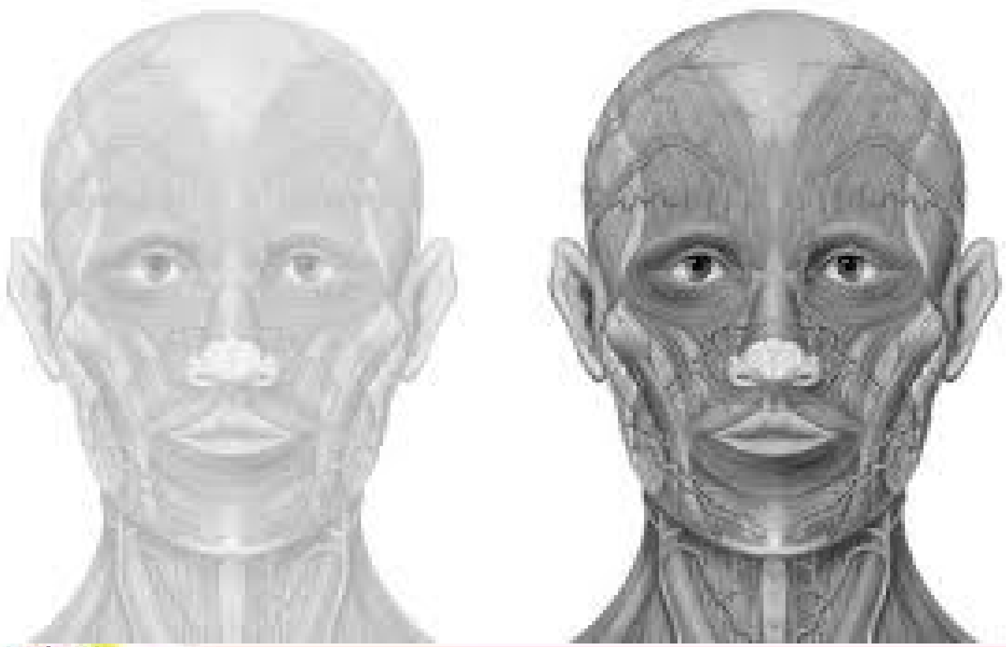
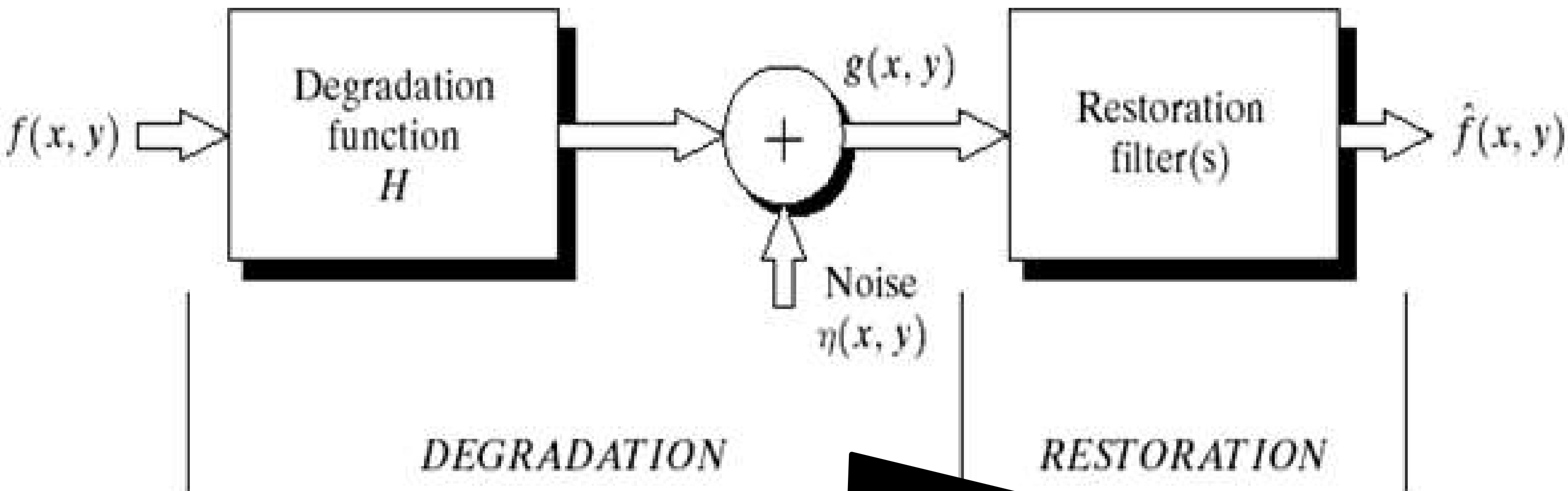


Image Deblurring

Image Restoration (Cont…)



g(x, y) = h(x, y) * f(x, y) + η(x, y)

Given ***g(x,y)***, some knowledge about the degradation function ***H***, and some knowledge about the additive noise term ***η(x,y)***, the objective of restoration is to obtain an estimate ***f'(x,y)*** of the original image.

Reference

- Chapter 03 and Chapter 05 of Gonzalez, R.C., Woods, R.E., Digital Image Processing, 3rd ed. Addison-Wesley Pub.

Learning Outcomes Revisit

- Now, you should be able to;
  - describe spatial domain of the digital image.
  - recognize the image enhancement techniques.
  - describe and apply the concept of intensity transformation.
  - express histograms and histogram processing.
  - describe image noise.
  - characterize the types of Noise.
  - describe concept of image restoration.

Next Lecture – Intensity Transformation and Spatial Filtering II

QUESTIONS ?