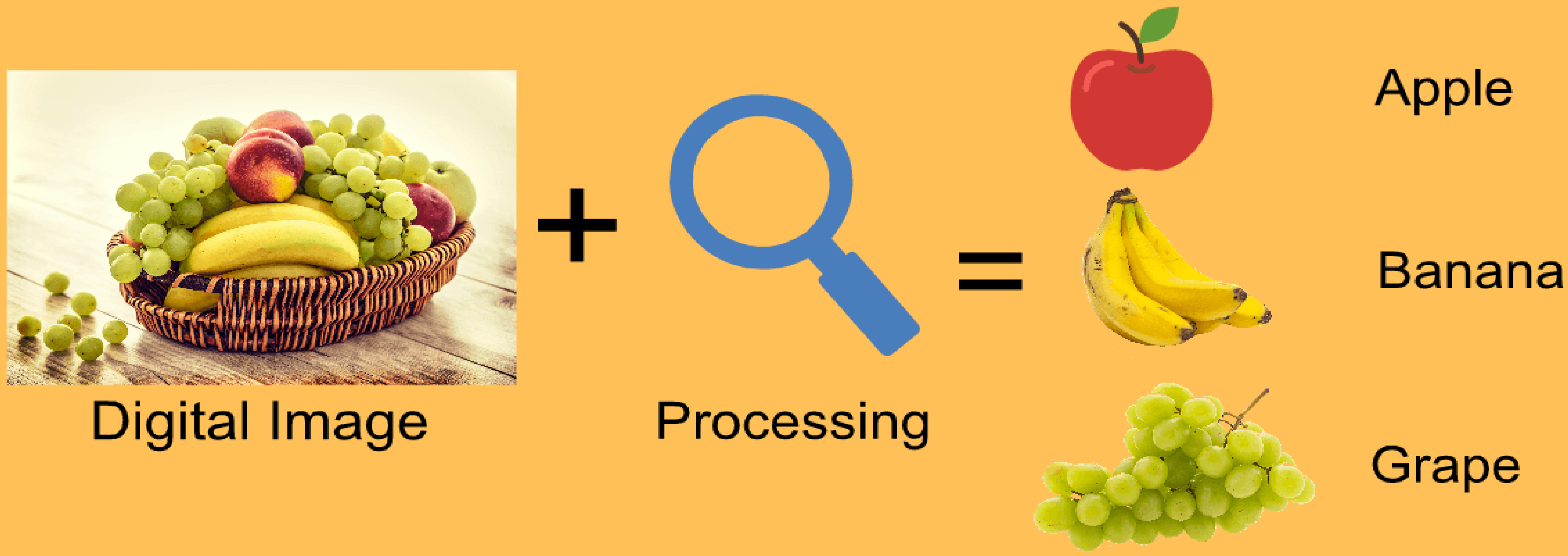
Digital Image Processing



Digital Image Processing

Lec. 4: Image Enhancement

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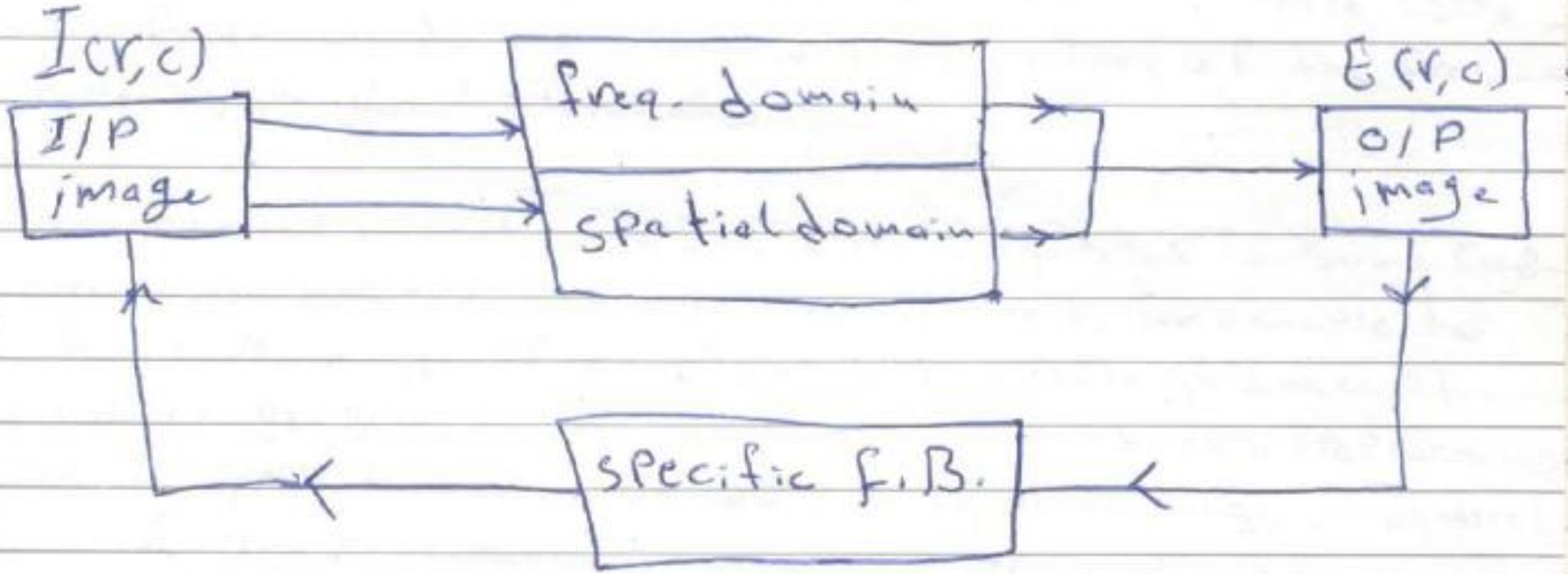
Image Enhancement

Image Enhancement

Image enhancement techniques are used to emphasize and sharpen features for display and analysis. Image enhancement is the process of apply-ing these techniques to facilitate the development of a solution to a Computer imaging problem, the enhancement methods are application specific and often developed empirically. The model of enhancement system shown bellow.



We define the enhancement image as E(r,c). The range of application includes using this technique as preprocess step to ease the next processing step, or image enhancement may be an end itself.

It use for Spatial & frequency domain, The Spacial domain refers to the image plane itself and approaches in this category are based on direct

manipulation of Pixels in an image. The frequency domain tech-
-niques are based on modifying the fourier transform of an image
The type of techniques includes

1) Point operation:- where each Pixel is modified according to a particular ~~eq~~ equation that is not dependent on other Pixel values.
2) Mask Opreation:- where each Pixel is modified according to the values of the pixels neighbors.
3) Global operation:- where all Pixel values in the image or (subimage) are taken into Consideration.

Spatial domain Processing methods include all three types. but frequency domain operations, by nature of the frequency transform, are global operations.

Enhancement is used as a preprocessing step in some Comp--uter vision applications to ease the vision task, for example, to enhance the edges of an object to facilitate guidance of a robotic gripper, enhancement is also used as a preprocessing step in applications where human viewing of an image is required befor further processing. for example, in one application, high-speed film images had to be Correlated with a computer simu--lated model of an aircraft,

Image enhancement is used for postprocessing to generate a visually desirable image, for example we may perform image restoration to eliminate image distortion and find that the output image has lost most of it's contrast, Alternatly, after a com--pressed image has been restord to it's "original" state (decompressed), som postprocessing enhancement may significantly improve the look of the image.

Image Enhancement Goals

- to improve the subjective quality of an image for human viewing

- to modify the image in such a way as to make it more suitable to further analysis by a human or a computer

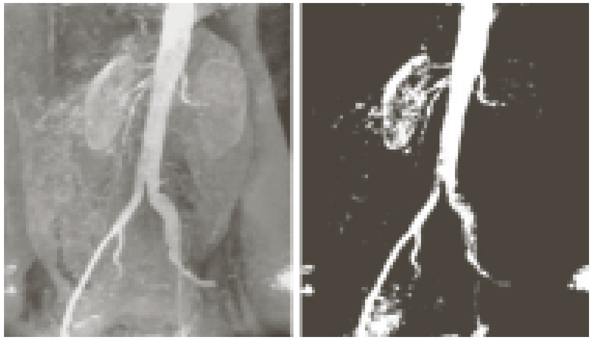


Image Enhancement - Examples

Poor contrast image

Enhanced image

Blurred image

Sharpened image

Main Techniques

- Intensity transformations
  - Thresholding
  - Intensity-level slicing
  - Contrast stretching
  - Gamma correction
  - Histogram equalization
- Spatial filtering
  - Unsharp masking

Thresholding

Example: Adding A Constant → Brightness Change

- Image has more brightness (larger intensity values) if the additive constant is positive.

Original

+ 50

- 50

By Oge Marques

Example: Multiplying with a Constant → Contrast Change

- Image has more contrast (larger range of intensity values) if the multiplicative constant is larger than one.

Original | x 0.7 | x 1.4

By Oge Marques

5-1. Spatial Domain Methods.

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مجموع/كمية

The term spatial domain refers to the aggregate of pixels composing an image, and spatial domain methods are procedures that operate directly on these pixels. Image processing functions in the spatial domain may be expressed as:-

$$g(x,y) = T\{f(x,y)\} \quad (5\text{-}1)$$

- Where $f(x,y)$ is the input image, $g(x,y)$ is the processed image, and T is an operation on f, defined over some neighborhood of (X,Y).

The principal approach to defining a neighborhood about (X,Y) is to use a square or rectangular area centered at (X,Y) as shown in figure (5-2).

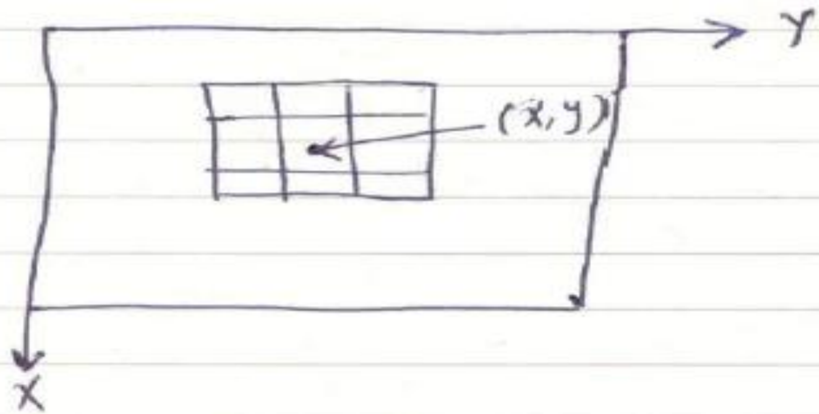


figure (5-2) A 3 * 3 neighborhood about a Point (x, y) in an image.

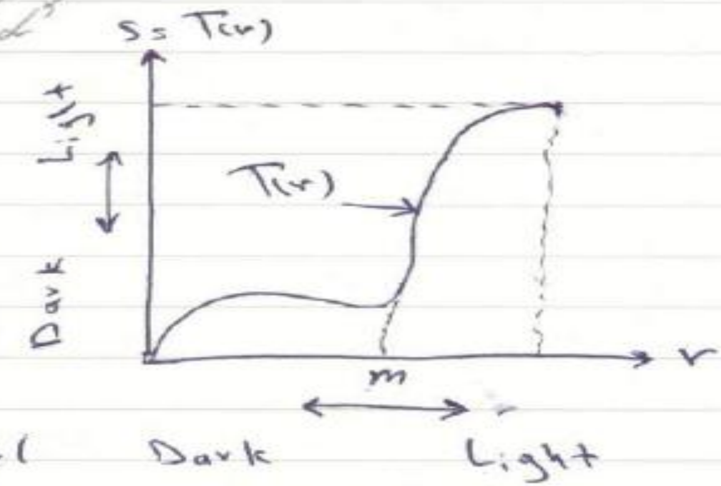
The center of the subimage is moved from Pixel to Pixel starting at the top left corner and applying the operator at each location (x, y) to yield g at that Location.

The Simplest form of T is when neighborhood is (1 X 1) in this case, g, depends only on the value of f at (x, y), and T become a gray-level transformation (mapping) function of the form.

$$s = T(r) \qquad (5-2)$$

where r and s are variables denoting the gray level of $f(x,y)$ and $g(x,y)$ at any point (x,y). For example, if $T(r)$ has the form shown in figure (5-3), the effect of this transformation is to produce an image of higher contrast than the original by darkening the level below m and brightening the level above m in the original image. This technique is called (Contrast Stretching)

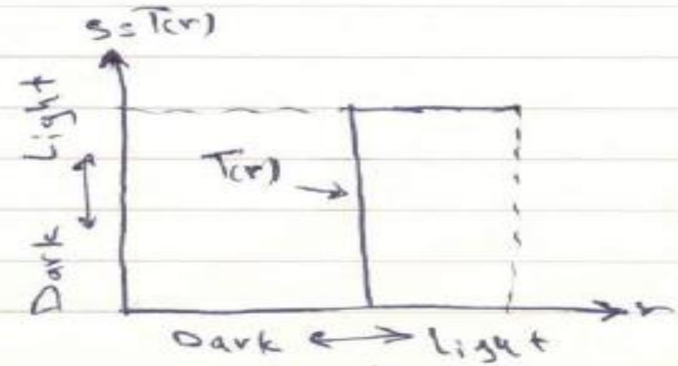
~~The opposite effect takes Place for values of r above~~



(5-3)

For figure (5-4), T(r) produces a two-level (binary) image.

Powerful processing approaches can be formulated with gray-level transformation. Because enhancement at any point in an image depends only on the gray level at that point, therefore this techniques are referred to as point processing.



(5-4)

Larger neighborhood, als called mask processing, windowing, or filtering, allow a variety of processing functions that go beyond just image enhancement.

5-2- Frequency Domain Methods:

The ~~function~~ foundation of frequency domain techniques is the Convolution theorm, Let $g(x,y)$ be an image formed by the convolution of an image $f(x,y)$ and a linear, Position invariant operator $h(x,y)$.

$$g(x,y) = h(x,y) * f(x,y) \qquad (5\text{-}3)$$

The frequency domain relation is

$$G(u,v) = \underbrace{H(u,v)}_{\text{Transform function.}} \cdot F(u,v) \quad \text{———} \quad (5\text{-}4)$$

from the eq. (5-4). In a typical image enhancement application $f(x,y)$ is given, and the goal, after computation of $F(u,v)$, is to select $H(u,v)$ so that the desired image.

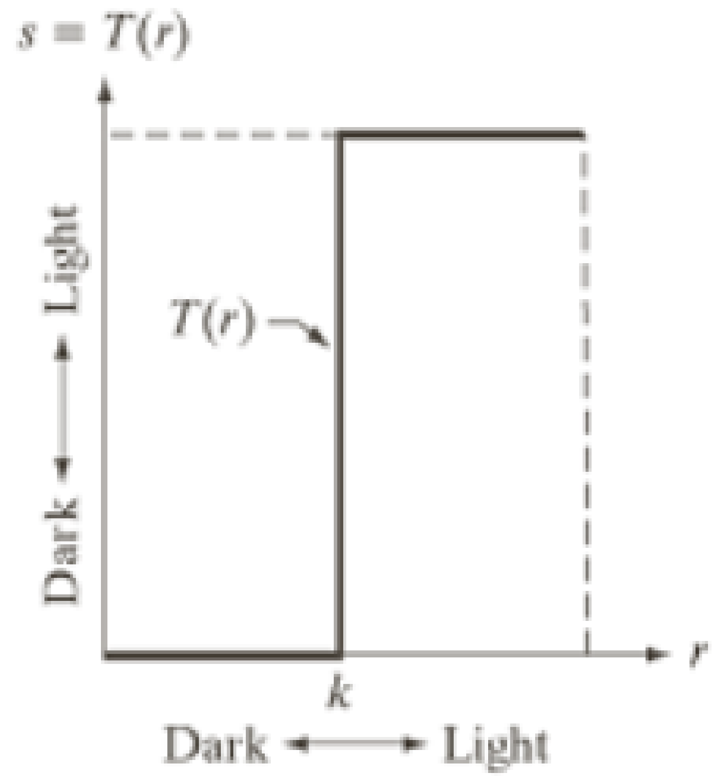
$$g(x,y) = \mathcal{F}^{-1}\left[H(u,v) \cdot F(u,v)\right] \quad \text{———} \quad (5\text{-}5)$$

عرض

exhibits some highlighted feature of $f(x,y)$, for example. edges in $f(x,y)$ can be accentuated by using a function ~~H(u, H(u,v)~~ $H(u,v)$ that emphasizes, the high-frequency components of $f(x,y)$.

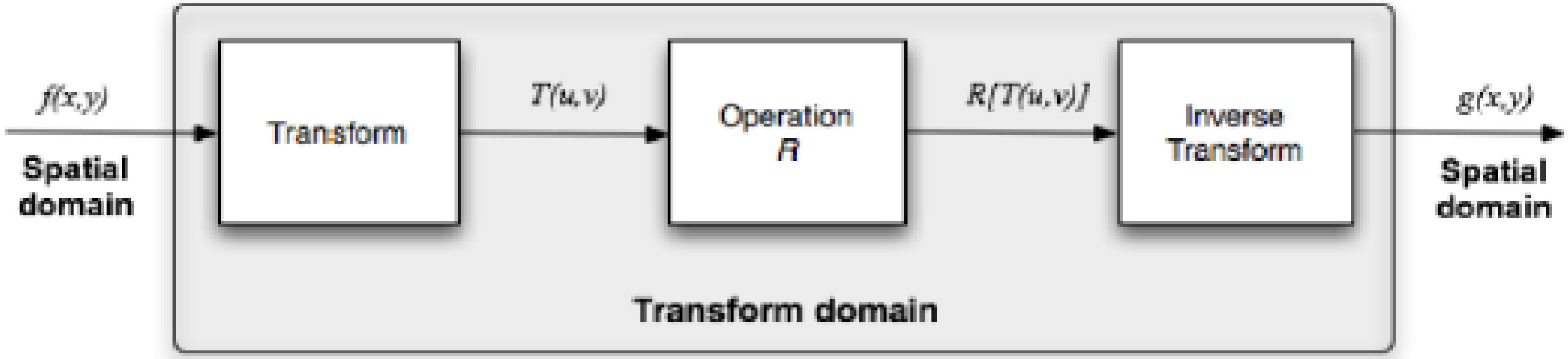
Thresholding

- r: input intensity value
- T(r): output intensity value
- k: intensity threshold



Transform Domain Operations

- Operations carried out in a transform (e.g., Fourier transform) domain.



5-3- Enhancement by Point Processing

Single-Point Processing are among the simplest of all image enhancement techniques. we denoted the intensity of Pixels befor and after Processing by r and S, respectively

5-3-1. Image negatives

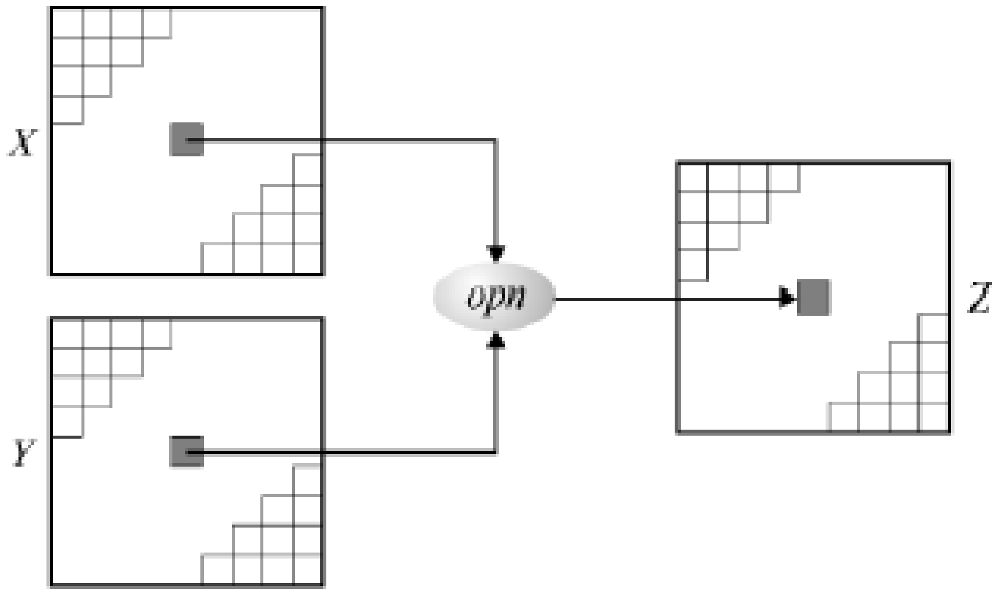
Negative of digital image are useful in numerous applications, such as displaying medical image and photographing a screen with monochorme Positive film.
The negative of adigital image is obtained by using the transformation function.

$$S = T(r) \quad\text{———}\quad (5\text{-}6)$$

as shown in fig.(5-5)

Operations Combining Multiple Images

- Two or more images combined pixel-by-pixel, using an arithmetic or logical operator, resulting in a third image



as shown in fig.(5-5)

Where L is the number of graylevels

The idea is to reverse the order from black to white so that the intensity of the output image decreases as the intensity of the input increases.

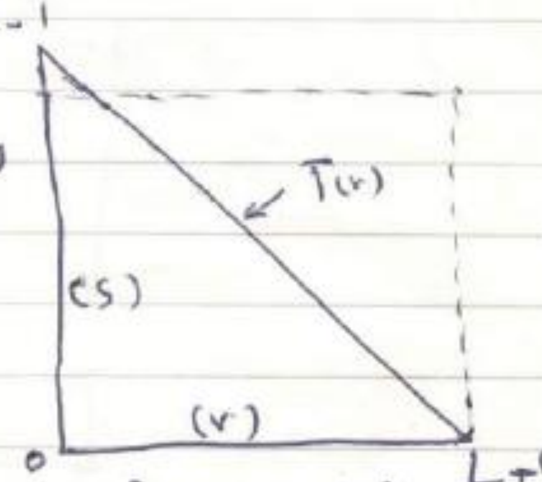
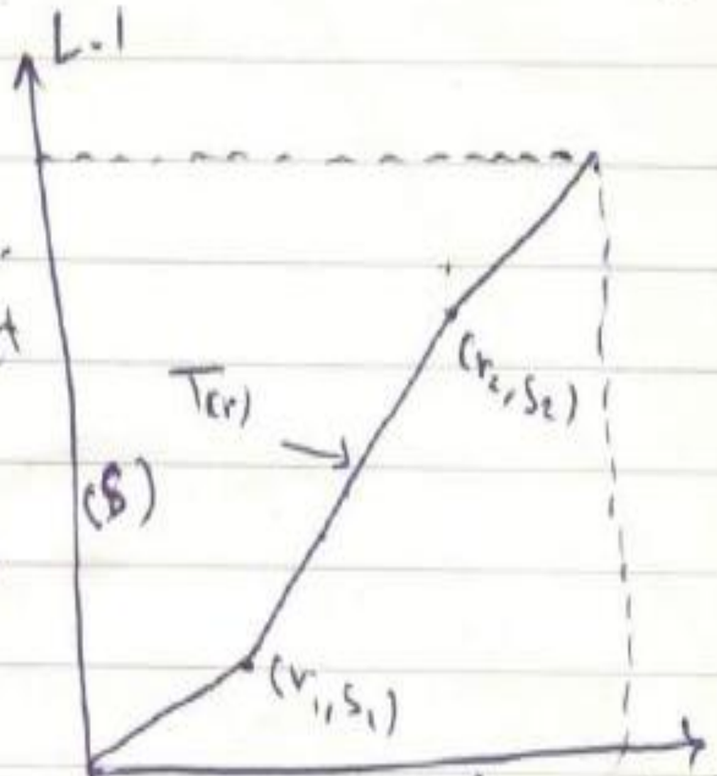


fig.(5-5)

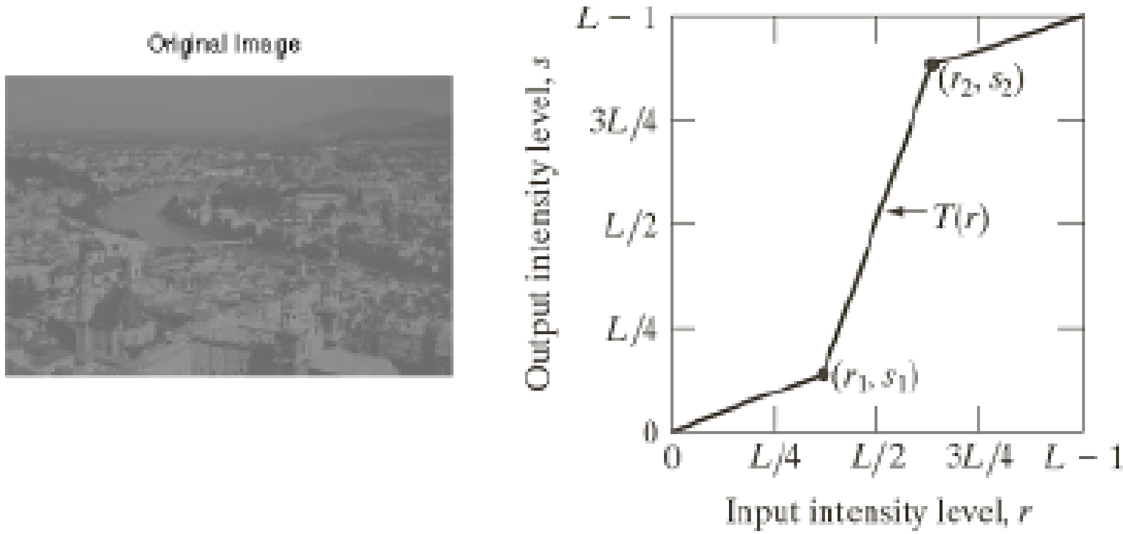
5-3-2- Contrast stretching

Low Contrast images can result from Poor illumination, Lack of dynamic range in the image sensor. The idea behind Contrast stretching is to increase the dynamic range of the gray levels in the image being processed. as shown in fig. (5-6). If $r_1 = s_1$ and $r_2 = s_2$, the transformation is a linear function, that produces no changes in gray levels. If $r_1 = r_2$, $s_1 = 0$ and $s_2 = L-1$, the transform becomes a thresholding function that creates a binary image. Intermediate values of (r_1, s_1) and (r_2, s_2) produce various degrees of spread in the gray levels of the output image



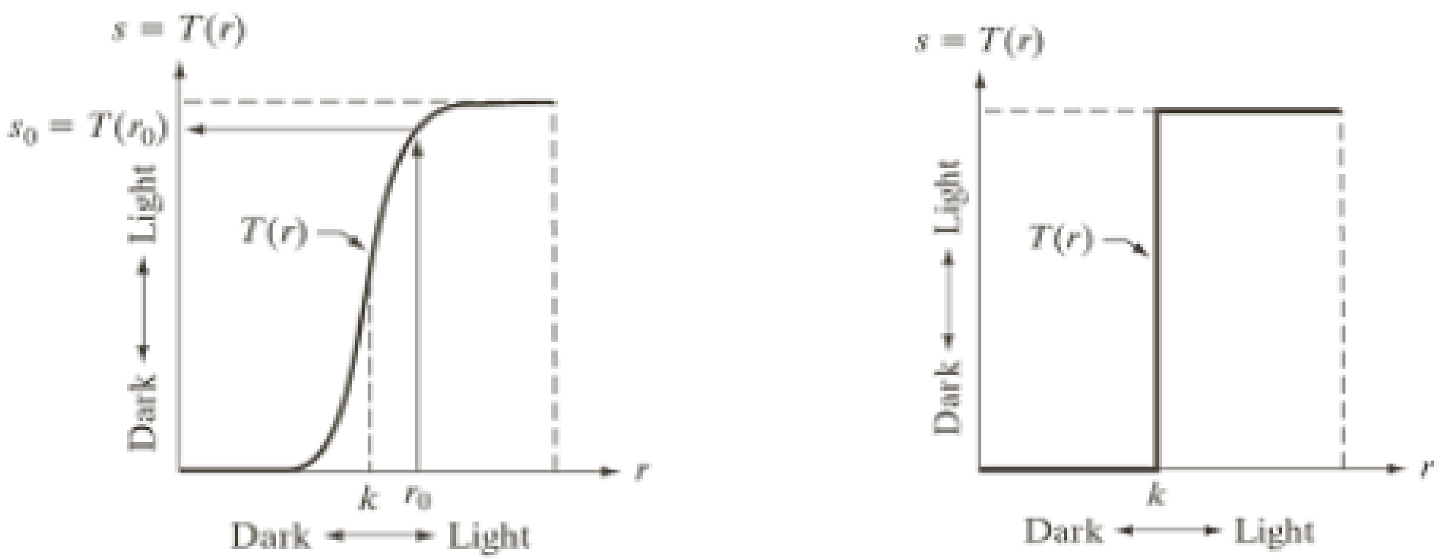
fig(5-6)

Contrast Stretching using Piecewise-Linear Transformations



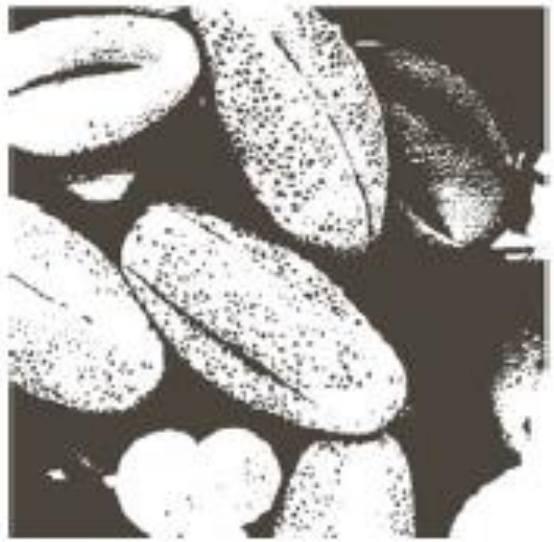
Contrast Stretching

- Small pixel values are compressed toward darker values while large pixel values are pushed toward brighter pixel values.
- Extreme case: binary thresholding

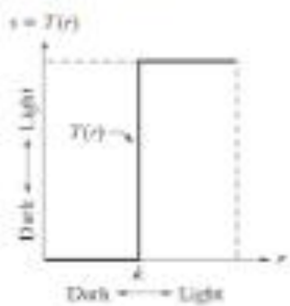


Thresholding vs. Contrast Stretching

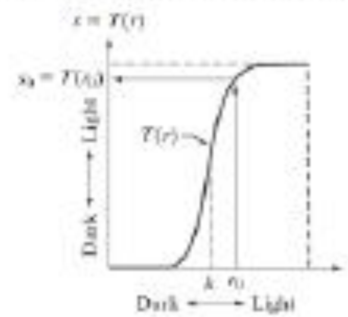
Original



Thresholded



Contrast Stretched



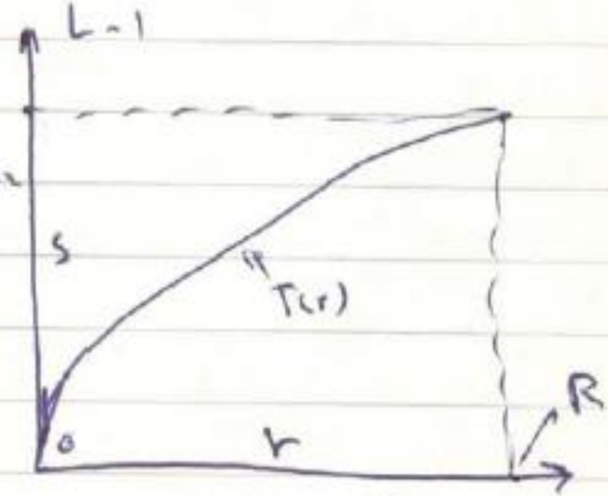
5-3-3. Compression of dynamic range.

Sometimes the dynamic range of a processed image far exceeds the capability of the display device. in ~~which~~ which case only the brightest parts of the image are visible on the display screen.

An effective way to compress the dynamic range of pixel values is to perform the following intensity transformation

$$S = c \log(1 + |r|) \quad (5\text{-}7)$$

where C is a scaling constant, and the logarithm function performs the desired compression. as shown in fig. (5-7) the transformation function shape.



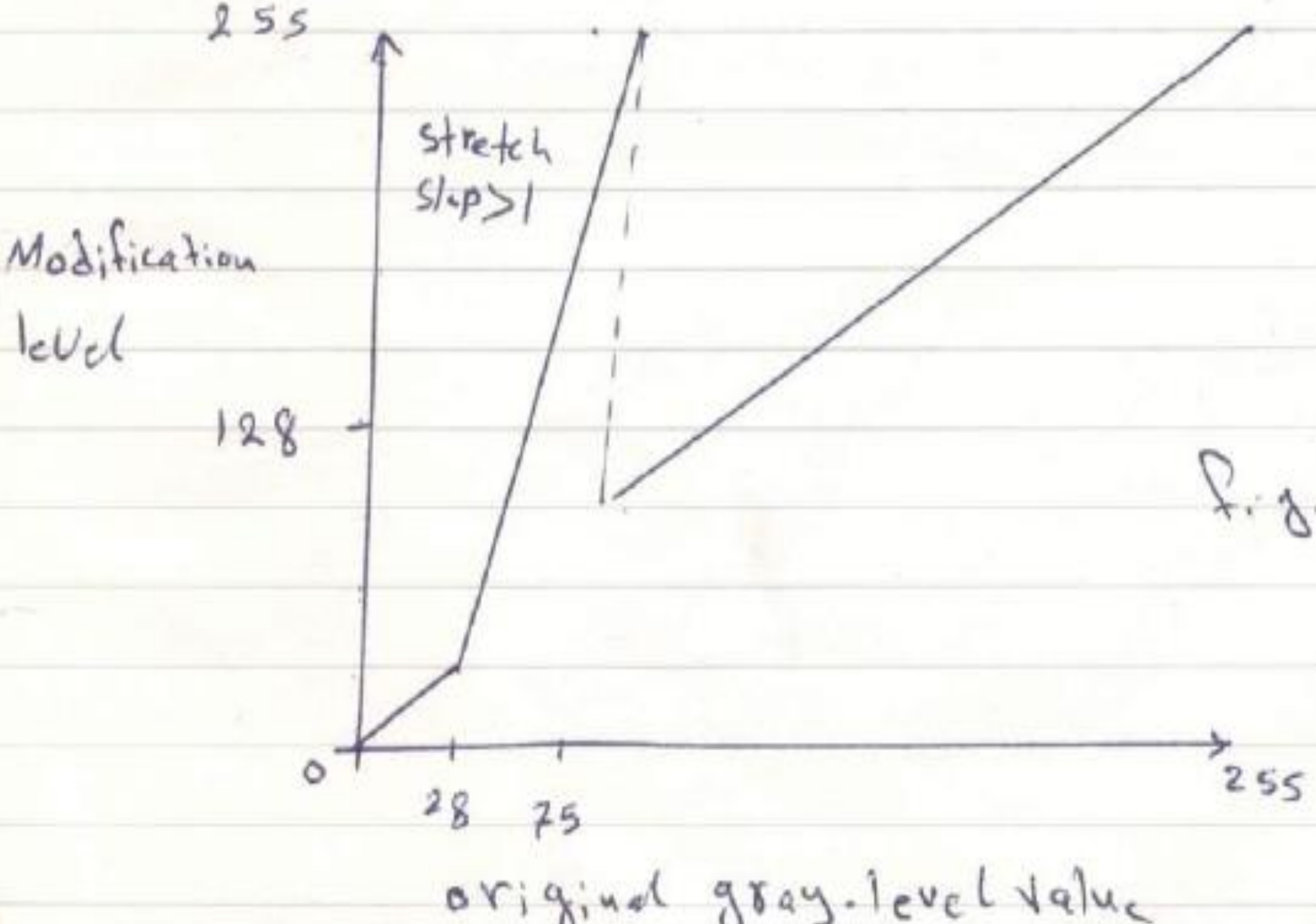
fig(5-7)

5-3-4 - Gray-Scale Modification

Gray-scale Modification methods belong in the category of point operation and function by changing the Pixel's (gray-level) values by a mapping equation. The mapping equation (linear or nonlinear) maps the original gray-level values to other, specified values.

$$E(r,c) = T(I(r,c)) \quad \text{------} \quad (5-8)$$

The primary operations applied to the gray scale of an image are to compress or stretch it. We typically compress gray-level ranges that are of little interest to us and stretch the gray-level ranges where we desir more information. fig.(5-8a) is illustrated this idea.

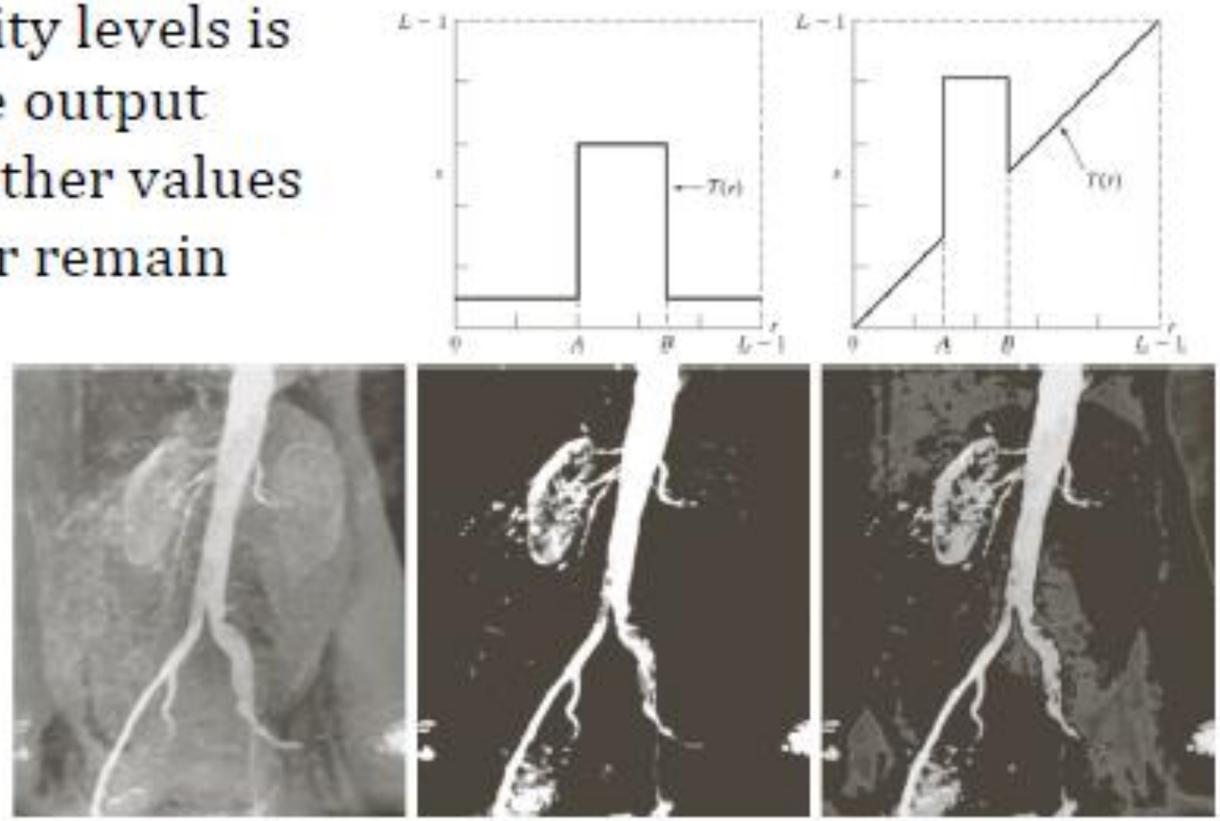


f.g.(5.8a)

The linear equations corresponding to the lines shown on the

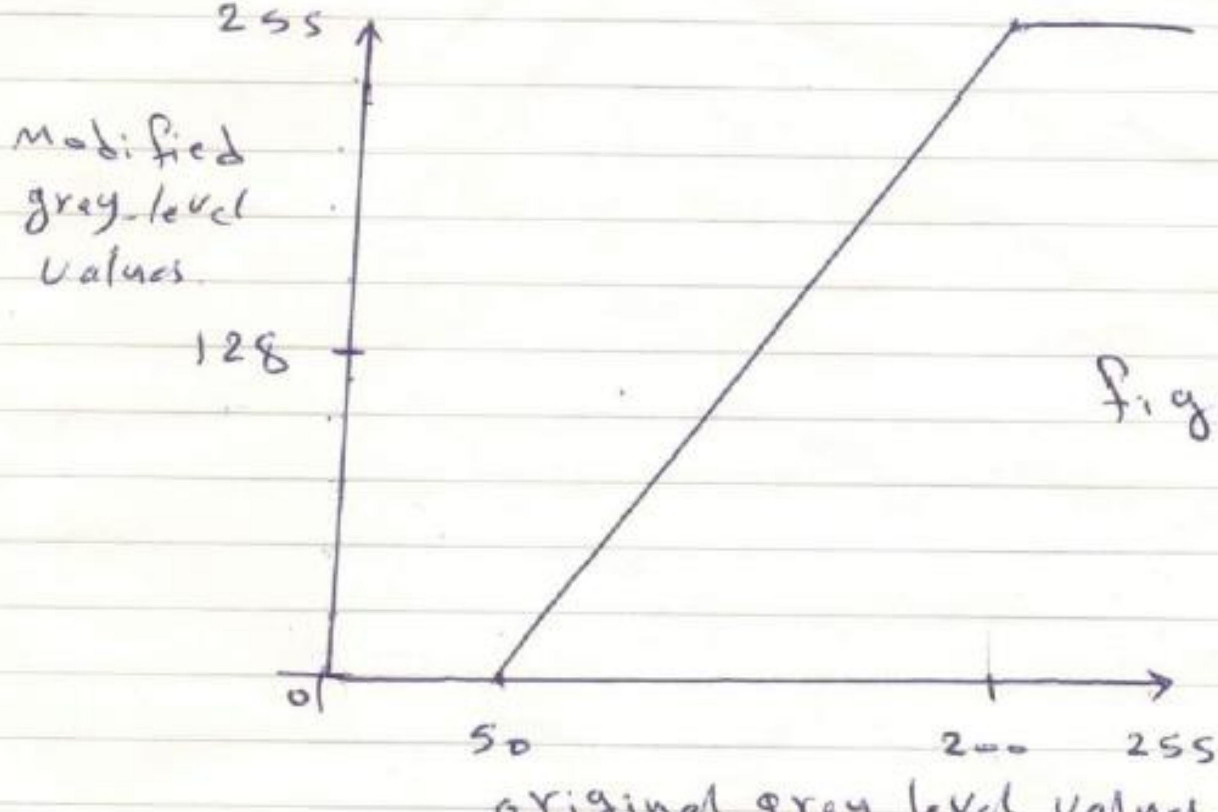
Intensity-Level Slicing

A range of intensity levels is highlighted in the output image, while all other values are suppressed or remain untouched.



graph represent the mapping equations. If the slop of the line is between zero and one, this is called gray-level compression whereas if the slop is greater than one, it is called gray-level stretching. the range of gray-level values from 28 to 75 is stretched, while the other gray values are left alone.

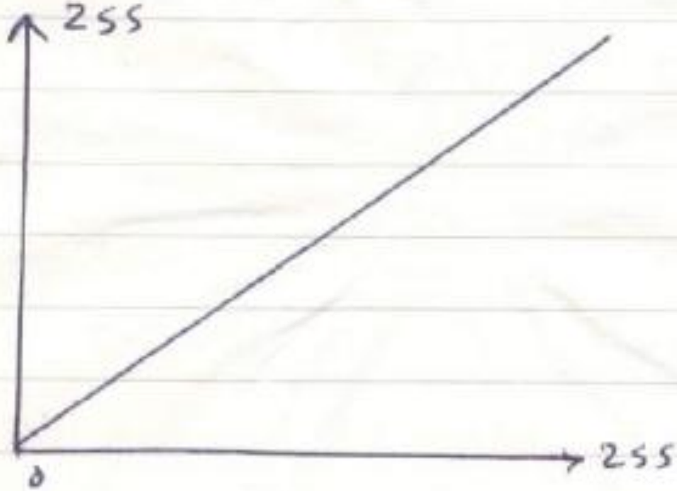
In some cases we may want to stretch a specific range of gray level, while clipping the values at the low and high ends. Fig.-(5-8.b) illustrates a linear function to stretch the grey leveles between (50 and 200) while clipping any values below (50 to 0) and any values above (200 to 255)



fig(5.8b)

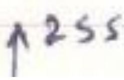
Another type of mapping equation, used for feature ext-raction, is called intensity-level slicing. we selecting specific gray-level values of interest and mapping them to a specified value. For example. we may have an application where it has been empirically determined that the objects of interest are in the gray-level range of (150 to 200)

Using the mapping equation shown in fig. (5-8C) we can generate the resultant images. ~~wth~~ with this type of oper-ation, we can either leave the "background" gray-level value alone, fig(5-8d) or turn them black as shown in fig (5-8e). Note that they do not need to be turned black, any gray-level value may be specified.



fig(5-8-C)
The operation returns the original gray-level.

where are you



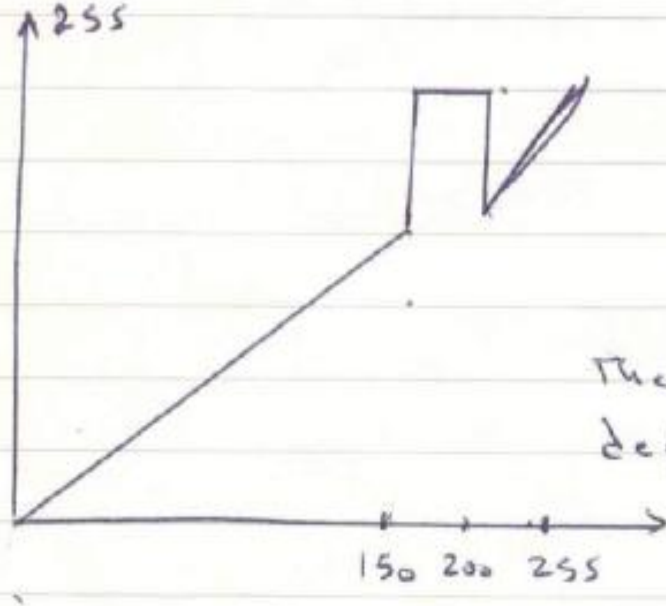


fig (5-8-d)
The operation intensifies the desired gray-level range, while not changing the other values.

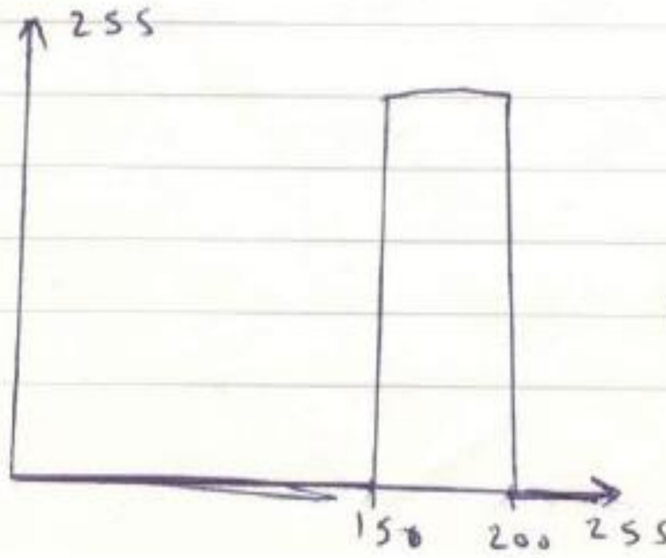
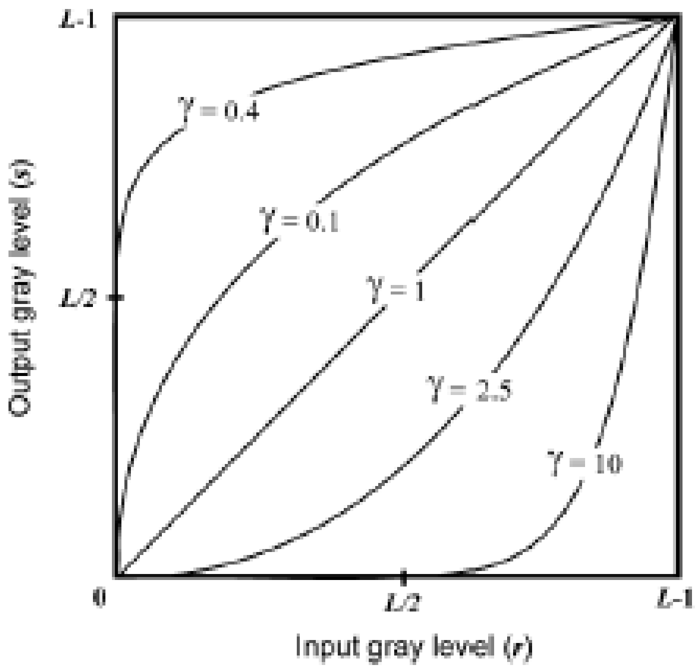


fig (5-8-e). The operation intensifies the desired gray-level range, while changing the other values to black.

Power-Law (Gamma) Transformation

$$s = c \cdot r^{\gamma}$$

- For gamma < 1, the output image is brighter than the input image
- For gamma > 1, the output image is darker than the input image

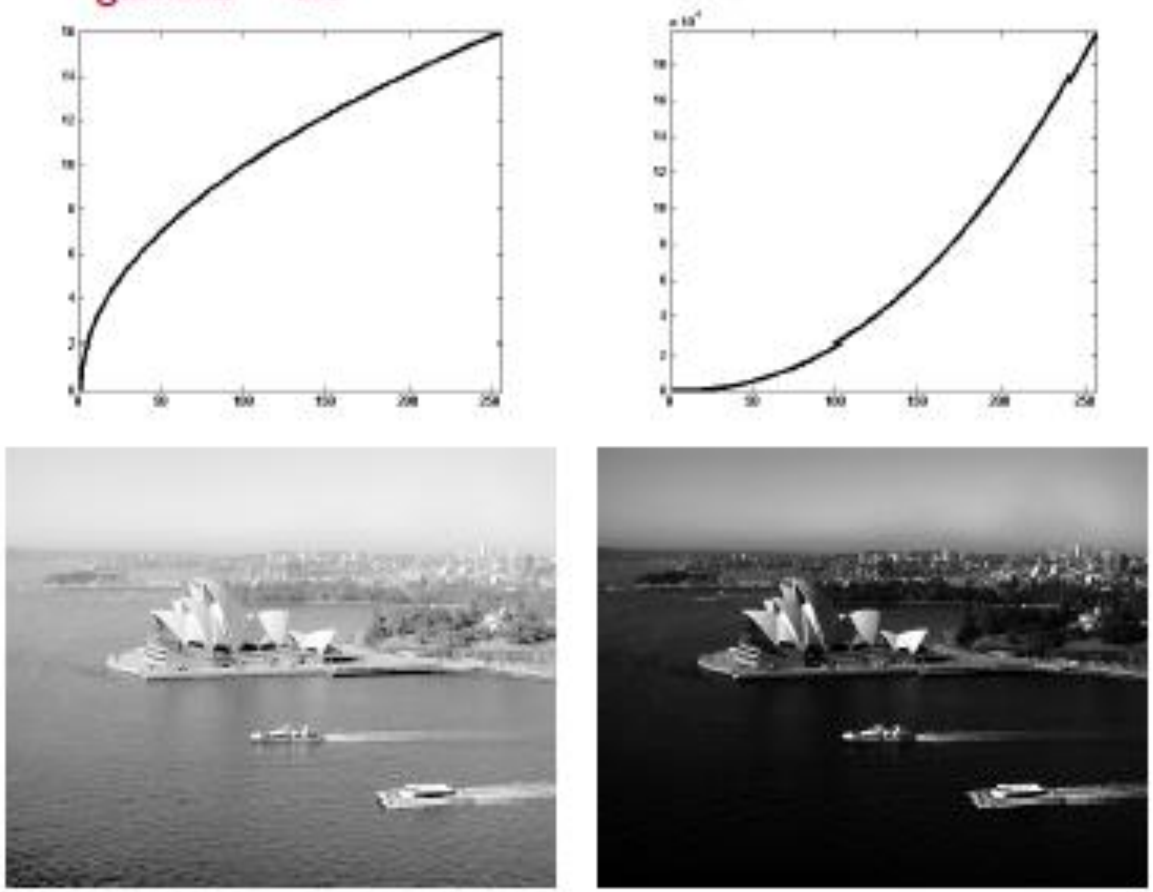


If r is between 0 and 255, choose c such that s is also between 0 and 255. Alternatively, use normalized r and s, i.e., $0 <= r, c, < 1$, in which case $c=1$.

Gamma Transformation

gamma = 0.5

gamma = 2.2



Gamma Correction

Scanner, printers, and display devices have a power-law response to input intensity:

$$s = r^{\gamma}$$

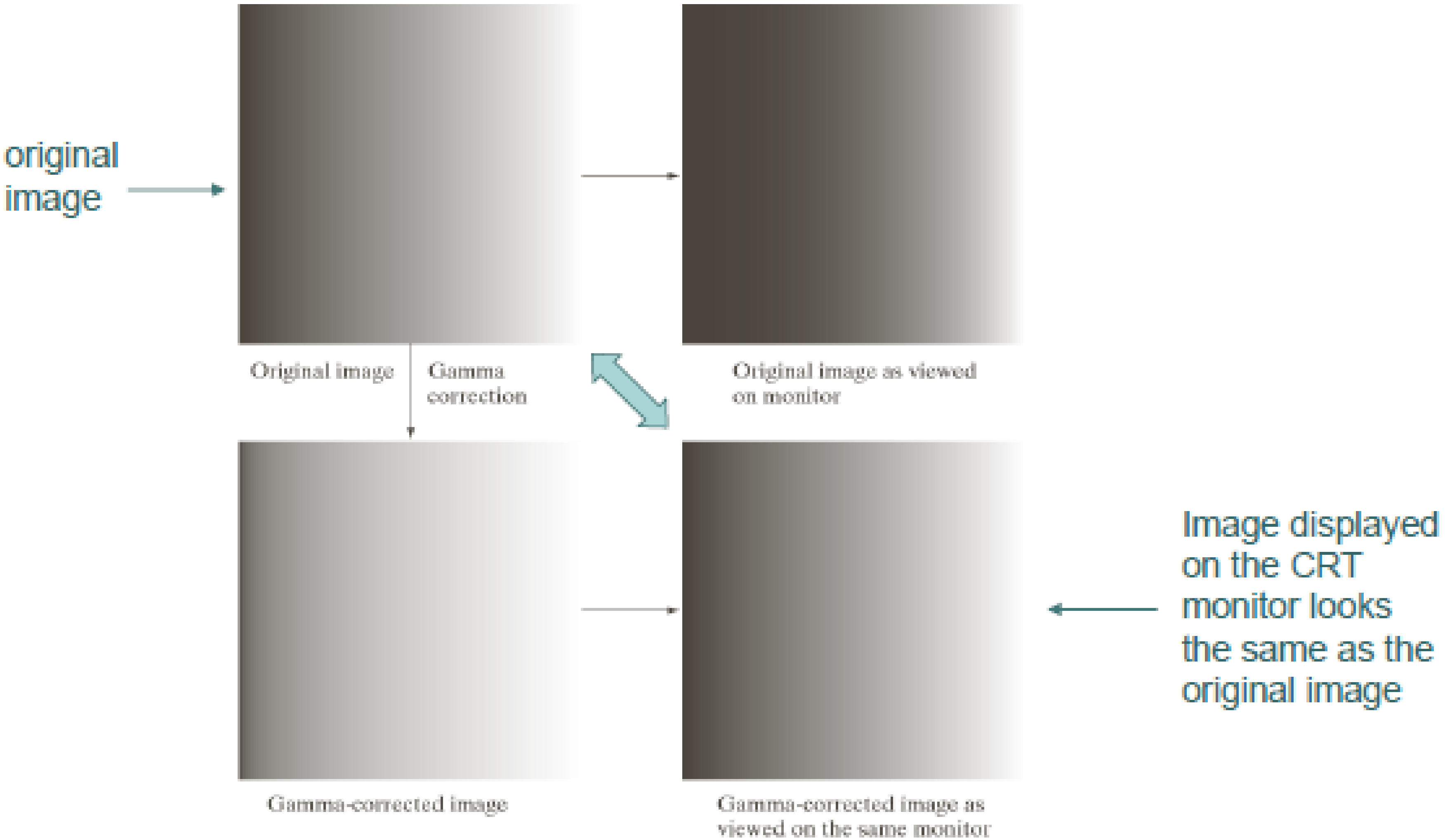
In particular for a CRT:

$$s = r^{2.5}$$

Gamma correction (preprocessing):

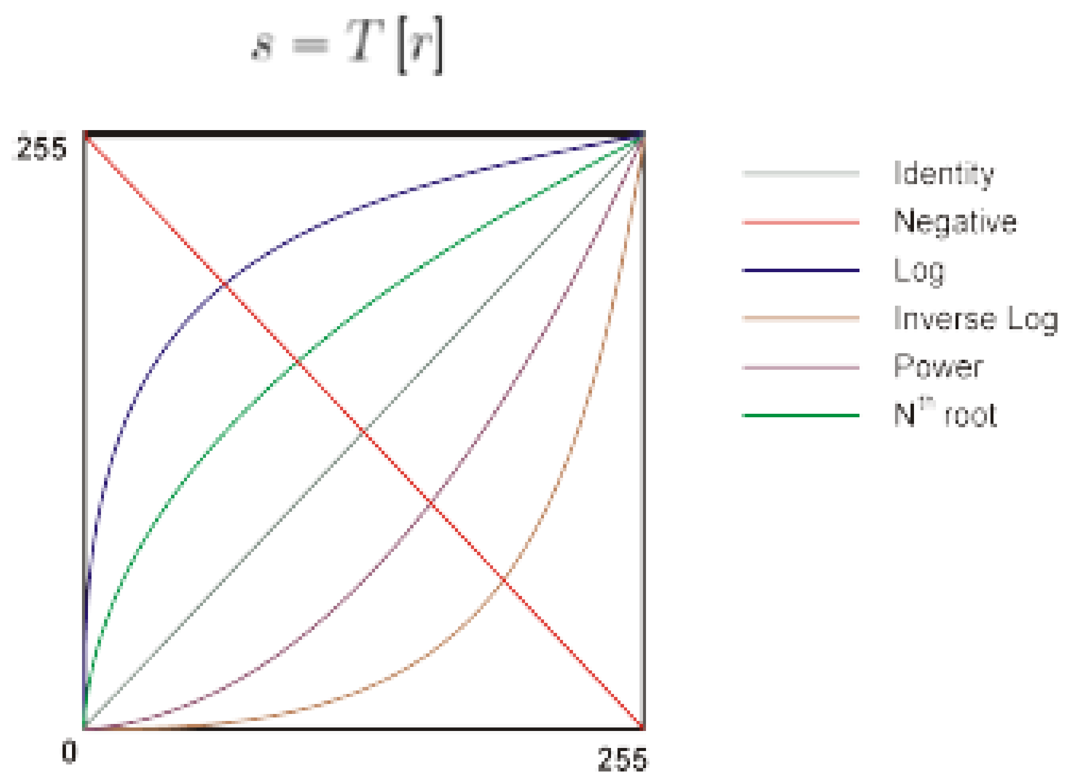
$$s = r^{0.4}$$

Gamma Correction



Summary of Intensity Transformations

- Linear (inc. negative)
- Piecewise linear (e.g., gray level slicing)
- Nonlinear (e.g., gamma correction, Nth root, log, power, inverse log)



What is a histogram?

- The histogram of a monochrome image is a representation of the **frequency of occurrence of each intensity level** in the image.

- The data structure that stores the frequency values is a 1D array of numerical values, $h(r)$, whose individual elements store the number (or percentage) of image pixels that correspond to each possible intensity level r.

5-4- Histogram Modification

The histogram of a digital image with gray level in the range [0, L-1] is a discrete function

$$P(r_k) = \frac{n_k}{n} \quad \text{———} (5-7)$$

where

r_k = is the kth gray level

n_k = is the number of pixels in the image with that gray level.

n = is the total number of pixels in the image

$k = 0, 1, \text{———} L-1$

$P(r_k)$ gives an estimate of the probability of occurr-ence of gray level r_k.

Aplot of this function for all values of k provide a global discription of the ~~appeara~~ appear of the images as shown in the fig. (2-9)

Histogram of an Image

$$h(r) = n$$

r: image intensity value (0,1,…,255)

n: total number (0,1,…,MN-1) of pixels in the image having the intensiy value r

$$\sum_{i,j} h(r) = MN$$

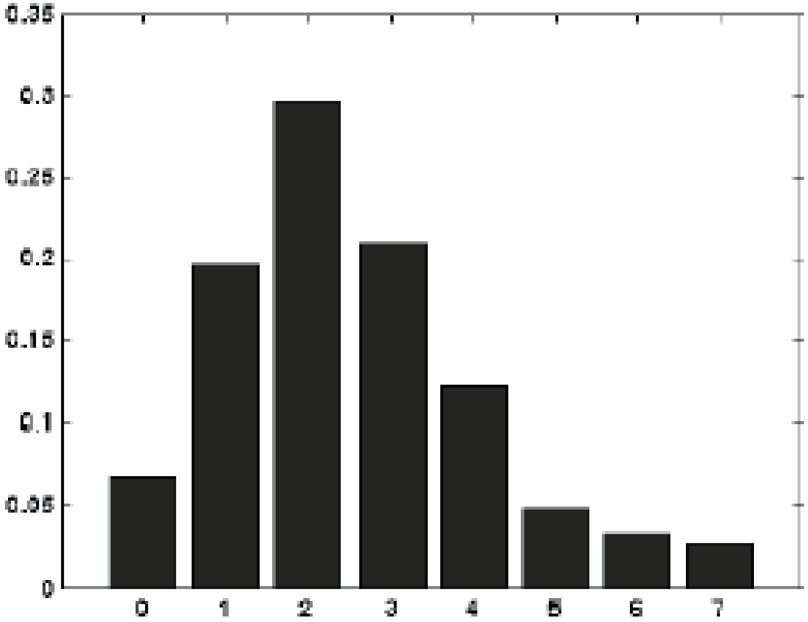
$$f(r) = \frac{1}{MN} h(r)$$

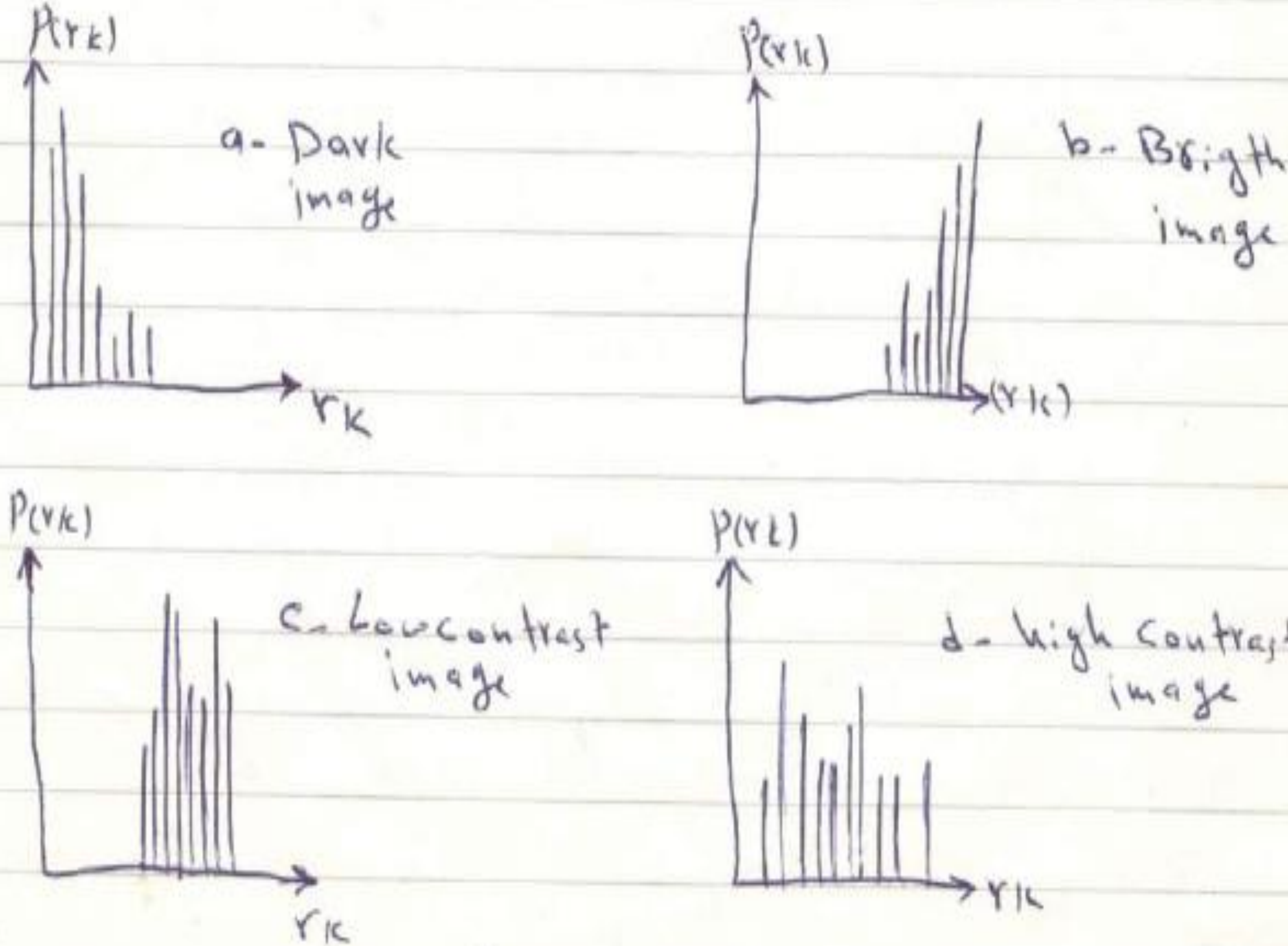
Probability density function (pdf) of image intensities

Histogram Example

- Histogram for a hypothetical image containing 128×128 pixels and 8 intensity levels.

Gray level (r_k)	n_k	$p(r_k)$
0	1120	0.068
1	3214	0.196
2	4850	0.296
3	3425	0.209
4	1995	0.122
5	784	0.048
6	541	0.033
7	455	0.028
Total	16384	1.000

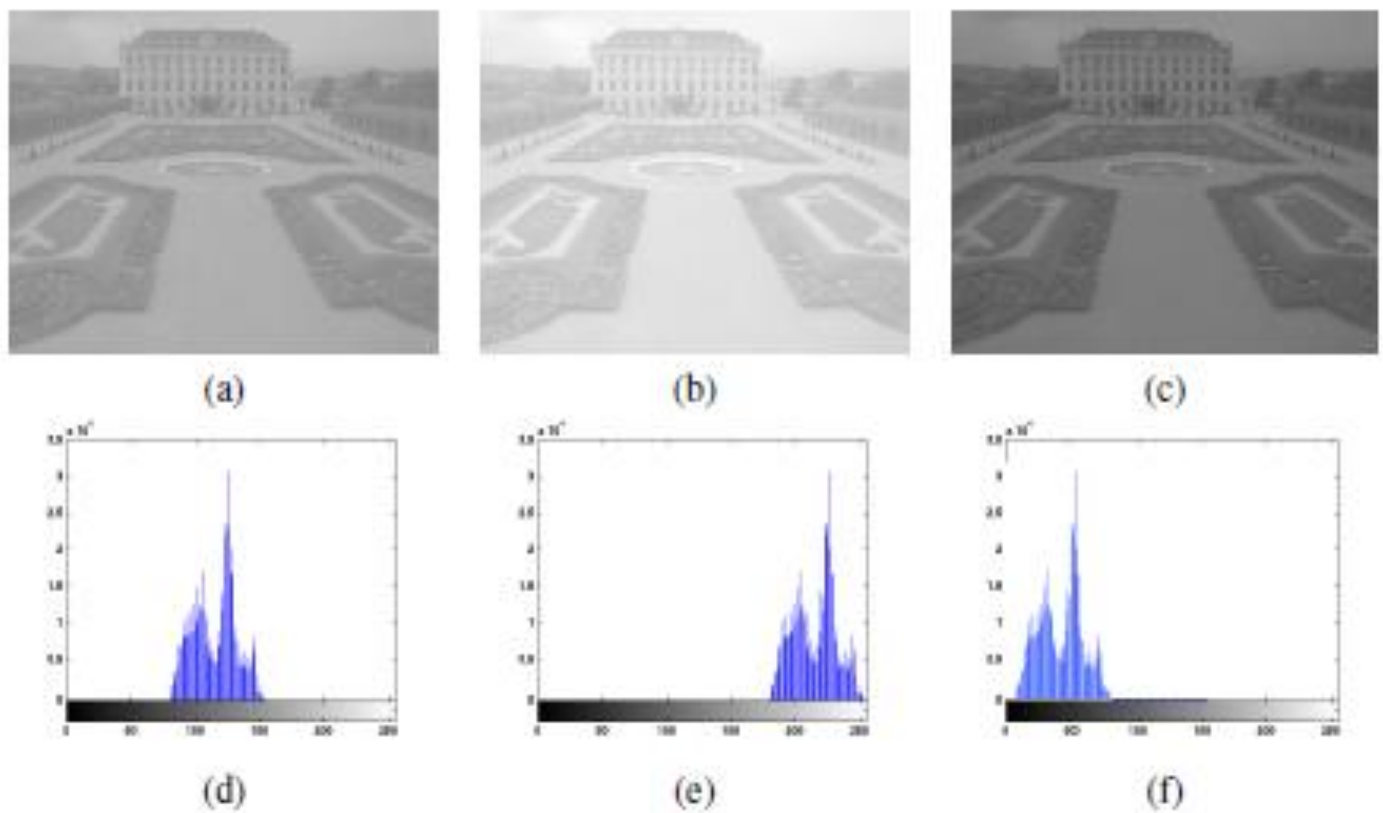



P(rk)
a- Dark image
rk
P(rk)
b- Brigth image
(rk)
P(rk)
c- Low contrast image
rk
P(rk)
d- high contrast image
rk

fig(5-9)

Histogram Sliding

- Same as adding or subtracting a constant value (brightness change)



The histogram can be modified by a mapping function, which will either stretch, ~~or~~, shrink (compress), or slide the histogram. Histogram stretching and histogram shrinking are forms of gray-scale modifiction, Sometimes referred to as histogram scaling. fig.(5-10) shown the histogram stretch, shrink, and slide.

fig (5-10)

The mapping function for a histogram stretch can be found by the following equation.

$$\text{stretch } I(r,c) = \left[\frac{I(r,c) - I(r,c)_{min}}{I(r,c)_{max} - I(r,c)_{min}}\right][max - min] + min$$

$(g - l_0)$

when

$I(r,c)_{max}$ is the largest gray-level value in the image $I(r,c)$

$I(r,c)_{min}$ is the smallest gray-level value in the $I(r,c)$

for 8 bit $I_{max} = 255$ & $I_{min} = 0$

Max Min

there for the stretch image is increasing the Contrast of a low Contrast image.

A pure histogram stretch will not improve the image. In this Case it is useful to allow a small percentage of the Pixel values to be Clipped at the low and high end of the range (for 8-bit image this means 0 & 255)

The opposite of a histogram stretch is a histogram shrink which will decrease image contrast by compressing the gray level, the mapping function for a histogram shrink can be found by the following equation.

$$\text{shrink}(I(r,c)) = \left[\frac{\text{shrink}_{max} - \text{shrink}_{min}}{I(r,c)_{max} - I(r,c)_{min}}\right]\{I(r,c) - I(r,c)_{min}\} + \text{shrink}_{min} \quad (5\text{-}11)$$

where

$I(r,c)_{max}$ is the largest gray-level value in the image $I(r,c)$

$I(r,c)_{min}$ " " smallest " " " " " "

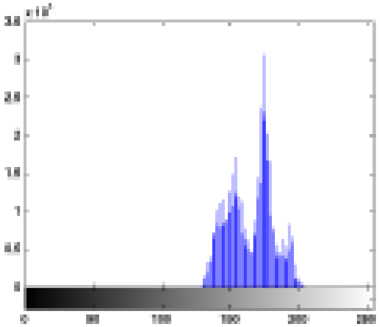
Histogram Stretching

- Expand the part of the histogram such that its nonzero intensity range occupies the full dynamic gray scale. (same as autocontrast)

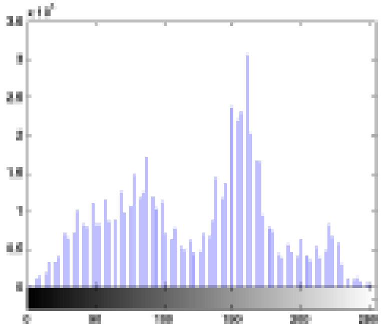
$$s = \frac{r - r_{min}}{r_{max} - r_{min}} \cdot (L - 1)$$

(a)

(b)



(c)



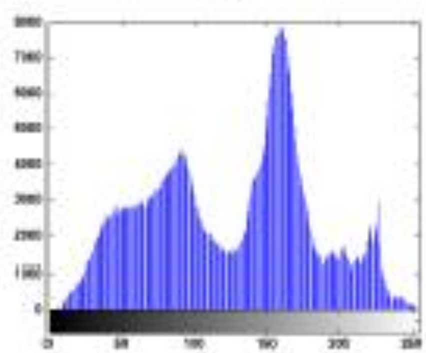
(d)

Histogram Shrinking

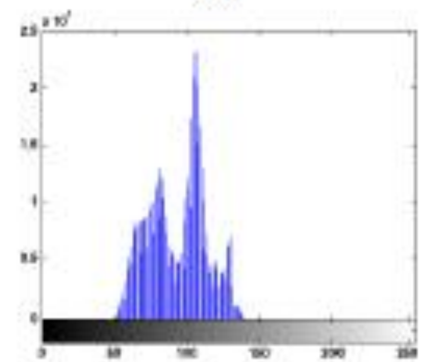
- Compress the dynamic range $$s = \left[\frac{s_{max} - s_{min}}{r_{max} - r_{min}}\right](r - r_{min}) + s_{min}$$

(a)

(b)



(c)



(d)

this process produces an image of reduced contrast and may not seem to be useful as an image enhancement tool. The histogram slide technique can be used to make an image either darker or lighter but retain the relationship between gray-level values. This can be accomplished by simply adding or subtracting a fixed number from all the gray-level values, as follows.

$$\text{slide}(I(r,c)) = I(r,c) + \text{offset}. \quad \text{——} \quad (5\text{-}12)$$

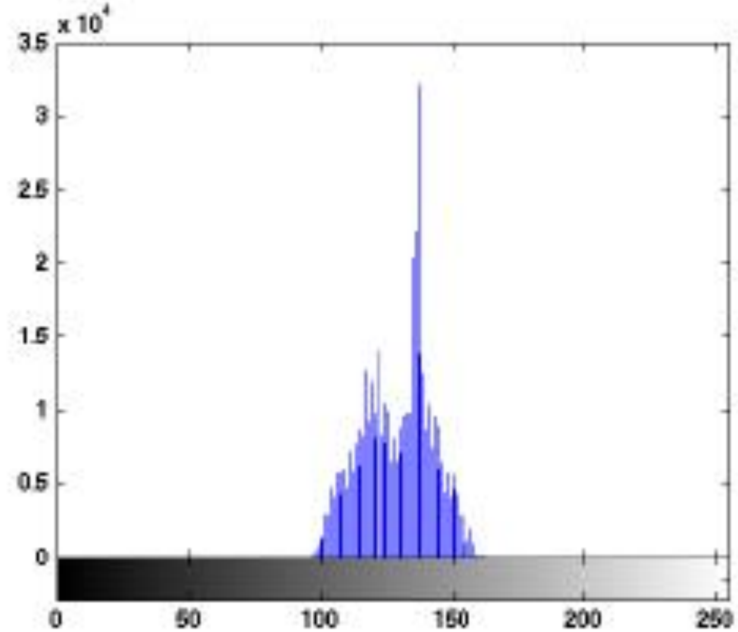
where the offset value is the amount to slide th hito.

In this equation we assume that any values slid past the min. and max. value will be clipped to the respective min. or max.. A positive offset value will increase the overall brightness, whereas a negative offset will create a darker image.

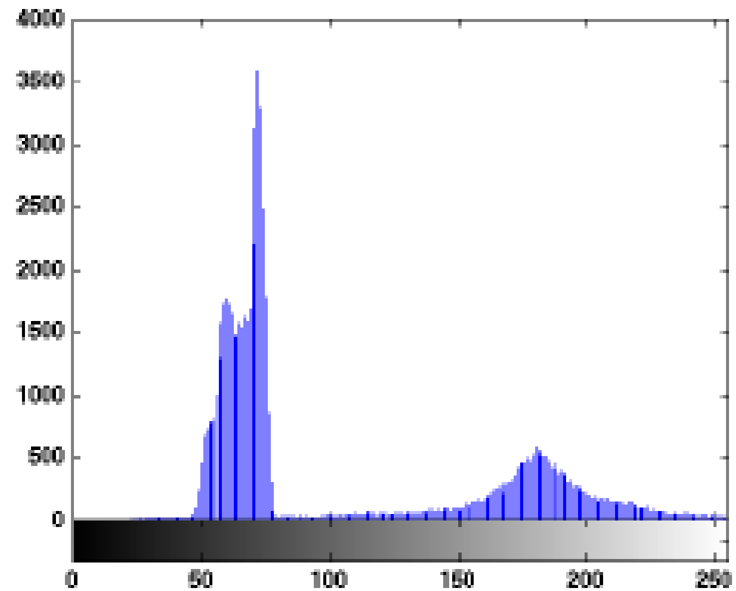
Example: Low Contrast Image

Pixels are grouped around intermediate gray-level values, indicating an image with low contrast

- In MATLAB: **`imhist`**

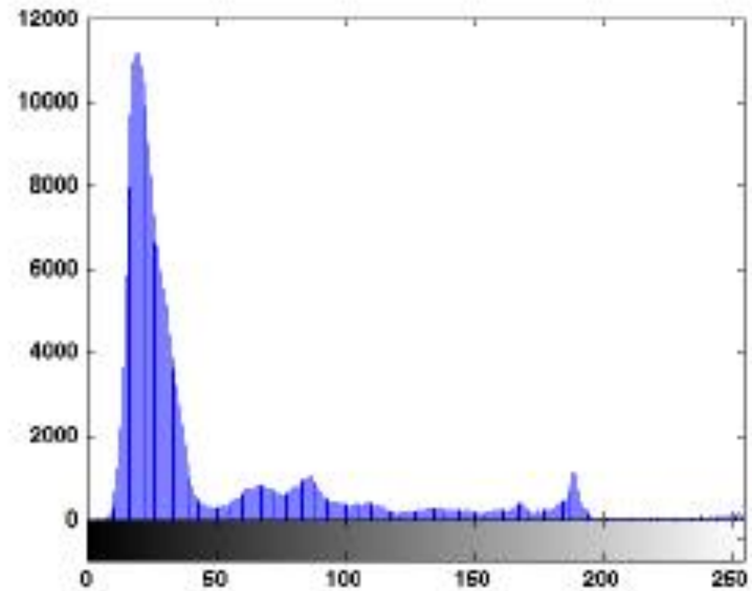


Example: Bimodal Image



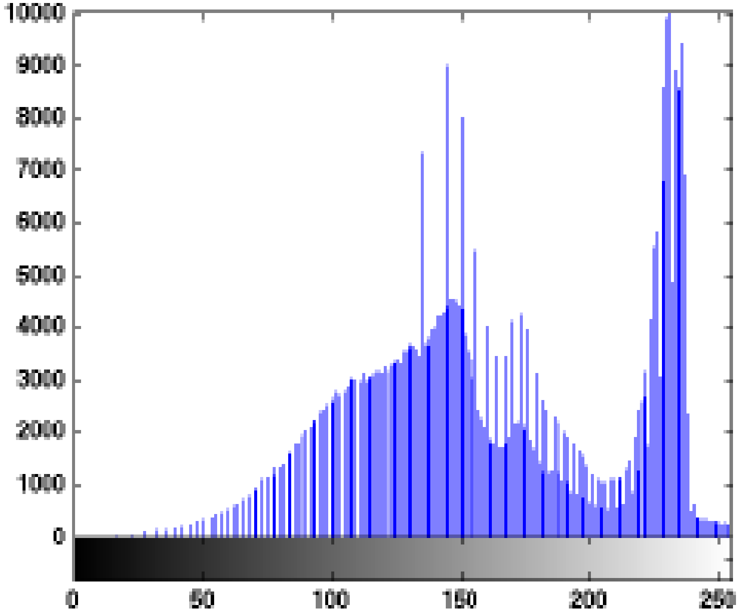
- Two distinct hills.
- Image has high contrast since the two modes are well seperated from each other.

Example: Dark Image



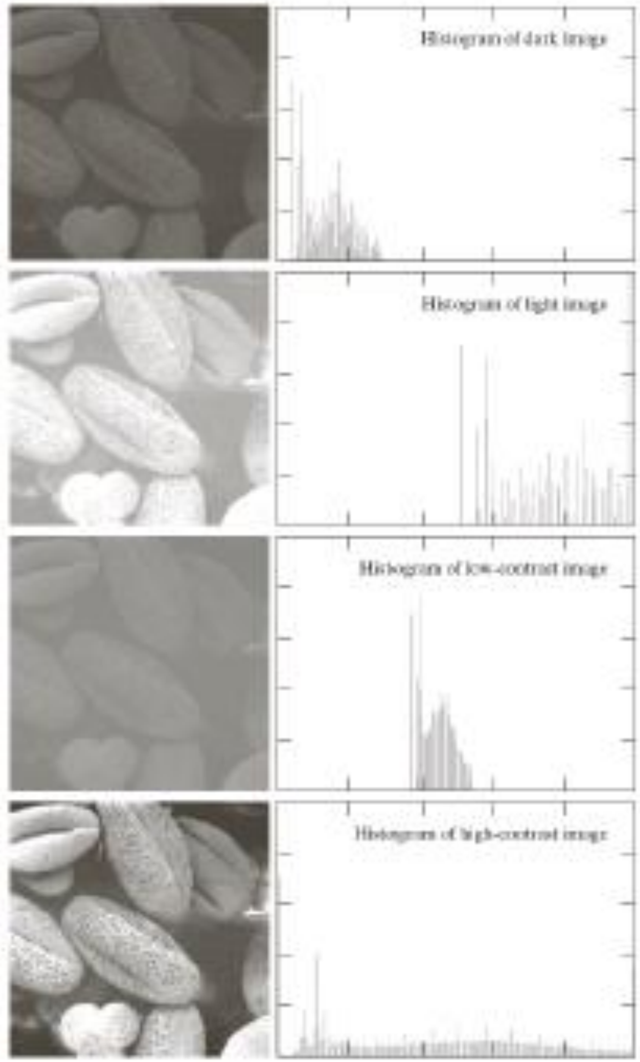
- Histogram is concentrated in lower gray levels, which corresponds to a moslty dark image.

Example: Bright Image



- Histogram is grouped close to the higher gray-levels, which corresponds to a bright image.

Histogram Comparison



Dark

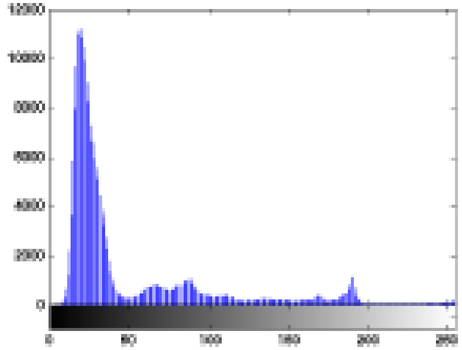
Light

Low contrast

High contrast

Utilization of Histograms

- Contemporary digital cameras have an optional real-time histogram overlay in their viewfinder.
- This information prevents taking underexposed or overexposed pictures.



Example:

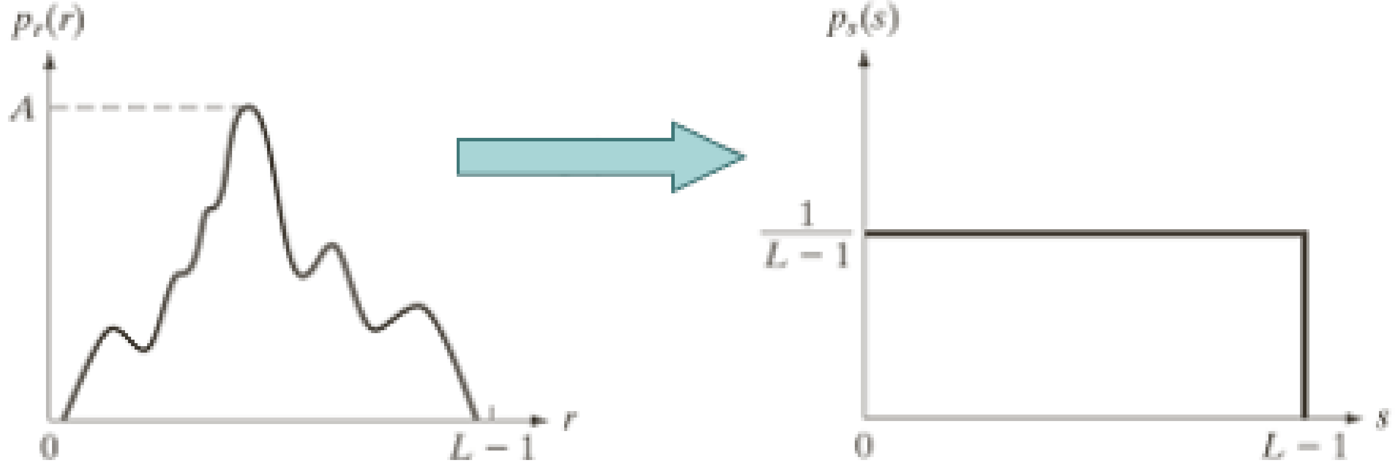
Too dark ➔ increase exposure

Summary

- Histograms provide a **statistical** representation of the intensity distribution in an image.
- Histograms can be used to evaluate image attributes such as minimum, average, and maximum intensity values, overall contrast and average brightness, and dominance of bright or dark pixels.
- Histograms do **not** contain any information about the spatial distribution of the pixels.
- Histograms can be **modified** to enhance the appearence of an image.

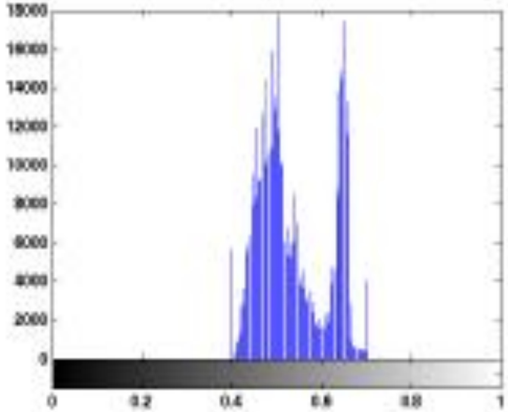
Histogram Equalization

Find an intensity mapping $s=T(r)$ such that the new intensity values have a <u>flat</u> probability density function (pdf):



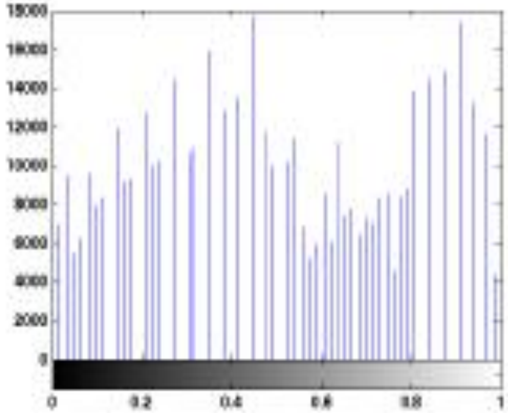
Histogram equalization

(a)



(b)

(c)



(d)

5-5- Histogram Equalization

Is a popular technique for improving the appearance of a poor image. Its function is similar to that of a histogram stretch but often provides more visually pleasing results across a wider range of image. Histogram equalization is a technique where the histogram of the resultant image is as flat as possible. The theoretical basis for histogram equalization involves probability theory, where we treat the histogram as the probability distribution of the gray levels.

The histogram equalization process for digital images consists of four steps.

1) find the running sum of the histogram values.
2) Normalize the values from step 1 by dividing by the total number of pixels.
3) Multiply the values from step 2 by the max. gray level value and round.
4) Map the gray level values to the results from step 3 using a one-to-one corresponding.

Ex/ We have an image with 3bit/pixel, So the possible range

Ex/ We have an image with 3bit/Pixel, So the Possible range of values is (0 to 7), using histogram equalization to enhance this image with the following histogram.

Gray-Level Value	No. of Pixel
0	10
1	8
2	9
3	2
4	14
5	1
6	5
7	2

Solve/

Step1 \ Create a running sum of the histogram values.

10, 10+8=18, 18+9=27, 27+2=29. So on

10, 18, 27, 29, 43, 44, 49, 51

Step2\ Normalize by dividing by the total No. of pixel

10/51, 18/51, 27/51, 29/51, 43/51, 44/51, 49/51, 51/51

Step3\ Multiply these values by the max. gray level value, and around.

$\frac{10}{51} \times 7 = 1,37 \simeq 1$, $\frac{18}{51} \times 7 = 2.47 \simeq 2$

$\frac{27}{51} \times 7 = 3.70 \simeq 4$, $\frac{29}{51} \times 7 = 3.98 \simeq 4$

$\frac{43}{51} \times 7 = 5.9 \simeq 6$, $\frac{44}{51} \times 7 = 6.03 \simeq 6$

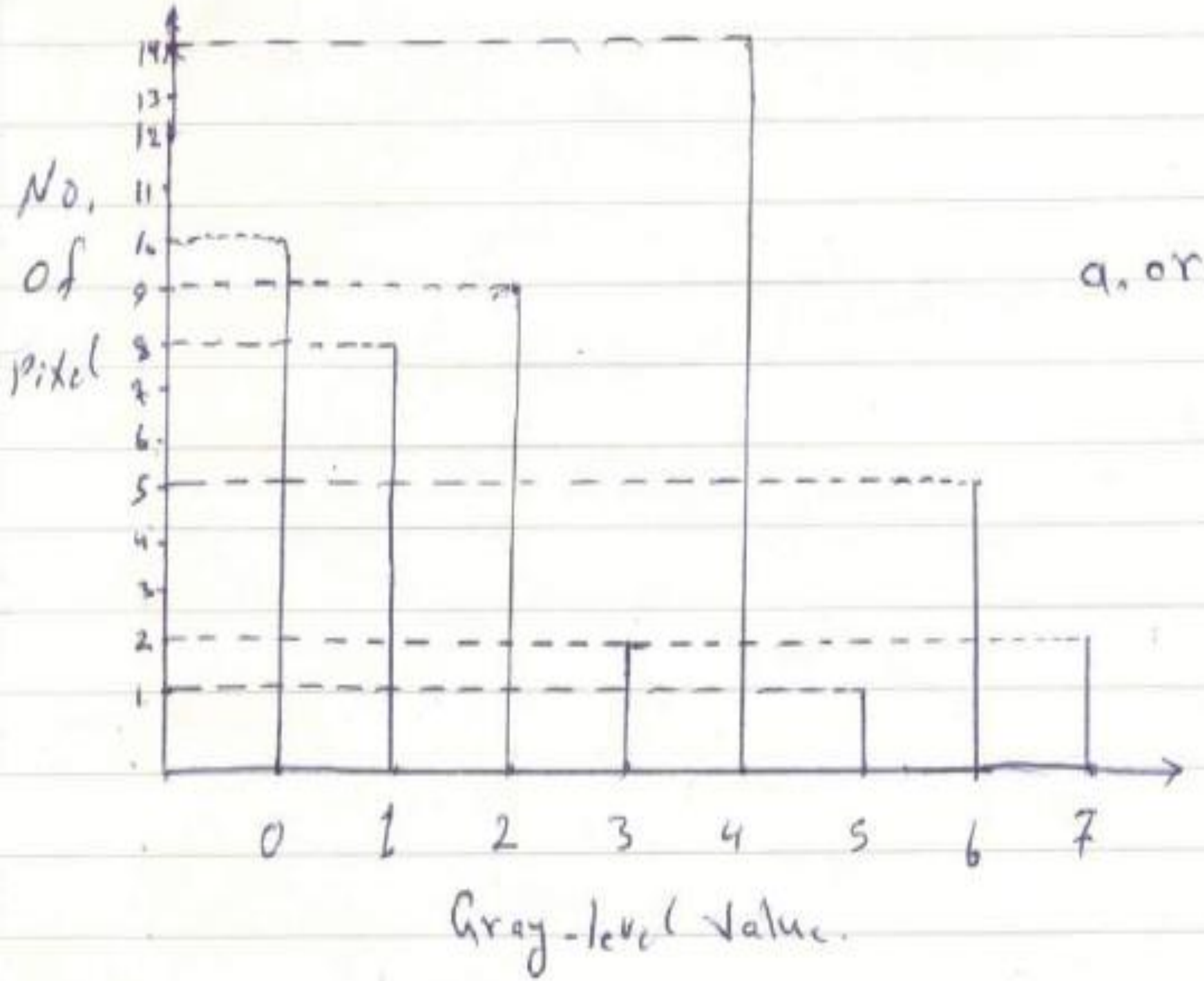
$\frac{49}{51} \times 7 = 6.7 \simeq 7$, $\frac{51}{51} \times 7 = 7$

step 4\ Map the original values to the results from step 3 by a one-to-one correspondance.

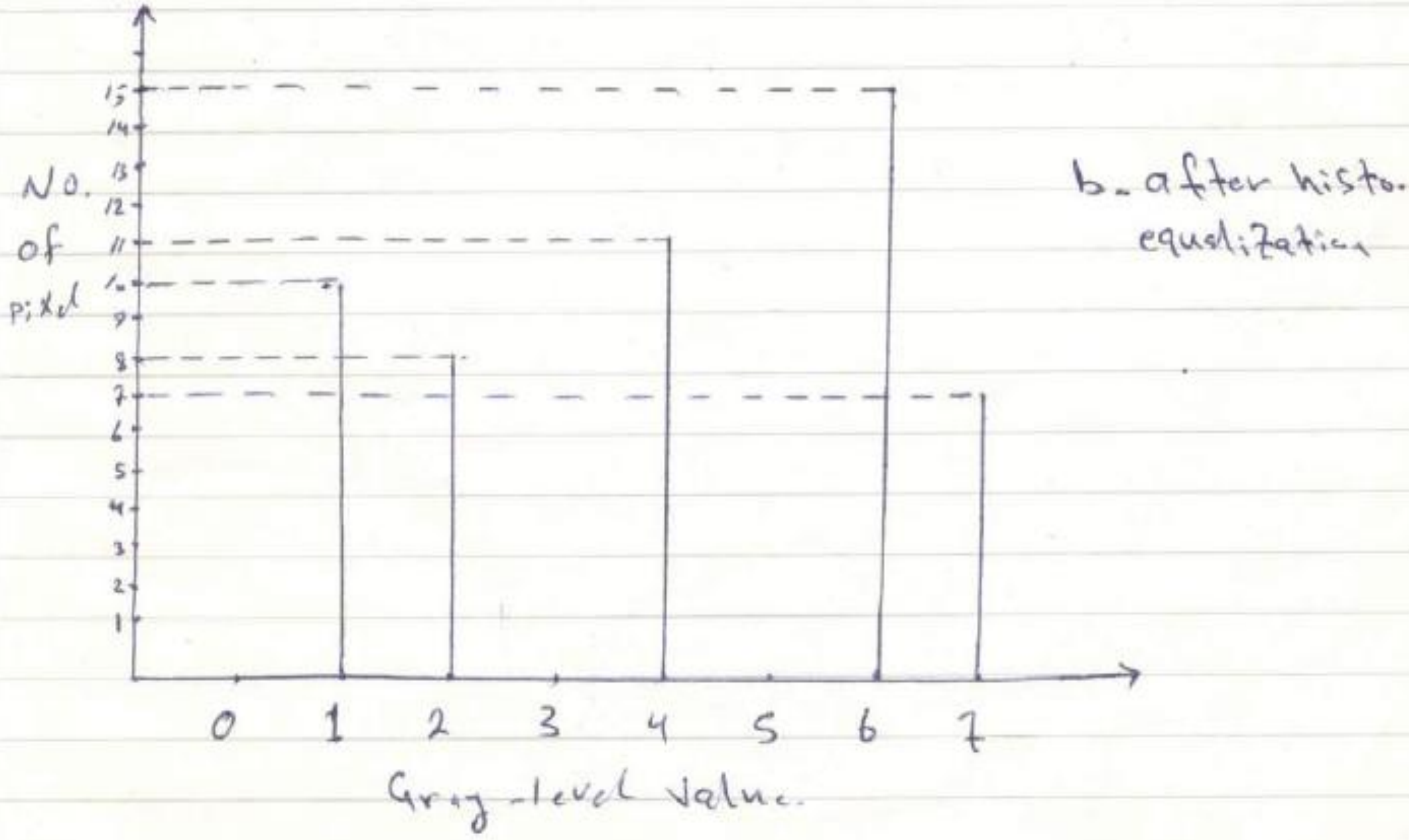
original Gray-Level value	Histogram Equalization value
0	1
1	2
2	4
3	4
4	6
5	6
6	7
7	7

All pixel in the original image with gray-level 0 are set to 1
1 set to 2, 2 set to 4, 3 set to 4 and so on.

fig (5-11) shows the original histogram and equalization histogram.



a. original histogram.

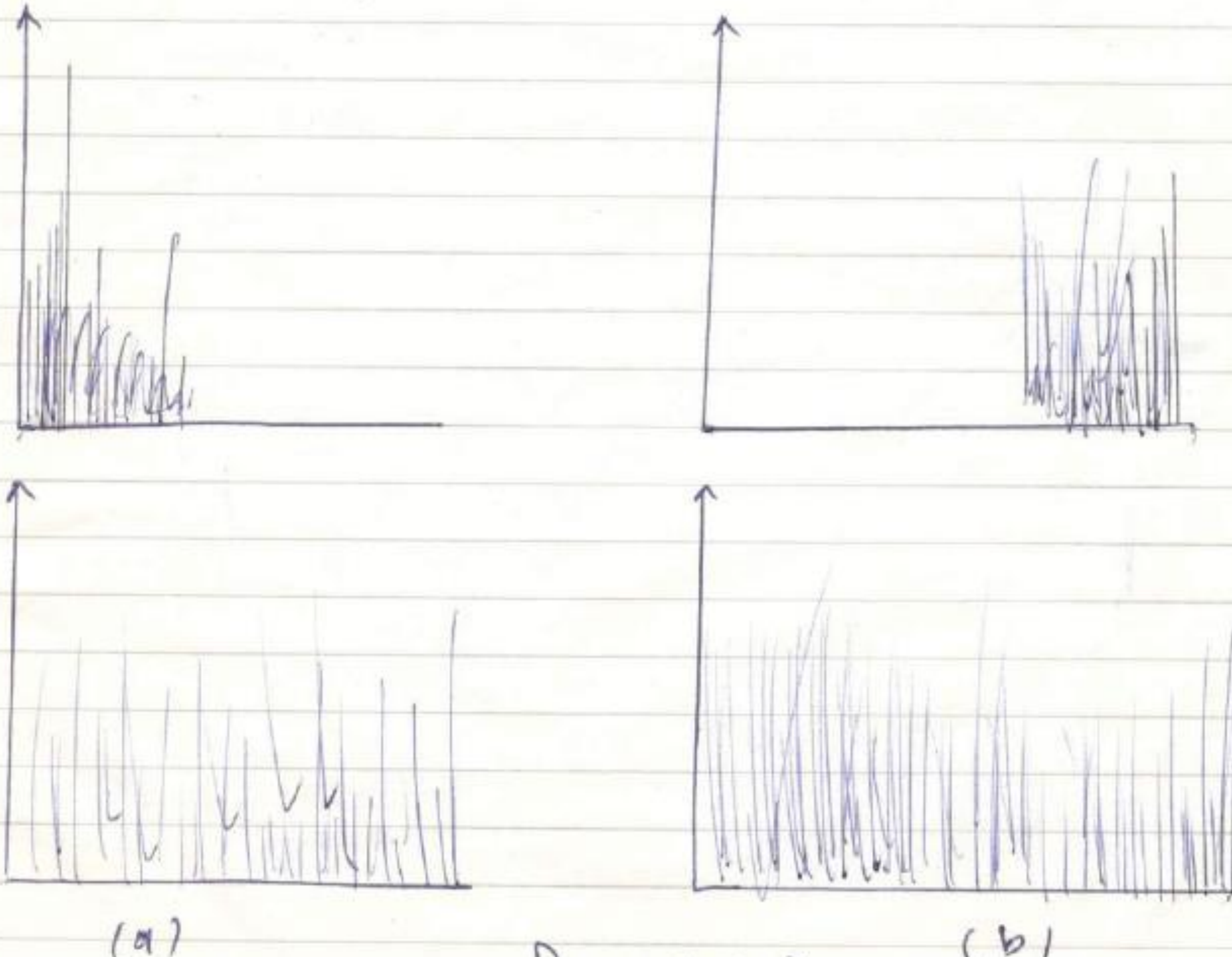


15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
No. of pixel
b- after histo. equalization
0
1
2
3
4
5
6
7
Gray-level value

fig.(5-11)

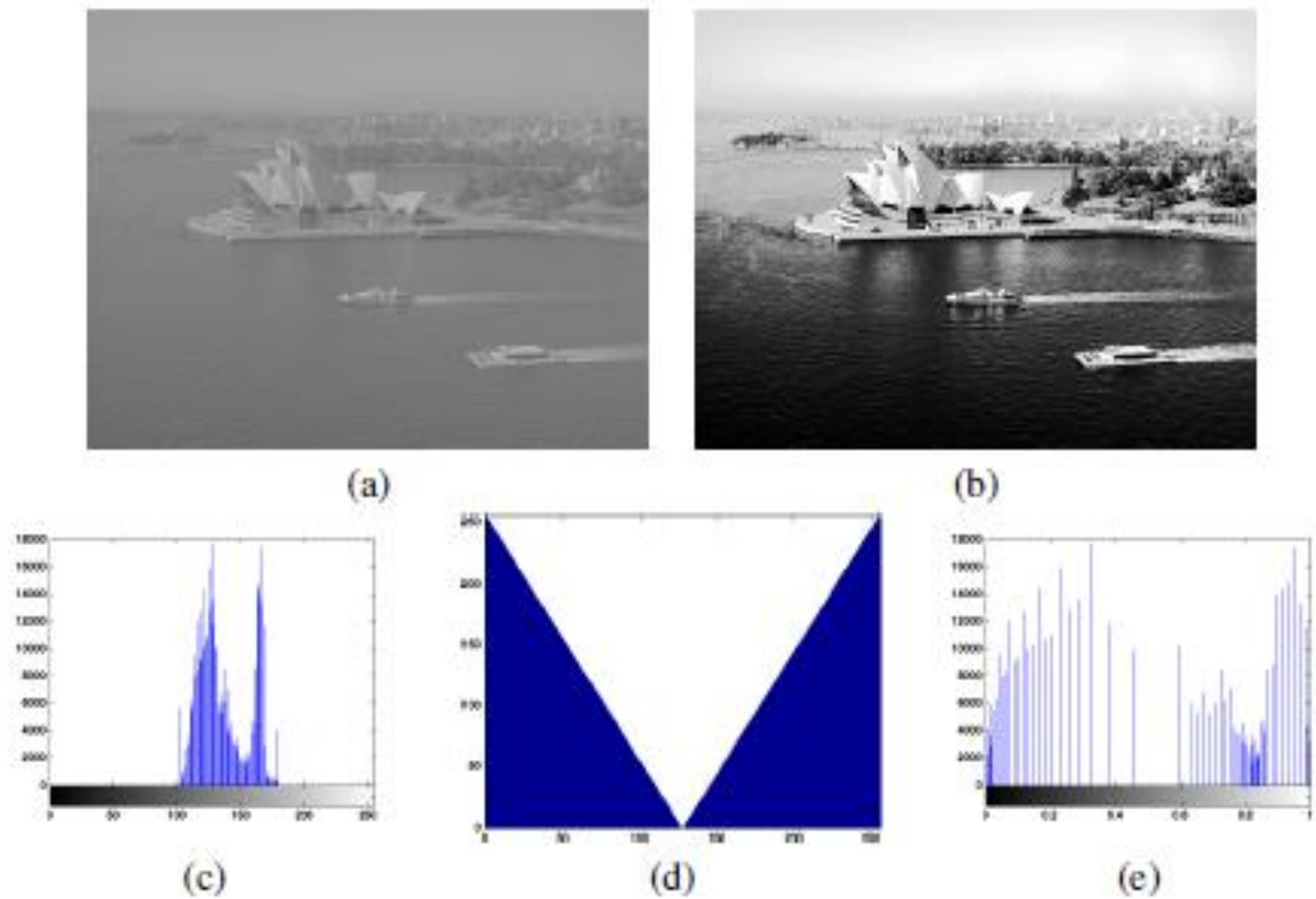
Histogram equalization of a digital image will not typically provide a histogram that is perfectly flat, but it will make it as flat as possible. For the equalized histogram to be completely flat, the pixels at a given gray level might need to be redistributed across more than one gray level. This could be done but would greatly complicate the process, as some redistribution criteria would need to be defined. In most cases the visual gains achieved by doing this would be negligible and could in som cases be negative. In practice, it is not done.

fig(5.12a). Shown the results of applying histogram equalization to a dark image, and fig(5.12.b) shown the results of applying histogram equalization to bright image.



fig(5-12)

Histogtram Specification



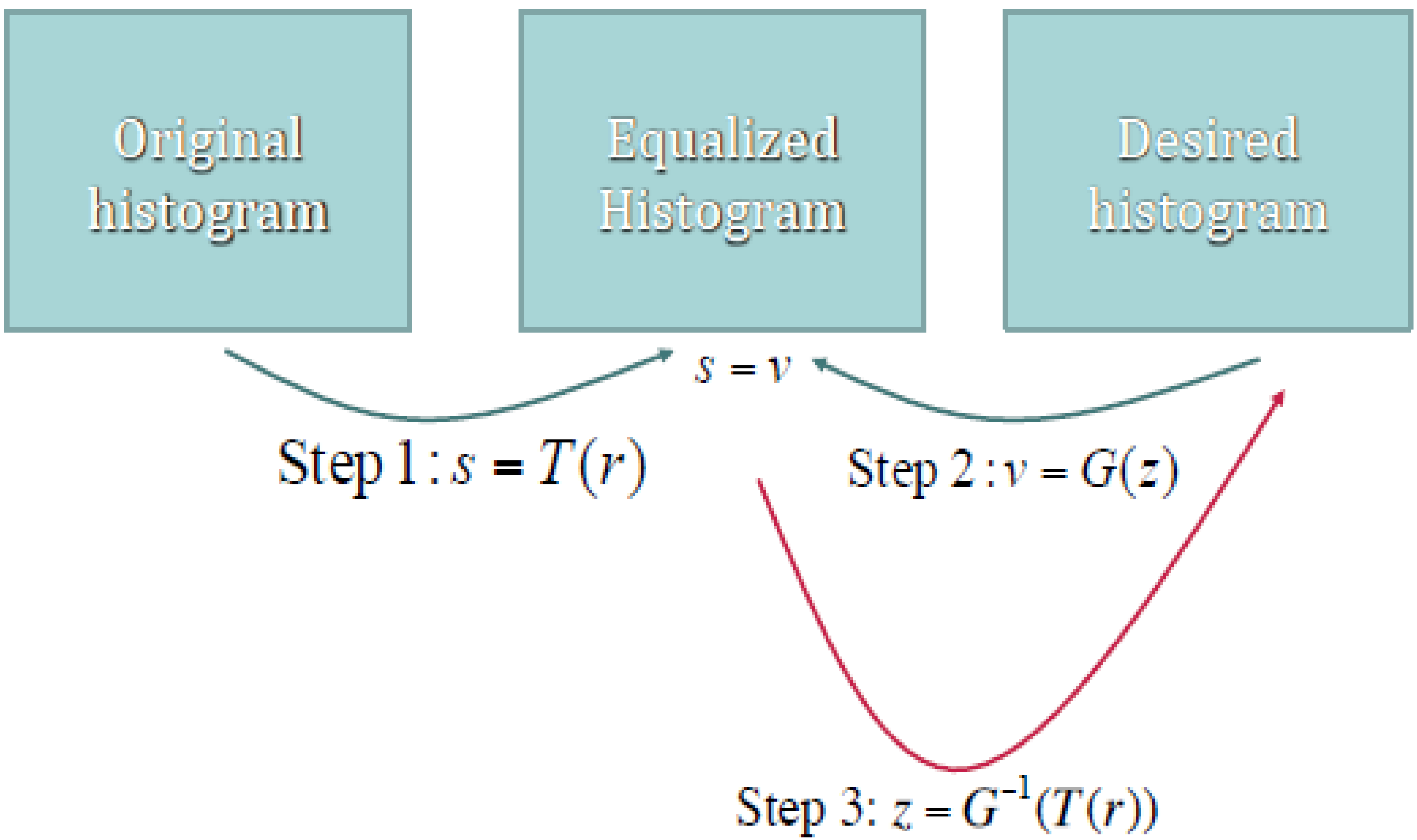
5-6- Histogram Specification

Is the process of defining a histogram and modifying the histogram of the original image to match the histogram as specified. This process can be implemented by :-

1) finding the mapping table to histogram-equalize the image.
2) Specifying the desired histogram.
3) finding the mapping table to histogram-equalize the values of the desired histogram.
4) mapping the original values to the values from step 3 by using the table from step 1.

ex/ From the previous example, we have.

Histogram Specification (Matching)



Step1\ original graylevel value, O   Histogram Equalized H

original graylevel value, O	Histogram Equalized H
0	1
1	2
2	4
3	4
4	6
5	6
6	7
7	7

Step2\ Specify the desired histogram.

g.L. value	No. of pixel in desired histo.
0, 1, 2, 3, 4, 5, 6, 7	1, 5, 10, 15, 20, 0, 0, 0

Step 3\ Find the histogram equalization mapping table for the desired histogram.

g.l. value	Histogram Equalized value - S
0	round (1/51) * 7 = 0
1	round (6/51) * 7 = 1
2	round (16/51) * 7 = 2
3	round (31/51) * 7 = 4
4	round (51/51) * 7 = 7
5	round (51/51) * 7 = 7
6	round (51/51) * 7 = 7
7	round (51/51) * 7 = 7

Step 4\ Map the original values to values from step 3 by using the table from step 1. This is done by setting up a table created by combining the table from step (1 & 3). We will denote O for the original gray-level, H for the histogram-equalized level, S for the specified and histogram-equalized values, and M for our final mapping.

O	H	S	M
0	1	0	1
1	2	1	2
2	4	2	3
3	4	4	3
4	6	7	4
5	6	7	4
6	7	7	4
7	7	7	4

The M column for this table is obtained by mapping the value in H to the closest value in S and then using the corresponding row in O for the entry in M, for ex., the first entry in H is 1, we find closest value is S, which is 1 this 1, from S, appears in row 1, so we write a 1 for that entry in M.

The fifth entry in H, is 6 must map to 7, but the 7 appears on rows 4, 5, 6, 7, which one do we select? It depends on what we want; picking the Largeset value will provide mad. contrast, but picking the smallest (closet value) will produc ... gradually changing image, Typically, The

a more gradually changing image. Typically, the smallest is chosen because we can always perform a histogram stretch or equalization on the o/p image. if we desire to max. contrast.
In practice, the desired histogram is often specified by nonlinear function (sine or a log. function).
To obtain the number for the specified histogram the function is sampled, and the values are normalized to 1. and the multiplied by the total number of pixels in the image.

$$S(k) = T(l_k) = \sum_{i=0}^{k} p_l(l_k)$$

and

Adaptive (Local) Histogram Equalization

Local Histogram Equalization

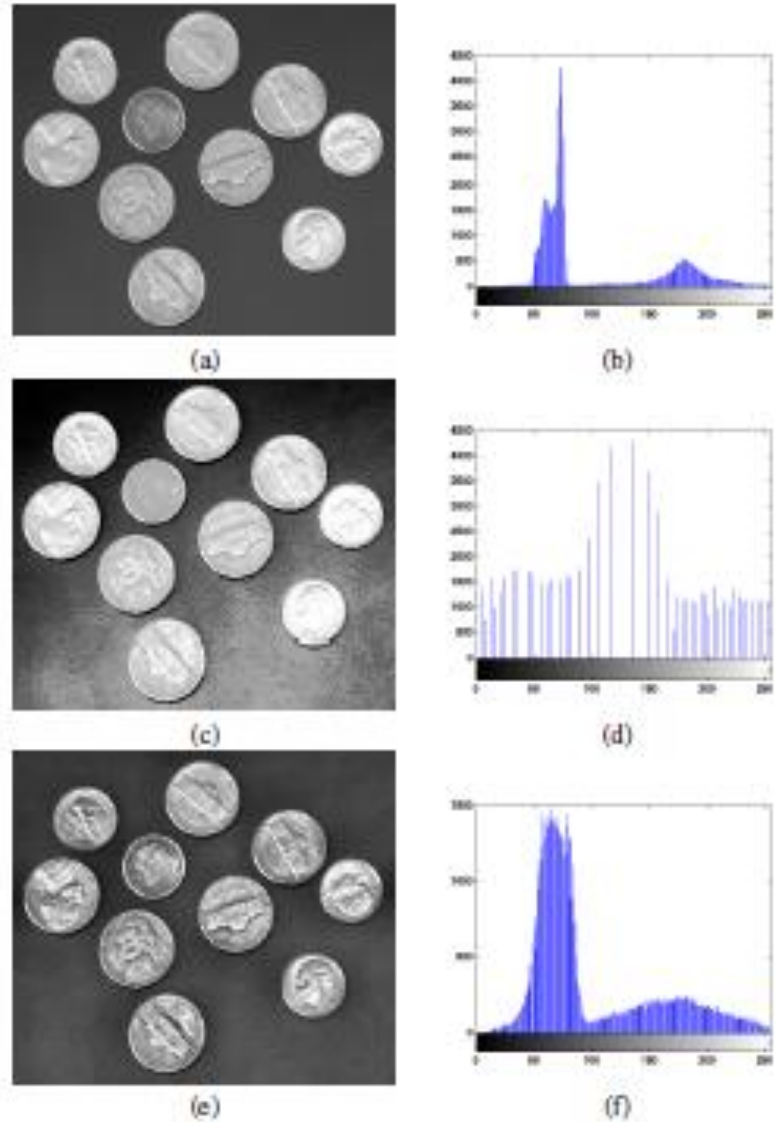
- Use a sliding (rectangular/square) **window**, which moves across the image.
- Compute the histogram in the window and compute the mapping function.
- Map the **center** pixel of the window using the mapping function.
- Much more computationally expensive than global histogram equalization.

Global vs. Local Histogram Equalization

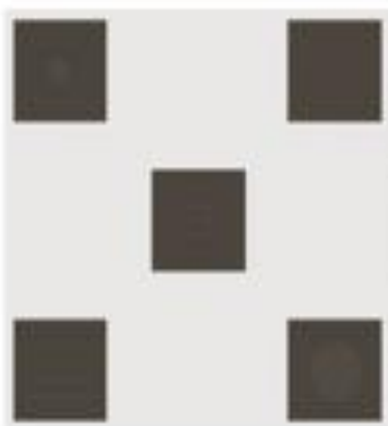
Original image and its histogram

After global histogram equalization

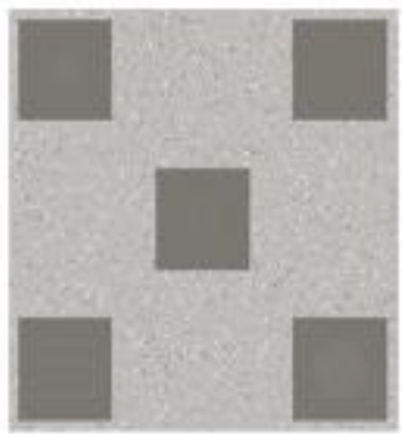
After local histogram equalization. Bimodal nature of the histogram is preserved while still improving the contrast.



Adaptive (Local) Histogram Equalization

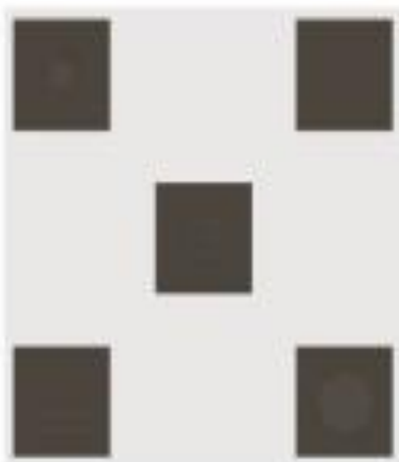


Original

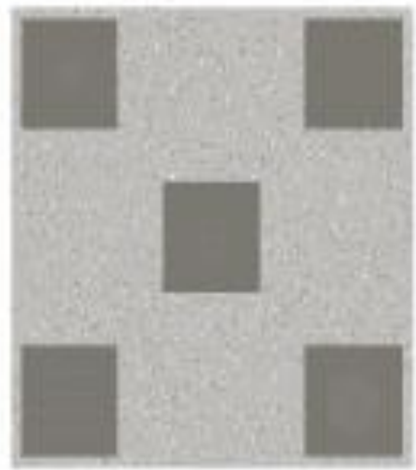


Global HE

Adaptive (Local) Histogram Equalization



Original



Global HE

Local HE