

Digital Image Processing

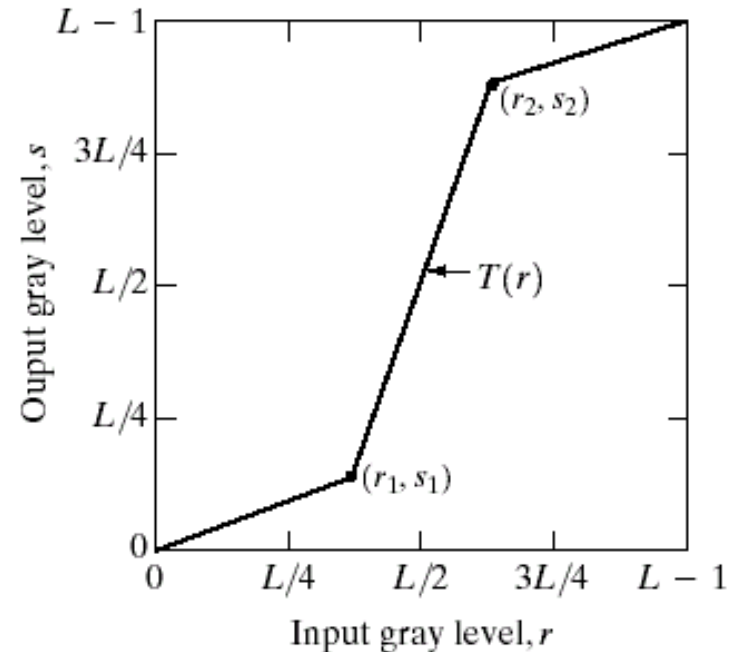
Lecture # 4 **Spatial Enhancement**

Piecewise Linear Transformation Functions

- ◆ Contrast stretching
- ◆ Intensity level slicing

Contrast Stretching

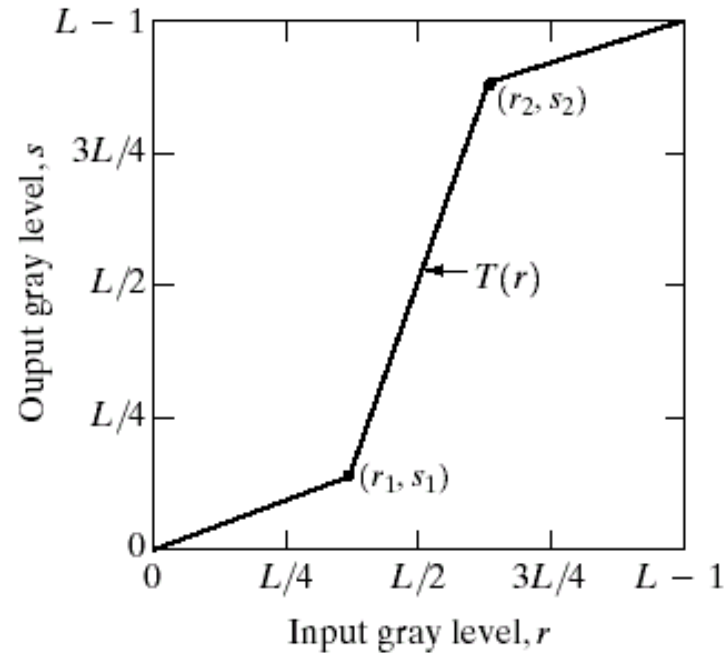
- ◆ Objective
 - Increase the dynamic range of the gray levels for low contrast images
- ◆ Rather than using a well defined mathematical function we can use arbitrary user-defined transforms



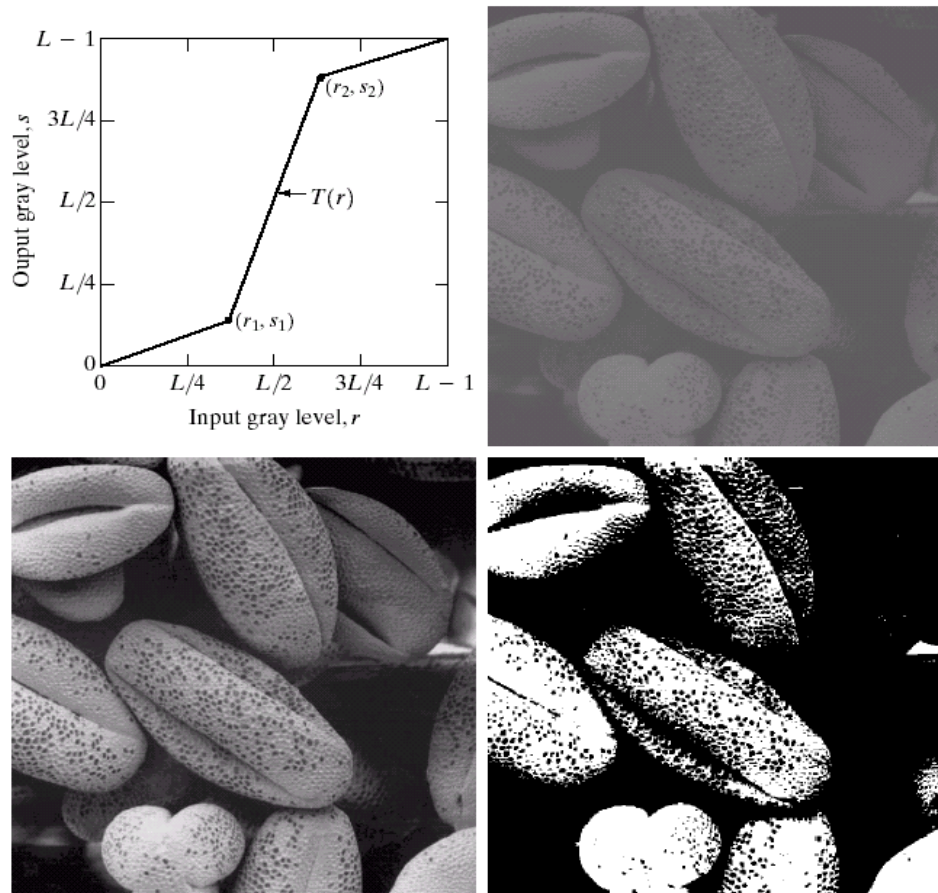
- ◆ If $r_1 = s_1$ & $r_2 = s_2$, no change in gray levels
- ◆ If $r_1 = r_2$, $s_1 = 0$ & $s_2 = L-1$, then it is a threshold function. The resulting image is binary

Contrast Stretching

$$r_1 = r_{min} \ \& \ s_1 = 0$$
$$r_2 = r_{max} \ \& \ s_2 = L-1$$



Contrast Stretching



a b
c d

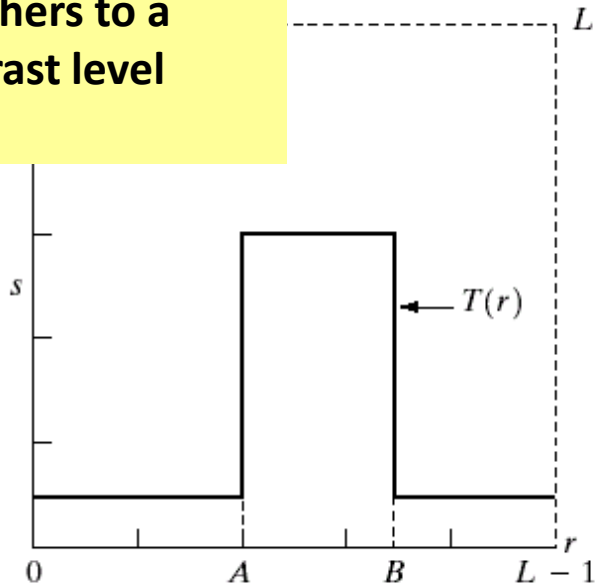
FIGURE 3.10
Contrast stretching. (a) Form of transformation function. (b) A low-contrast image. (c) Result of contrast stretching. (d) Result of thresholding. (Original image courtesy of Dr. Roger Heady, Research School of Biological Sciences, Australian National University, Canberra, Australia.)

Grey Level Slicing

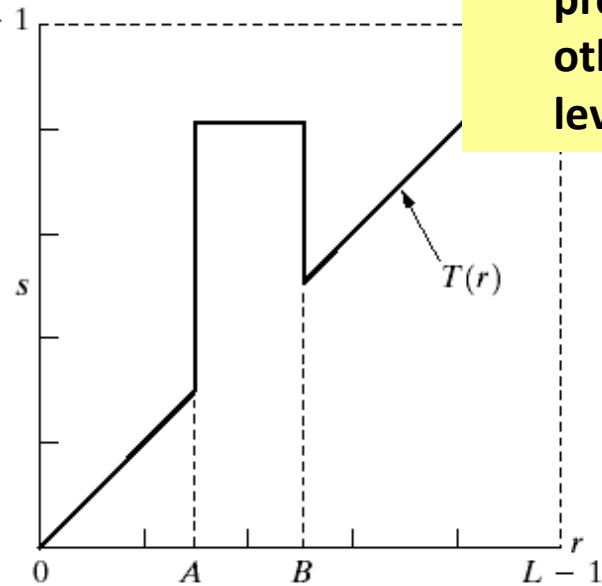
- ◆ Highlights a specific range of gray levels in an image
 - Similar to thresholding
 - Other levels can be suppressed or maintained
 - Useful for highlighting features in an image

Grey Level Slicing

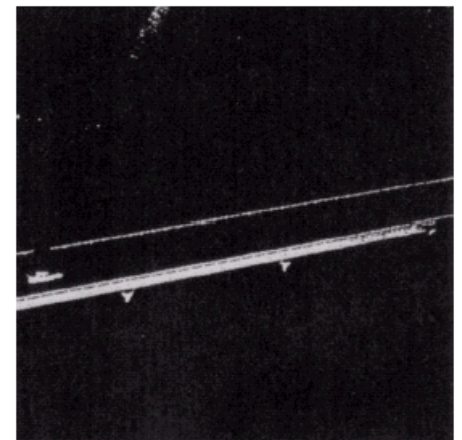
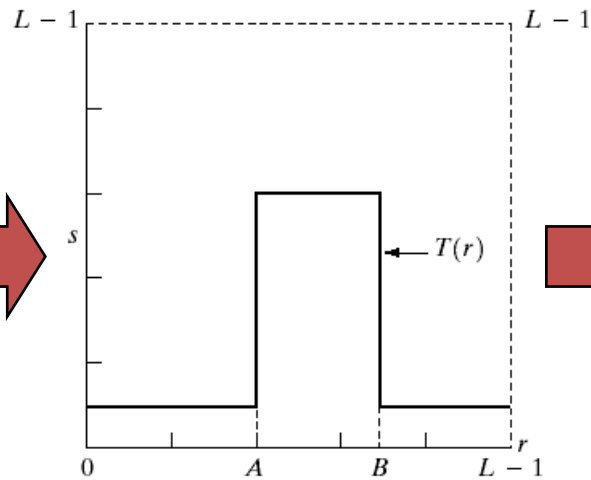
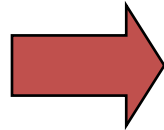
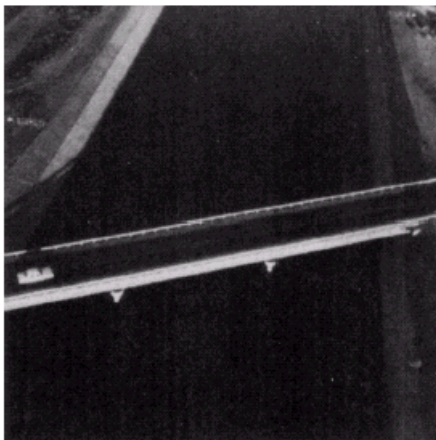
Highlights range $[A,B]$ of gray levels and reduces all others to a contrast level



Highlights range $[A,B]$ but preserves all other gray levels

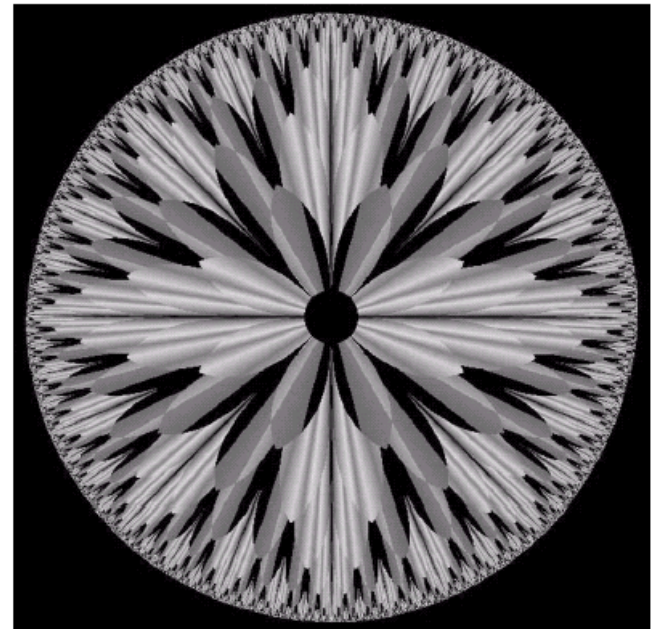
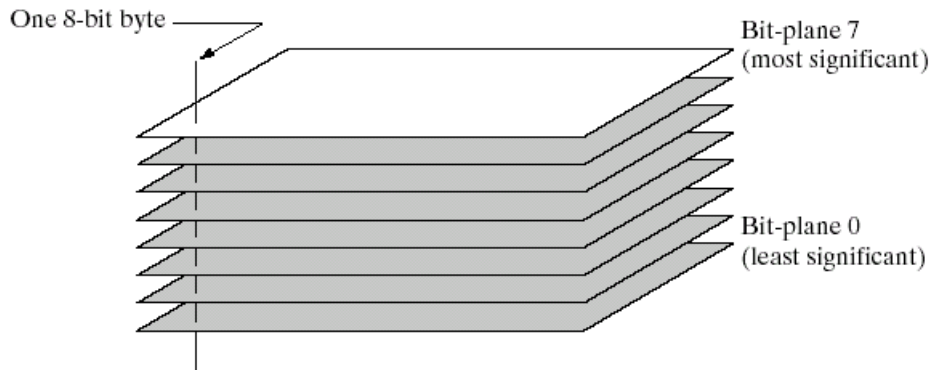


Grey Level Slicing

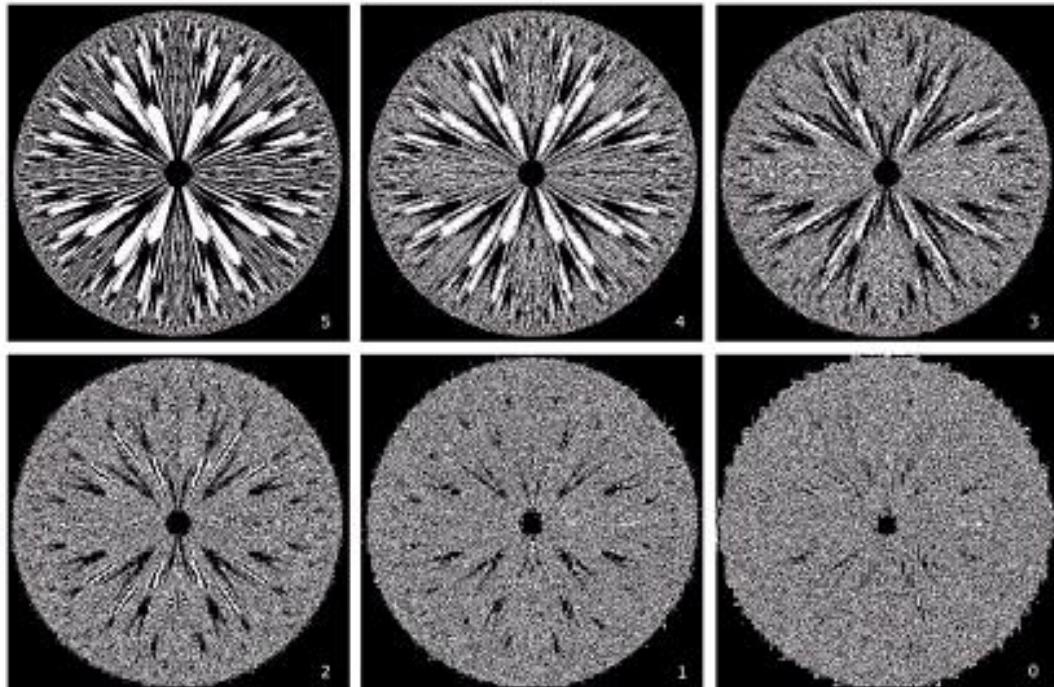
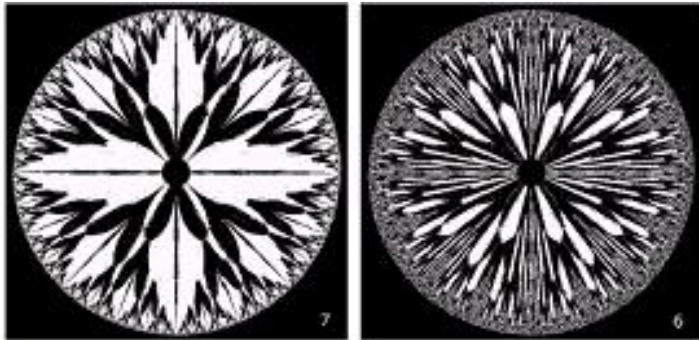


Bit Plane Slicing

- Often by isolating particular bits of the pixel values in an image we can highlight interesting aspects of that image
 - Higher-order bits usually contain most of the significant visual information
 - Lower-order bits contain subtle details

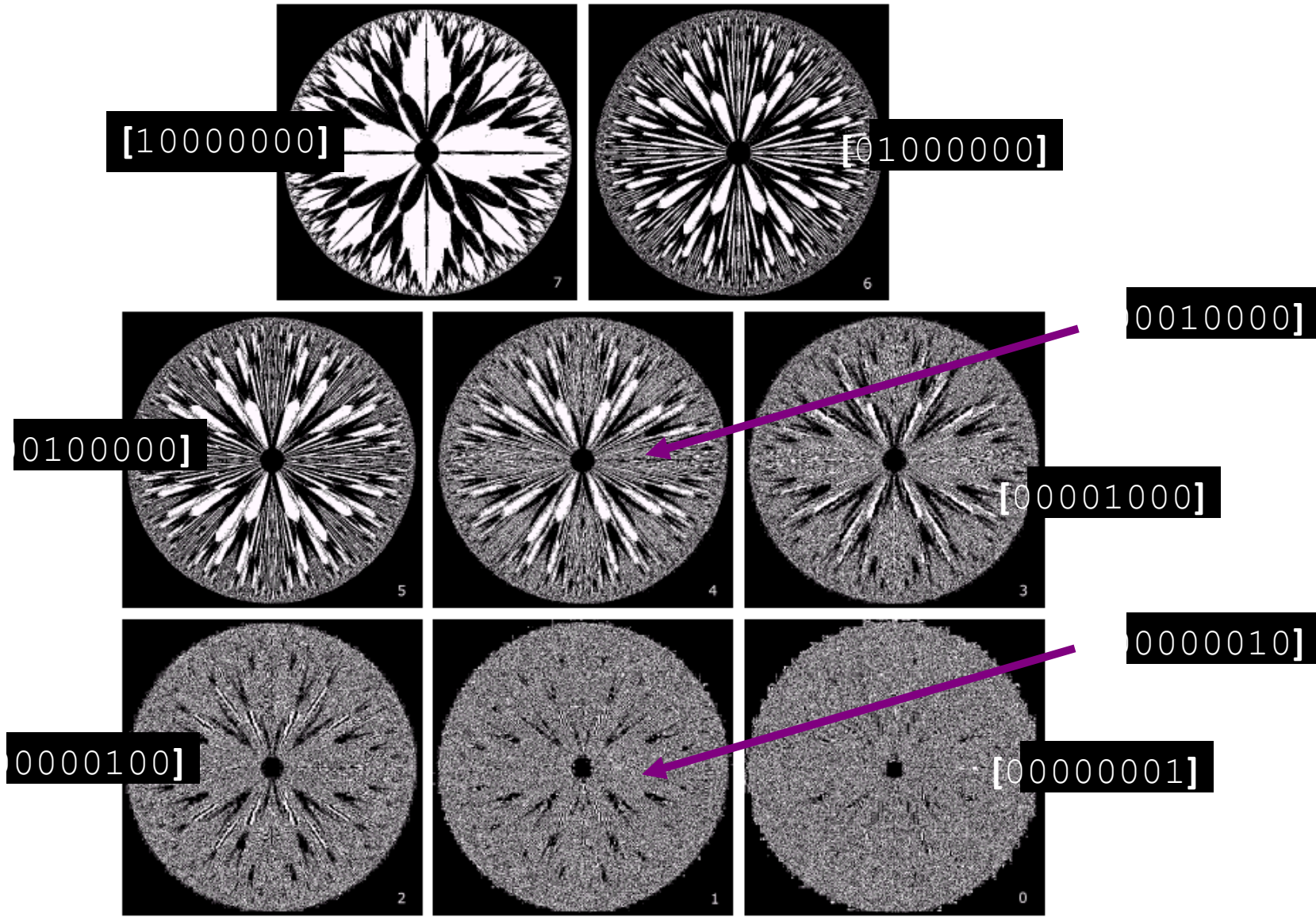


8 bit planes



Bit-plane 7		Bit-plane 6	
Bit-plane 5	Bit-plane 4	Bit-plane 3	
Bit-plane 2	Bit-plane 1	Bit-plane 0	

Bit Plane Slicing Example



Bit Plane Slicing (cont...)



a	b	c
d	e	f
g	h	i

FIGURE 3.14 (a) An 8-bit gray-scale image of size 500×1192 pixels. (b) through (i) Bit planes 1 through 8, with bit plane 1 corresponding to the least significant bit. Each bit plane is a binary image.

Bit Plane Slicing (cont...)



Reconstructed image using only bit planes 8 and 7



Reconstructed image using only bit planes 8, 7 and 6



Reconstructed image using only bit planes 7, 6 and 5

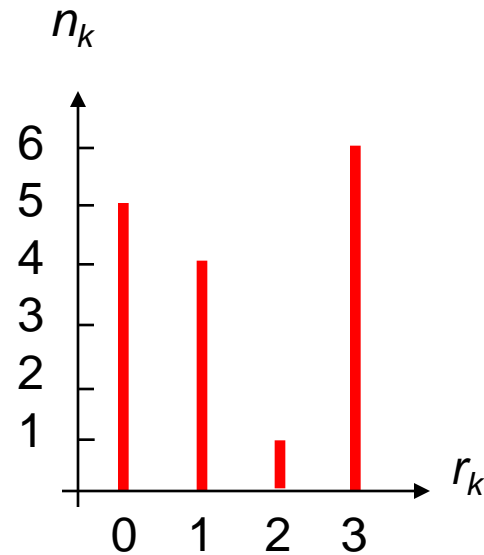
Histogram of a Grayscale Image

- ◆ Let I be a 1-band (grayscale) image.
- ◆ $I(r,c)$ is an 8-bit integer between 0 and 255.
- ◆ Histogram, h_I , of I :
 - a 256-element array, h_I
 - $h_I(g)$ = number of pixels in I that have value g .
for $g = 0, 1, 2, 3, \dots, 255$

HISTOGRAM

- A discrete function $h(r_k)=n_k$
 - r_k is the k^{th} gray level
 - n_k is the number of pixels having gray level r_k in the image
- Ex:

0	1	2	3
1	3	3	0
0	1	3	0
3	0	3	1

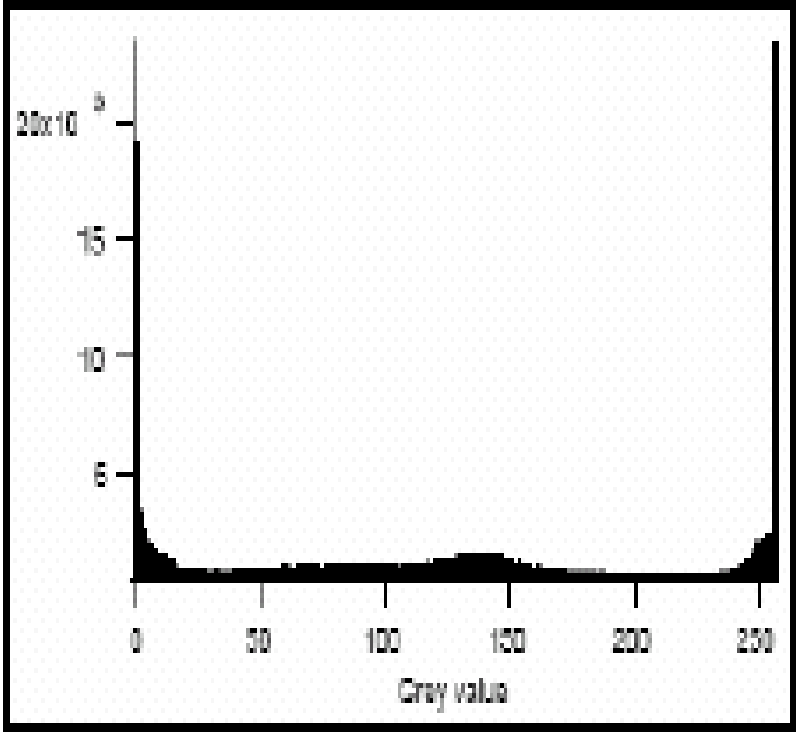


UNIQUENESS



Unique

Non-unique



Histogram of a Grayscale Image

- ◆ Histogram of a digital image with gray levels in the range $[0, L-1]$ is a discrete function

$$h(r_k) = n_k$$

Where

- $r_k = k^{th}$ gray level
- $n_k =$ number of pixels in the image having gray level r_k
- $h(r_k) =$ histogram of an image having r_k gray levels

Normalized Histogram

- ◆ Dividing each of histogram at gray level r_k by the total number of pixels in the image, n

$$p(r_k) = n_k / n \quad \text{for } k = 0, 1, \dots, L-1$$

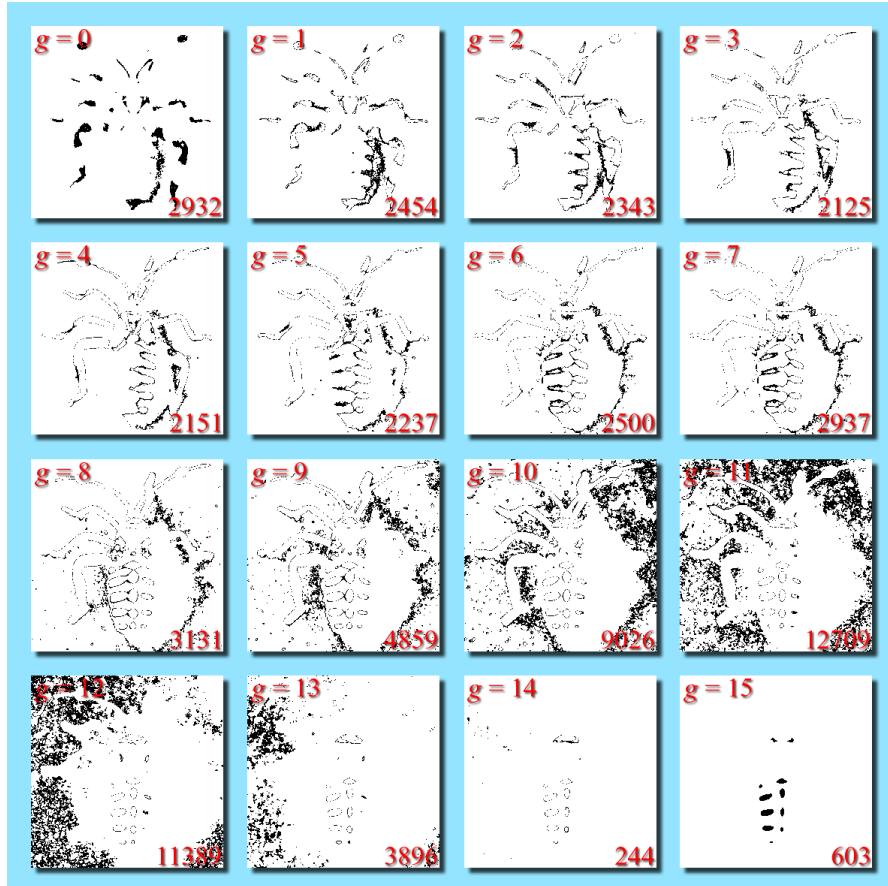
- ◆ $p(r_k)$ gives an estimate of the probability of occurrence of gray level r_k
- ◆ The sum of all components of a normalized histogram is equal to 1

Histogram of a Grayscale Image



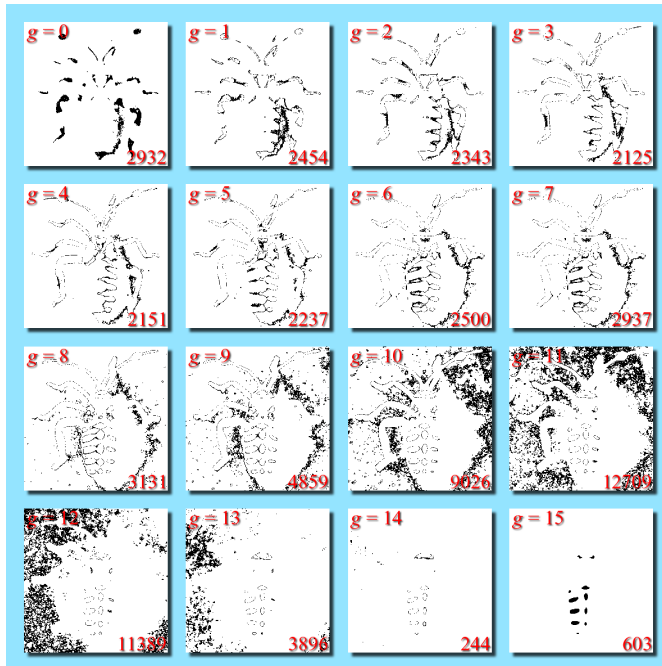
16-level (4-bit) image

lower RHC: number of pixels with intensity g



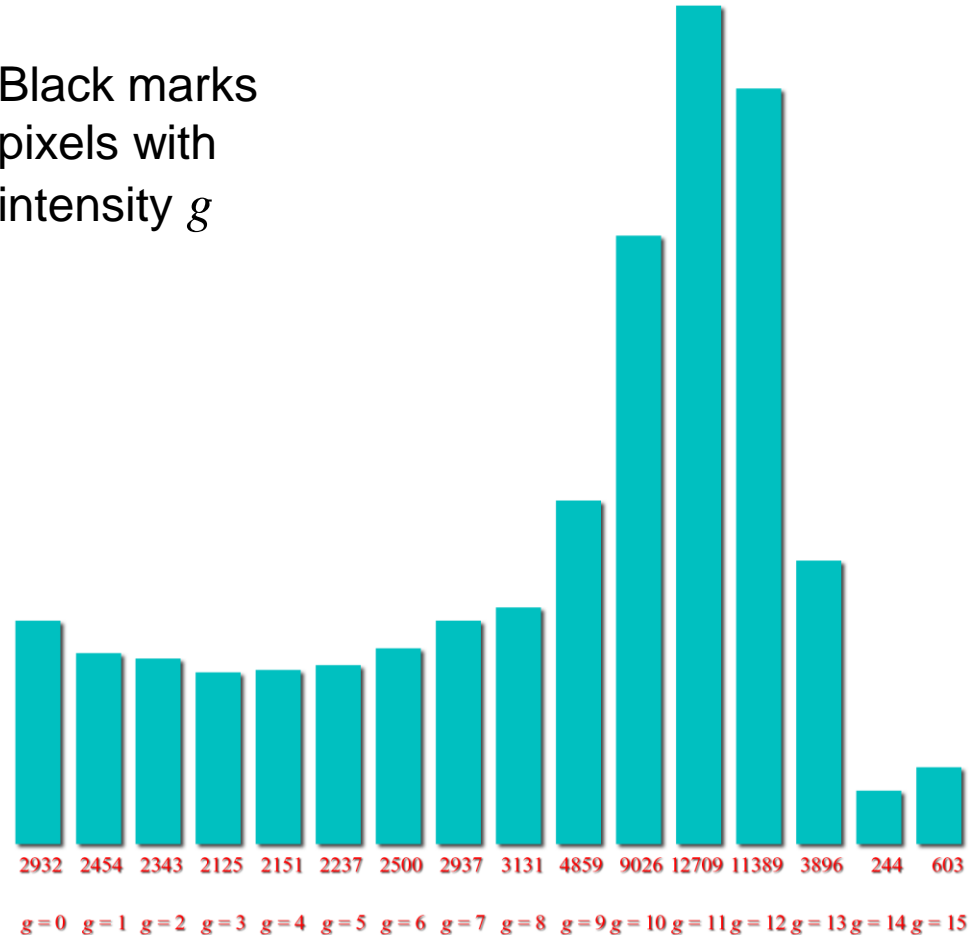
black marks pixels with intensity g

Histogram of a Grayscale Image

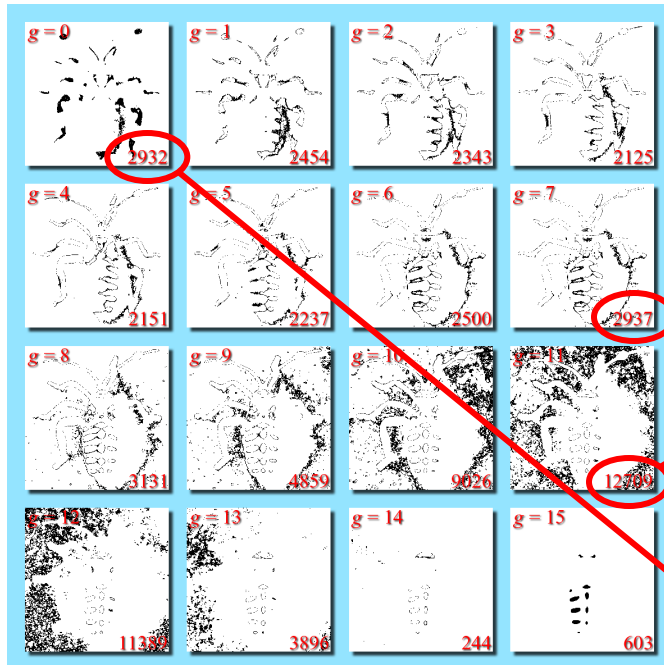


Black marks
pixels with
intensity g

Plot of histogram:
number of pixels with intensity g

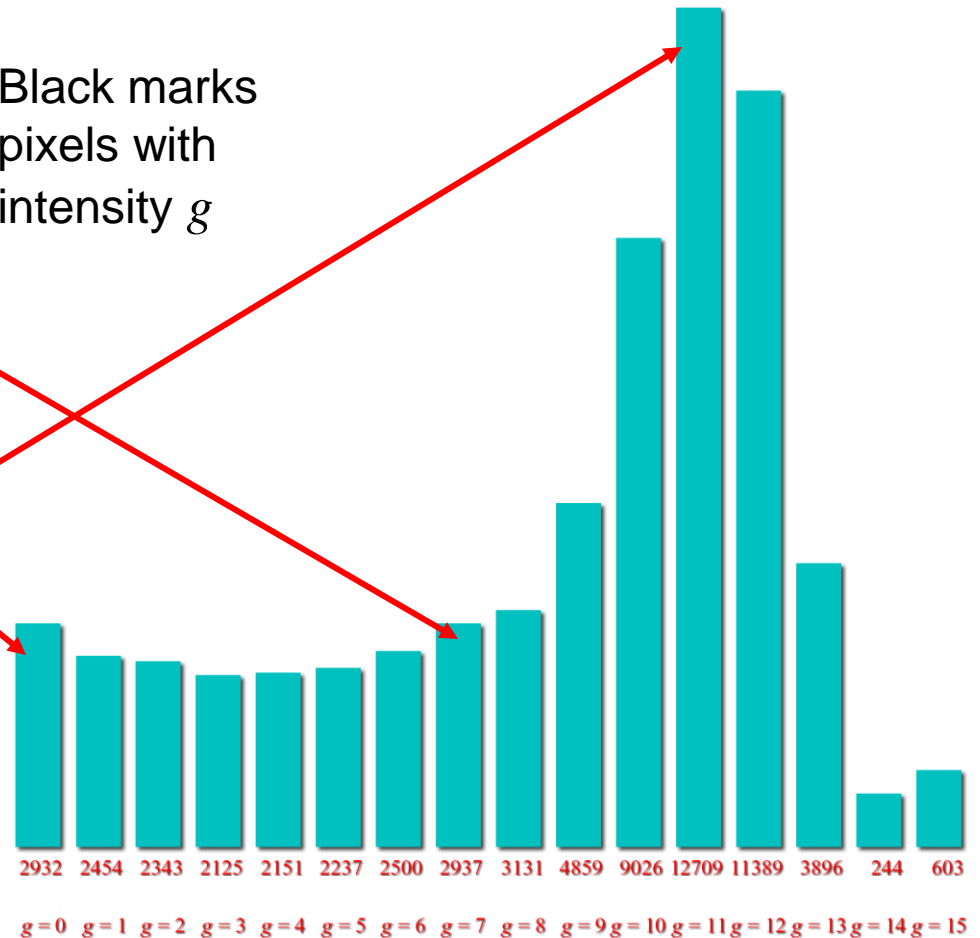


Histogram of a Grayscale Image



Black marks
pixels with
intensity g

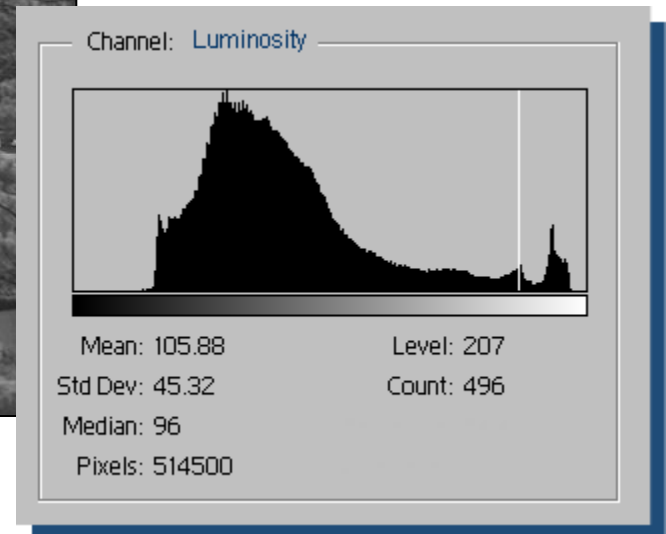
Plot of histogram:
number of pixels with intensity g



Histogram of a Grayscale Image



$h_I(g) =$ the number of pixels in I with graylevel g .

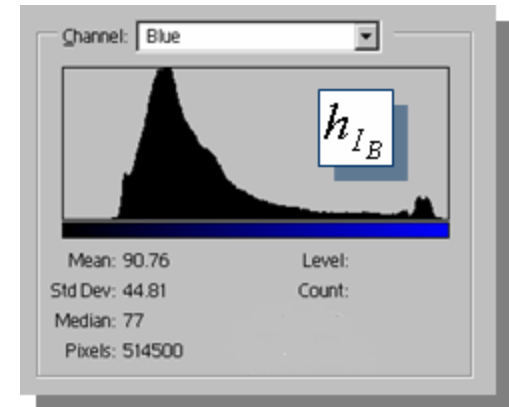
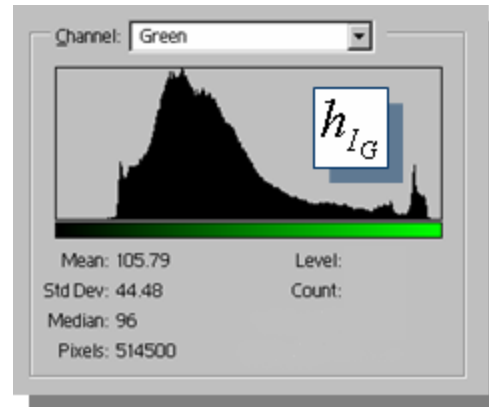
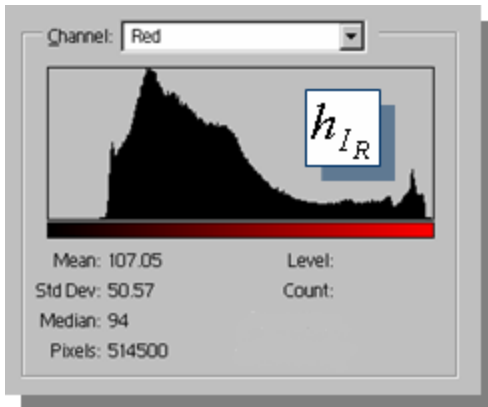
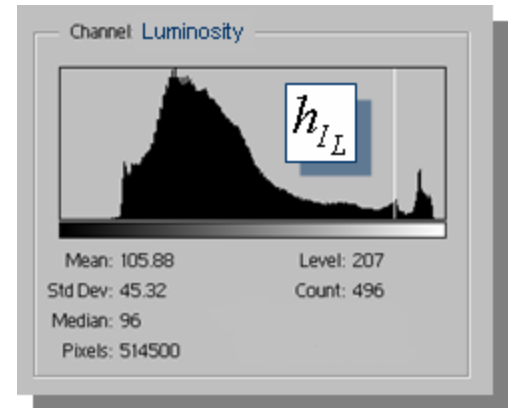


Histogram of a Color Image

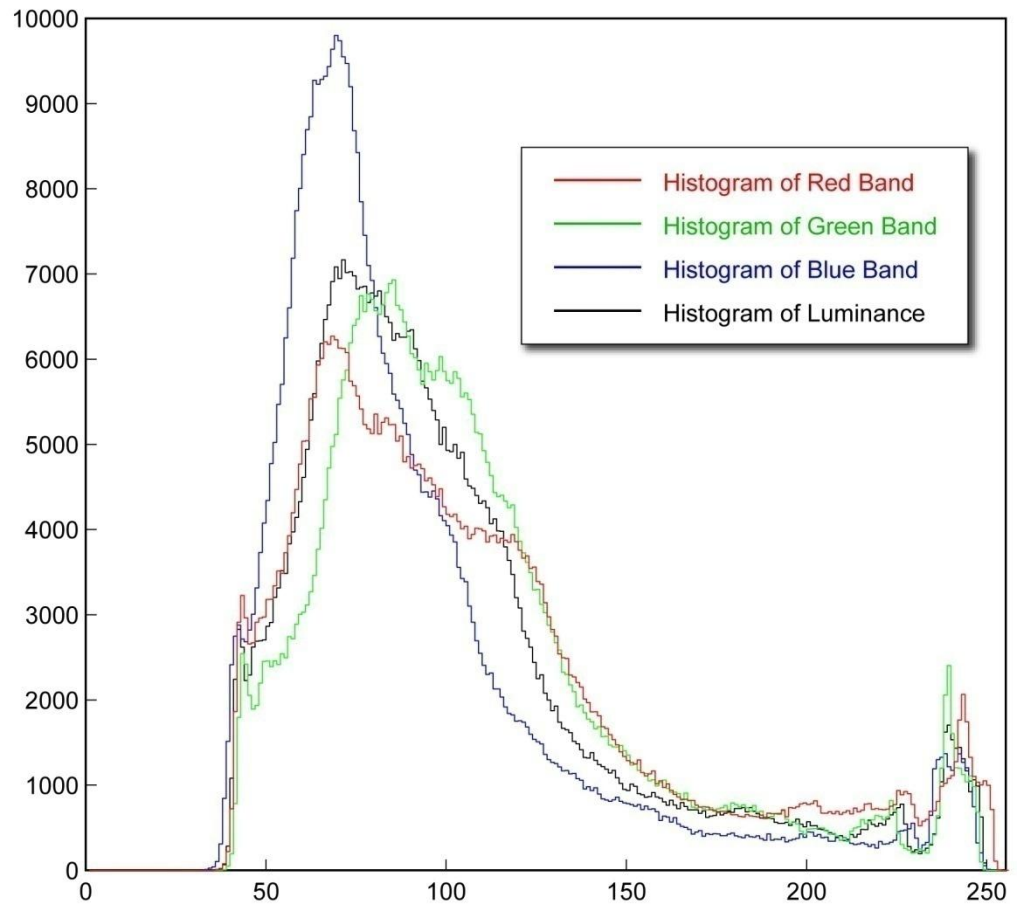
- ◆ If I is a 3-band image
- ◆ then $I(r,c,b)$ is an integer between 0 and 255.
- ◆ I has 3 histograms:
 - $h_R(g)$ = # of pixels in $I(:, :, 1)$ with intensity value g
 - $h_G(g)$ = # of pixels in $I(:, :, 2)$ with intensity value g
 - $h_B(g)$ = # of pixels in $I(:, :, 3)$ with intensity value g

Histogram of a Color Image

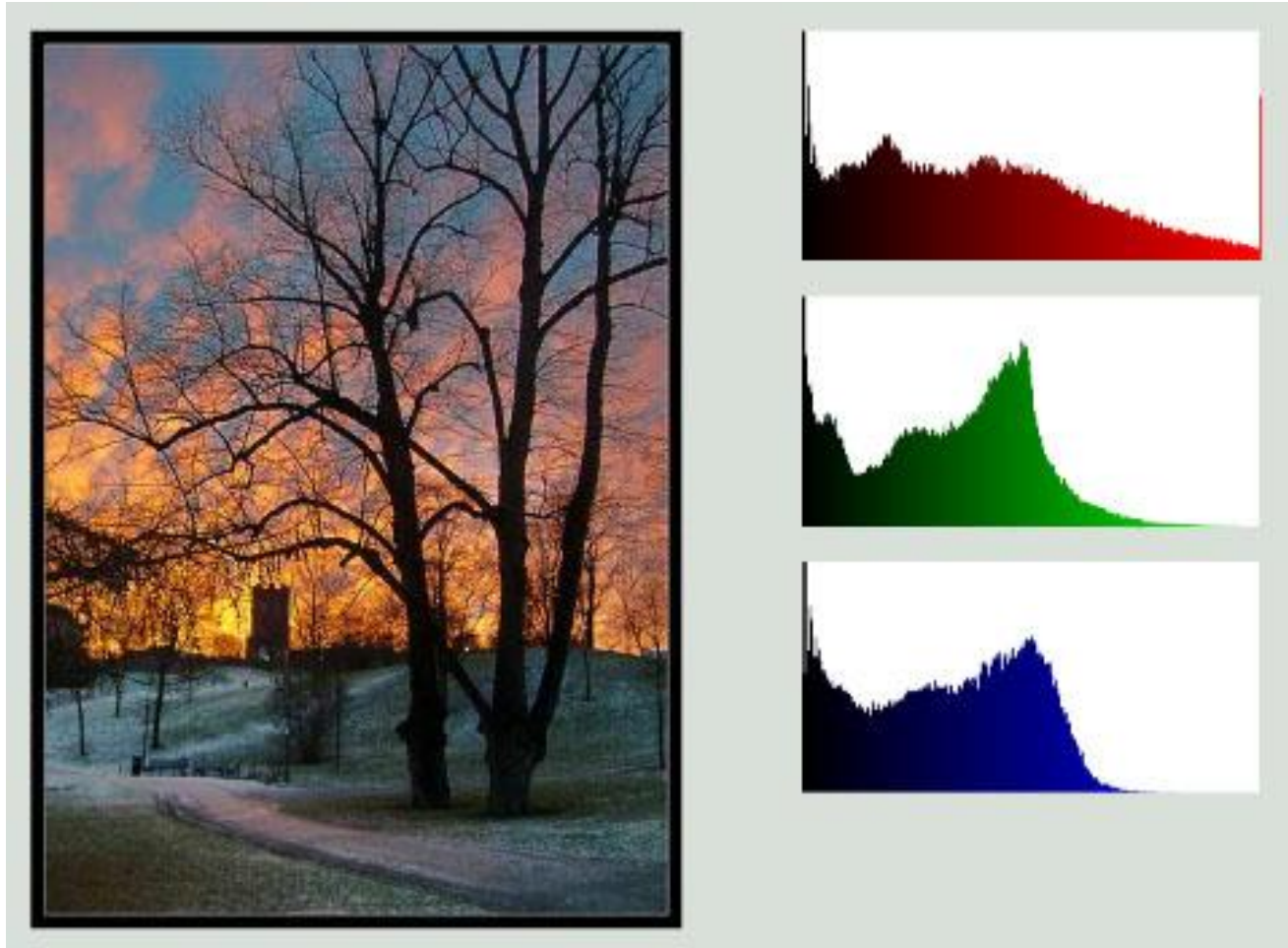
There is one histogram per color band R, G, & B. Luminosity histogram is from 1 band = $(R+G+B)/3$



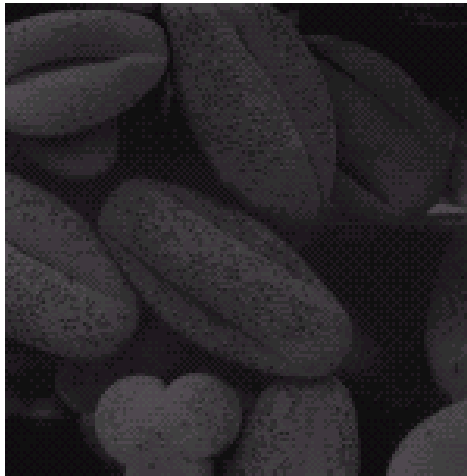
Histogram of a Color Image



Histogram of a Color Image



Histogram: Example



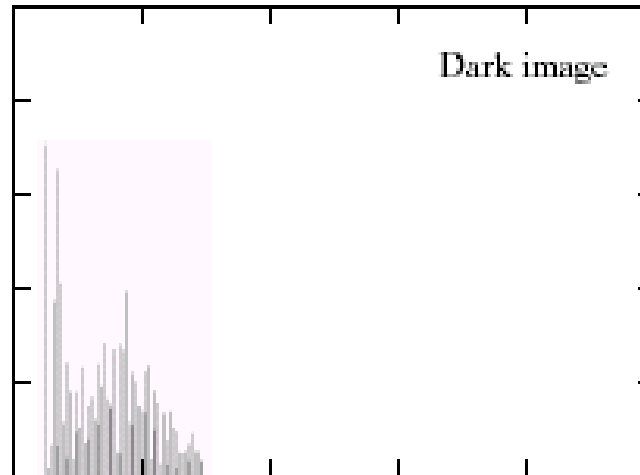
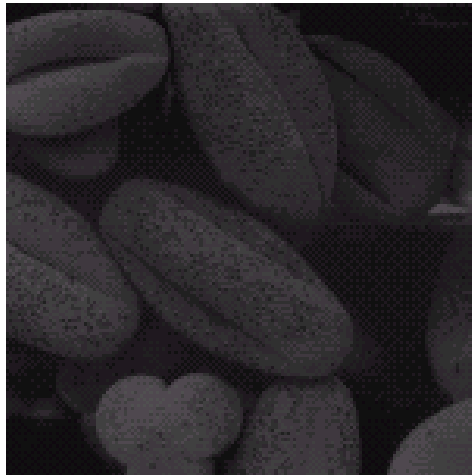
← Dark Image

How would the histograms of these images look like?



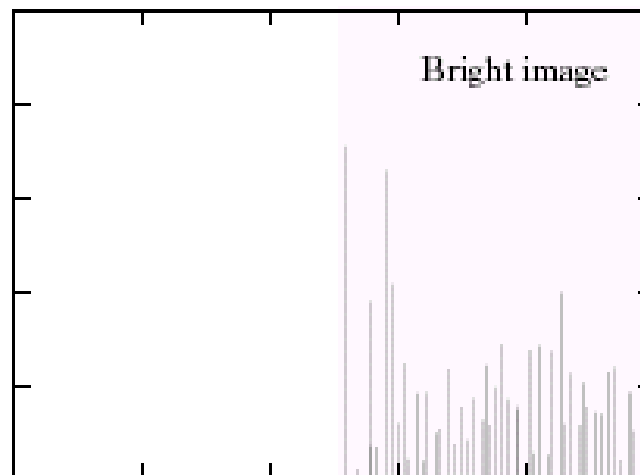
← Bright Image

Histogram: Example



Dark image

Components of histogram are concentrated on the low side of the gray scale

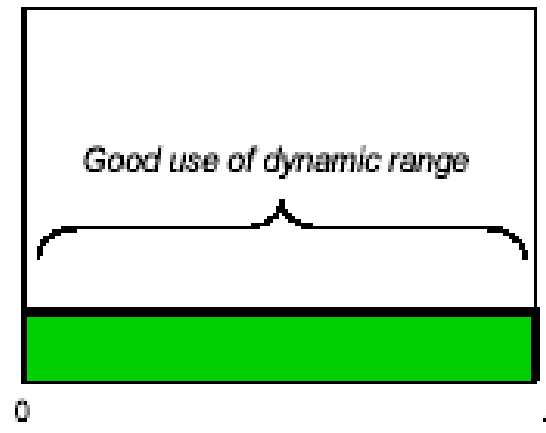
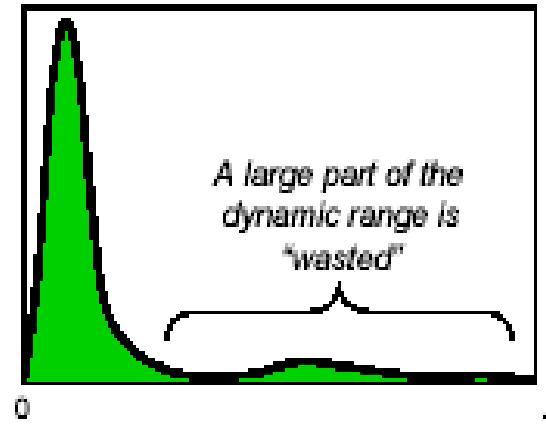


Bright image

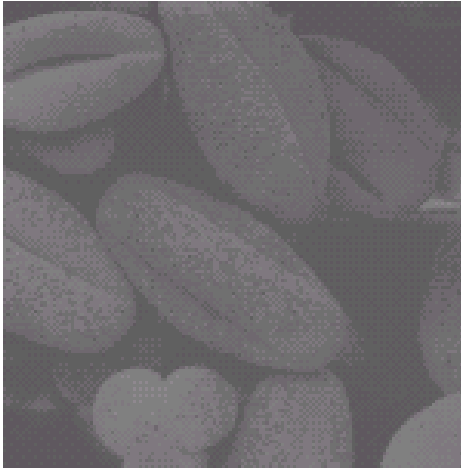
Components of histogram are concentrated on the high side of the gray scale

HISTOGRAM INSIGHT INTO CONTRAST

- A high contrast image makes good use of the full dynamic range available.
- Hence in some applications it may be desirable to make more optimal use of the full dynamic range.
- In some circumstances this results in a clearer image.



Histogram: Example



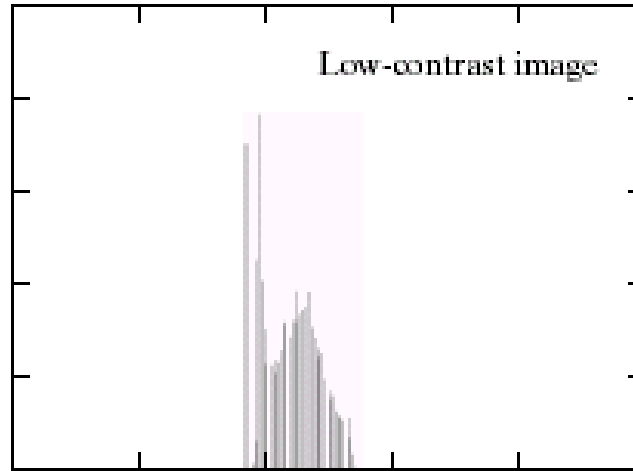
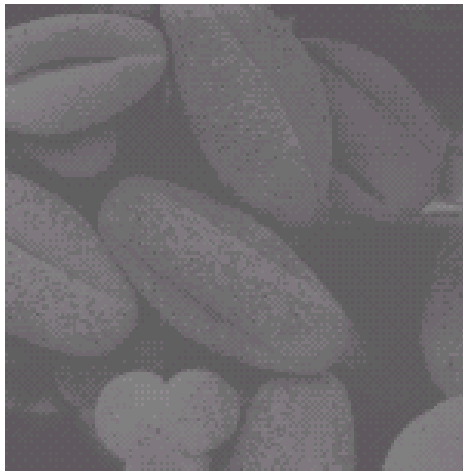
Low Contrast Image

How would the histograms of these images look like?



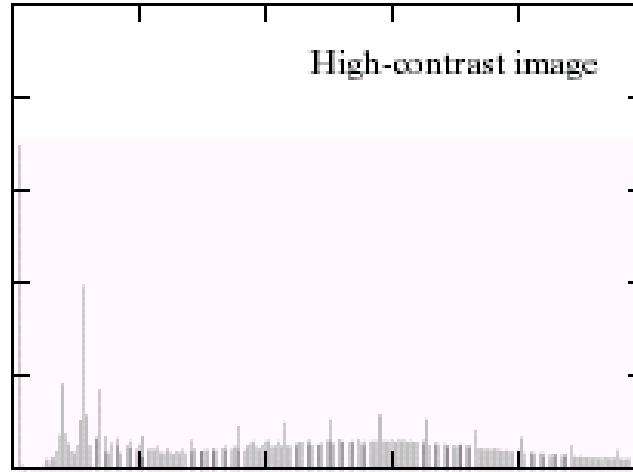
High Contrast Image

Histogram: Example



Low contrast image

Histogram is narrow and centered toward the middle of the gray scale

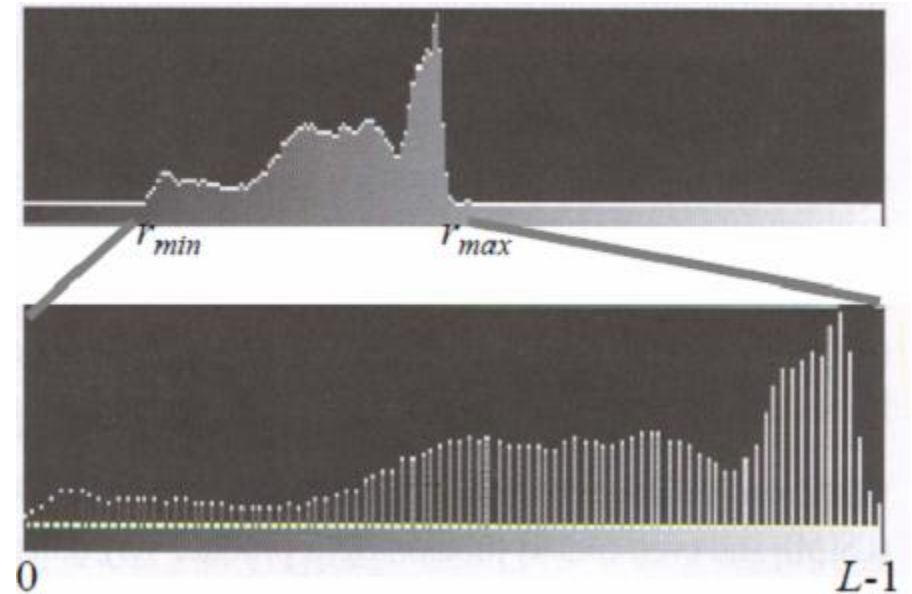


High contrast image

Histogram covers broad range of the gray scale and the distribution of pixels is not too far from uniform with very few vertical lines being much higher than the others

Contrast Stretching

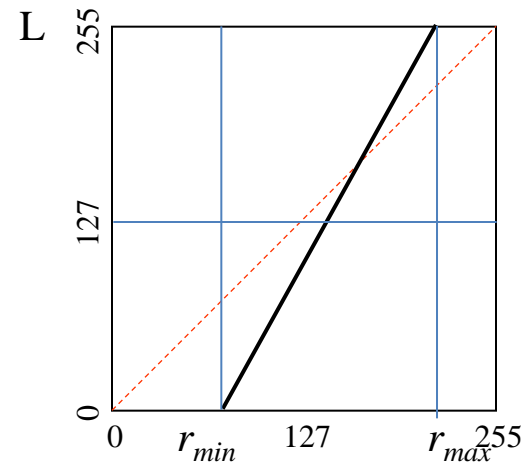
Improve the contrast in an image by `stretching' the range of intensity values it contains to span a desired range of values, *e.g.* the full range of pixel values



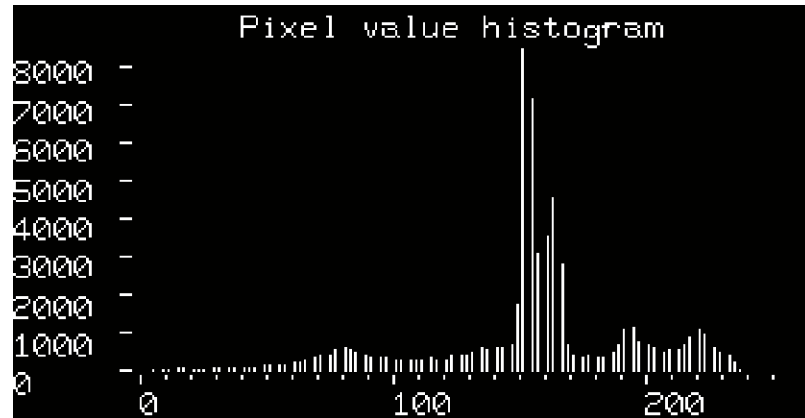
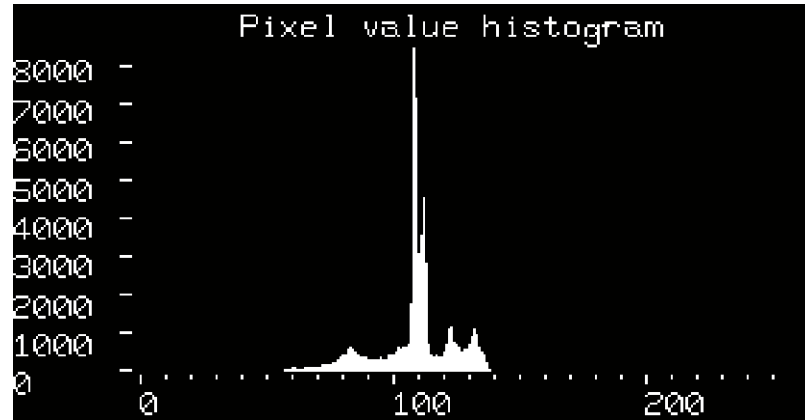
Contrast Stretching

If r_{max} and r_{min} are the maximum and minimum gray level of the input image and L is the total gray levels of output image, the transformation function for contrast stretch will be

$$s = T(r) = (r - r_{min}) \left[\frac{L-1}{r_{max} - r_{min}} \right]$$

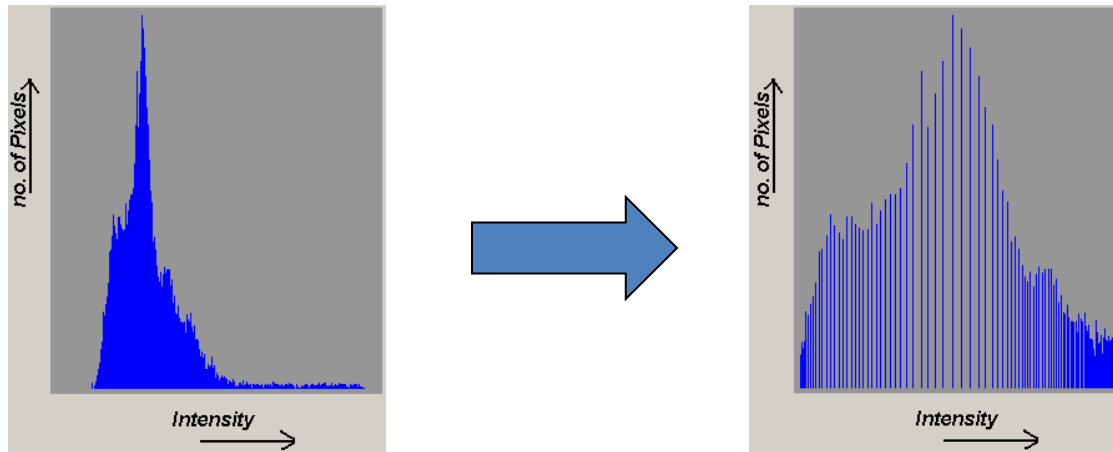


Contrast Stretching

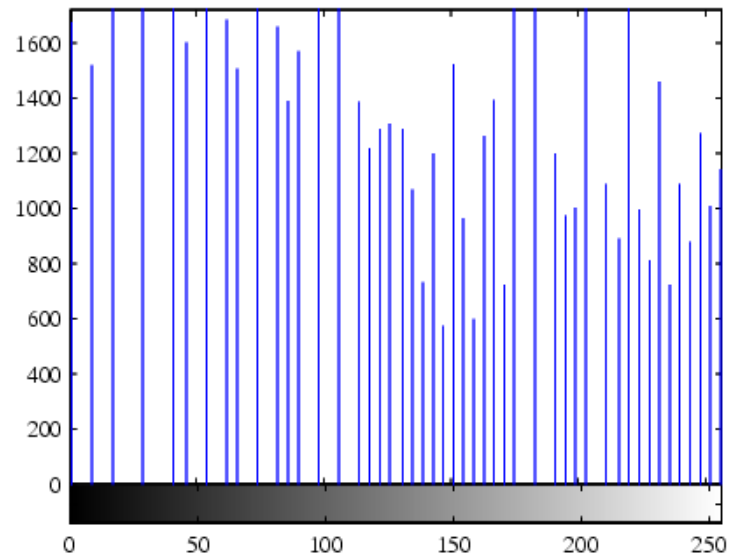
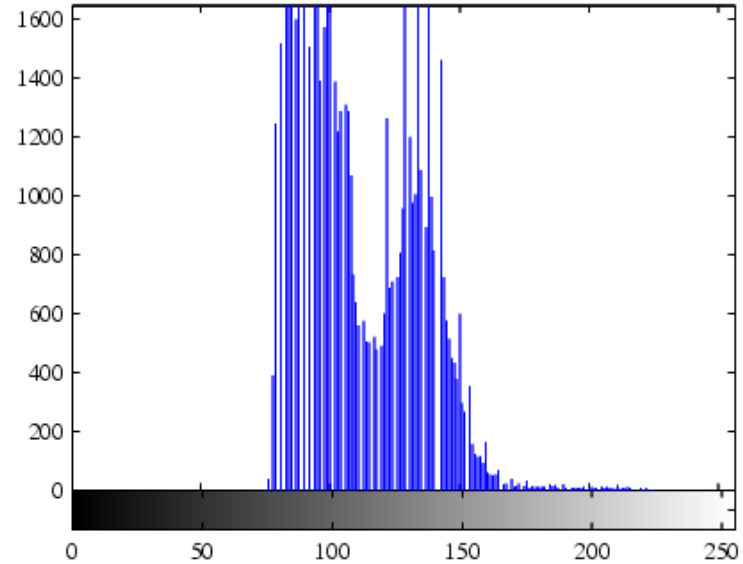


Histogram Equalization

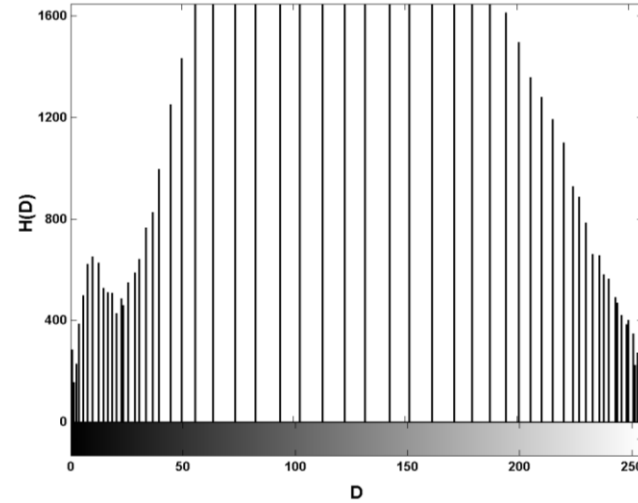
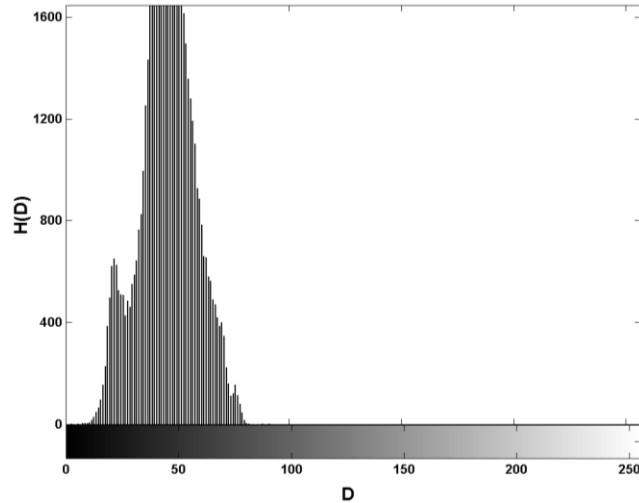
Histogram equalization re-assigns the intensity values of pixels in the input image such that the output image contains a uniform distribution of intensities



HISTOGRAM EQUALIZATION



AERIAL PHOTOGRAPH OF THE PENTAGON



**Resulting image uses more of dynamic range.
Resulting histogram almost, but not completely, flat.**

The Probability Distribution Function of an Image

$$\text{Let } A = \sum_{g=0}^{255} h_I(g)$$

Note that since $h_I(g)$ is the number of pixels in I with value g ,

A is the number of pixels in I . That is if I is R rows by C columns then $A = R \times C$.

Then,

$$p_I(g) = \frac{1}{A} h_I(g)$$

This is the probability that an arbitrary pixel from I has value g .

The Probability Distribution Function of an Image

- $p(g)$ is the fraction of pixels in an image that have intensity value g .
- $p(g)$ is the probability that a pixel randomly selected from the given image has intensity value g .
- Whereas the sum of the histogram $h(g)$ over all g from 0 to 255 is equal to the number of pixels in the image, the sum of $p(g)$ over all g is 1.
- p is the **normalized histogram** of the image

The Cumulative Distribution Function of an Image

Let $q = I(r,c)$ be the value of a randomly selected pixel from I . Let g be a specific gray level. The probability that $q \leq g$ is given by

$$P_I(g) = \sum_{\gamma=0}^g p_I(\gamma) = \frac{1}{A} \sum_{\gamma=0}^g h_I(\gamma) = \frac{\sum_{\gamma=0}^g h_I(\gamma)}{\sum_{\gamma=0}^{255} h_I(\gamma)},$$

where $h_I(\gamma)$ is the histogram of image I .

This is the probability that any given pixel from I has value less than or equal to g .

The Cumulative Distribution Function of an Image

Let $q = I(r,c)$ be the value of a randomly selected pixel from I . Let g be a specific gray level. The probability that $q \leq g$ is given by

$$P_I(g) = \sum_{\gamma=0}^g p_I(\gamma) = \frac{1}{A} \sum_{\gamma=0}^g h_I(\gamma) = \frac{\sum_{\gamma=0}^g h_I(\gamma)}{\sum_{\gamma=0}^{255} h_I(\gamma)},$$

where $h_I(\gamma)$ is the histogram of image I .

Also called CDF for "Cumulative Distribution Function".

This is the probability that any given pixel from I has value less than or equal to g .

The Cumulative Distribution Function of an Image

- $P(g)$ is the fraction of pixels in an image that have intensity values less than or equal to g .
- $P(g)$ is the probability that a pixel randomly selected from the given band has an intensity value less than or equal to g .
- $P(g)$ is the cumulative (or running) sum of $p(g)$ from 0 through g inclusive.
- $P(0) = p(0)$ and $P(255) = 1$;

Histogram Equalization

Task: remap image I so that its histogram is as close to constant as possible

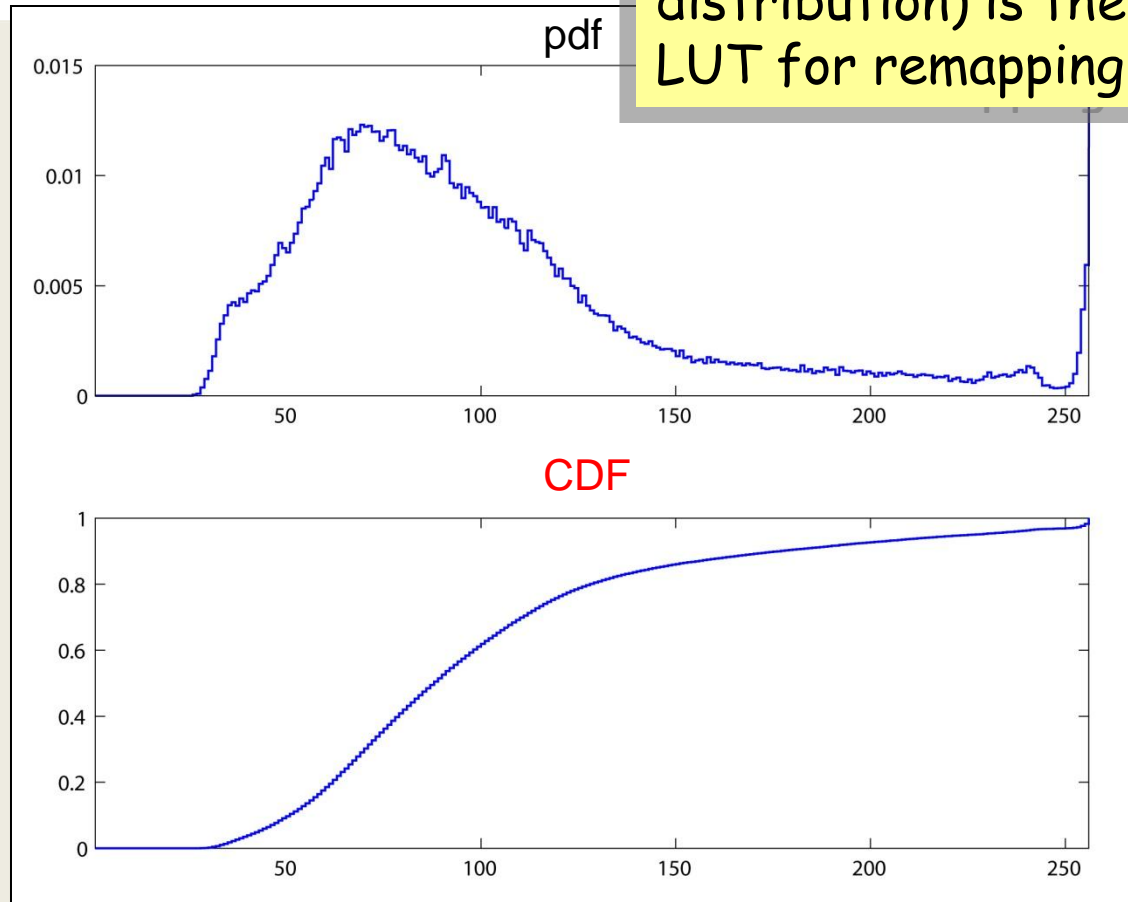
Let $P_I(\gamma)$

be the cumulative (probability) distribution function of I .

The CDF itself is used as the LUT.

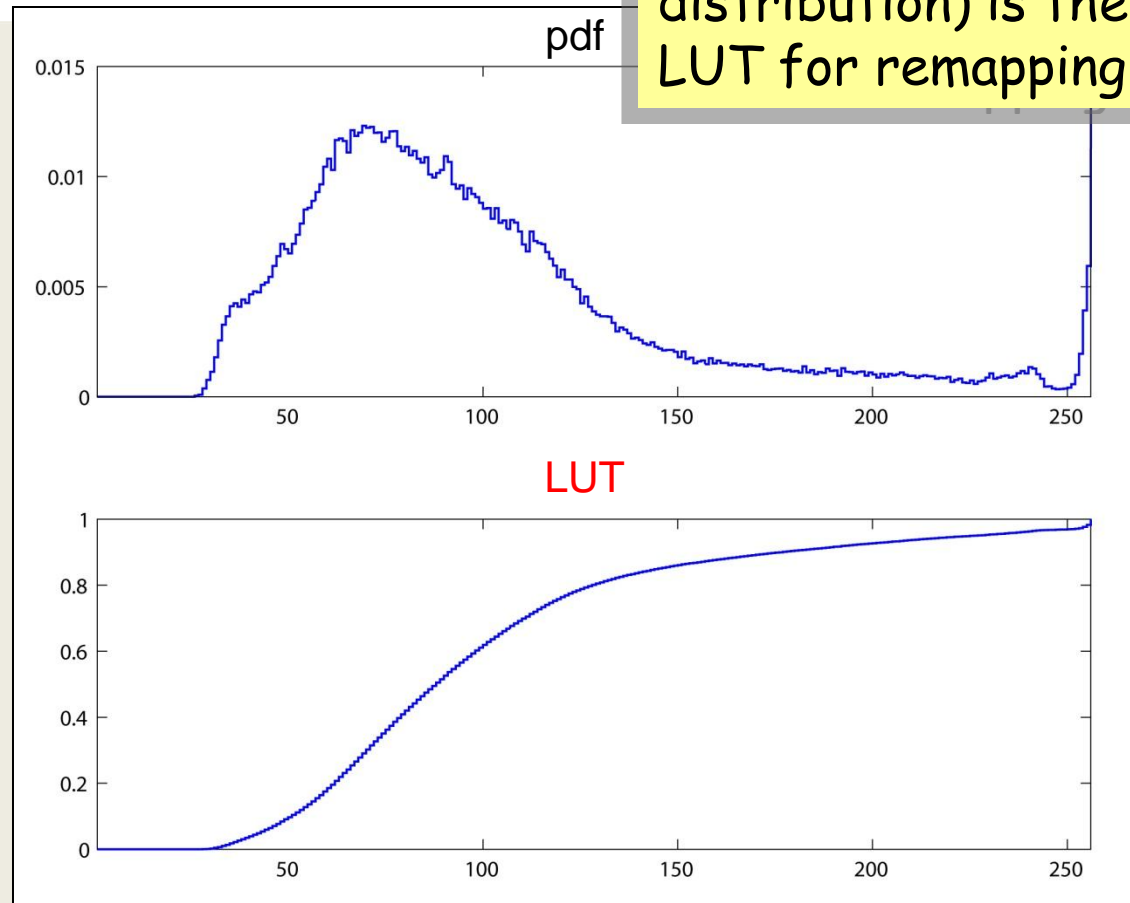
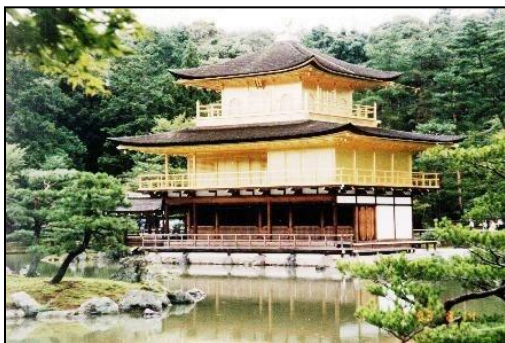
Histogram Equalization

The CDF (cumulative distribution) is the LUT for remapping.



Histogram Equalization

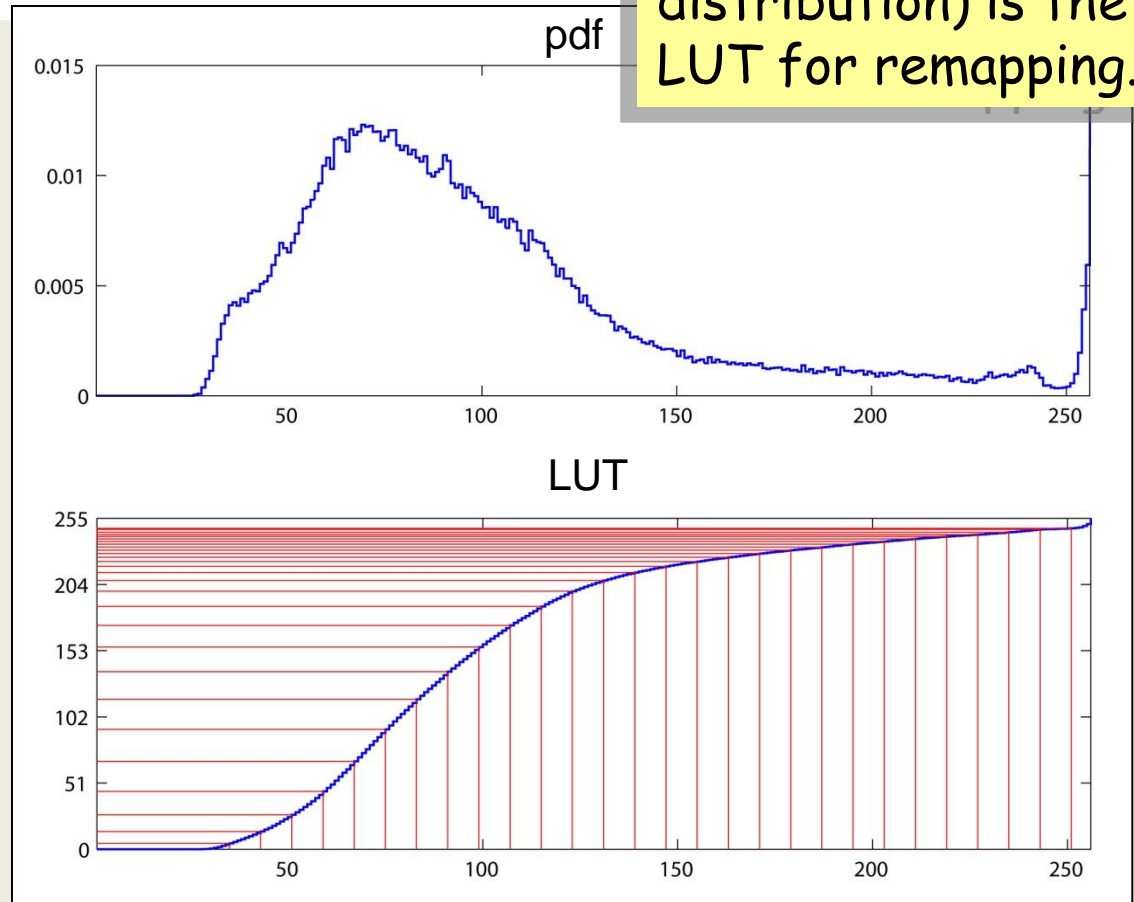
The CDF (cumulative distribution) is the LUT for remapping.



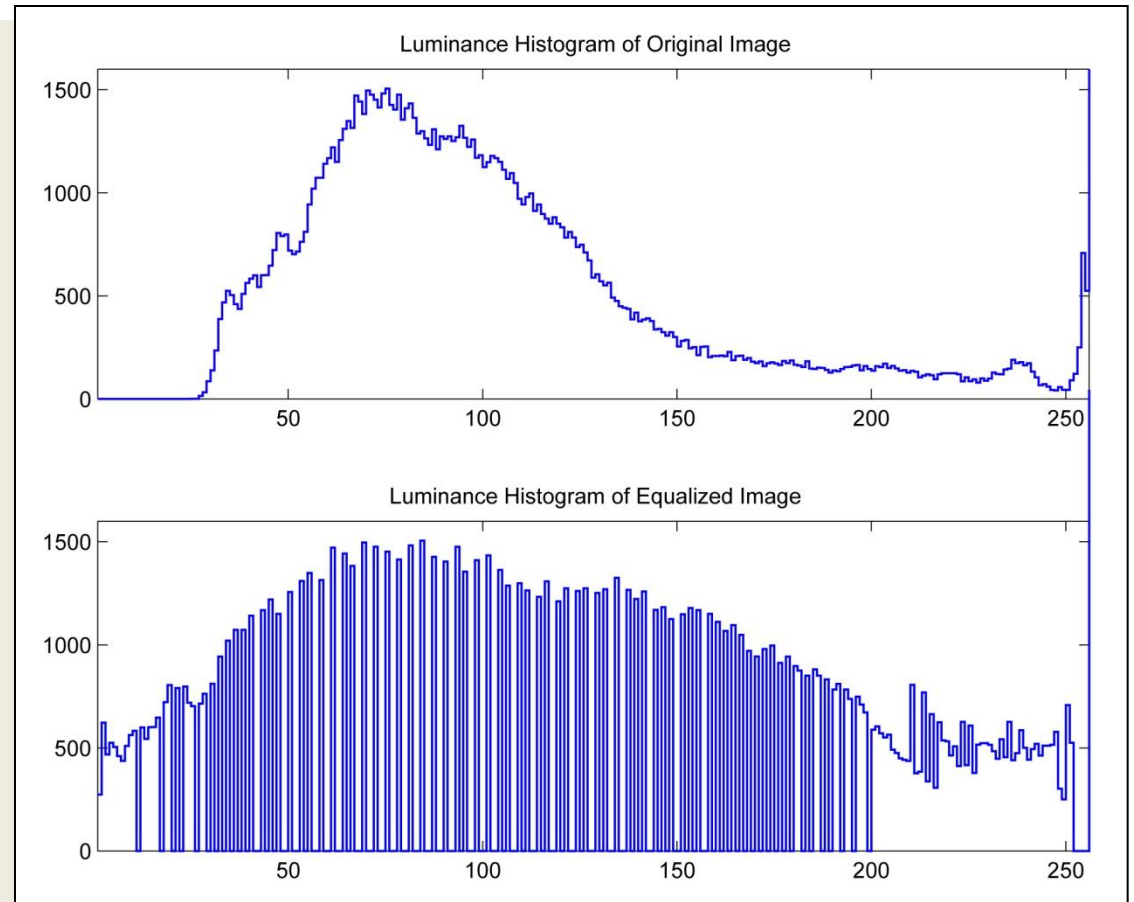
Histogram Equalization



The CDF (cumulative distribution) is the LUT for remapping.



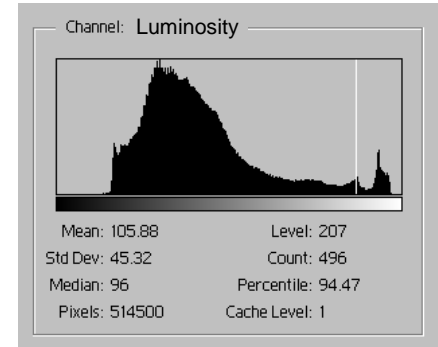
Histogram Equalization



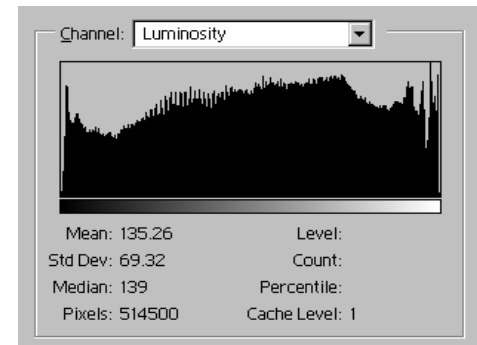
Histogram Equalization



$$J(r,c) = 255 \cdot P_I [I(r,c)].$$



before



after

HISTOGRAM EQUALIZATION IMPLEMENTATION

0	0	0	0	0
1	1	1	1	4
4	5	6	6	6
8	8	8	8	9

2	2	2	2	2
4	4	4	4	5
5	5	7	7	7
9	9	9	9	9

Gray levels	<table border="1"> <tr><td>0</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td></tr> </table>										0	1	2	3	4	5	6	7	8	9
0	1	2	3	4	5	6	7	8	9											
Counts ($h(r_k)$)	5	4	0	0	2	1	3	0	4	1										
	r_0	r_1			r_2	r_3	r_4		r_5	r_6										
Normalized h ($P(r_k)$)	5/20	4/20	0	0	2/20	1/20	3/20	0	4/20	1/20										
cdf $F(r_k)$	5/20	9/20			11/20	12/20	15/20		19/20	20/20										
$s_k = \text{round}(9 \cdot F(r_k))$	2	4			5	5	7		9	9										
	s_0	s_1			s_2	s_3	s_4		s_5	s_6										

Histogram Equalization: Example



52	55	61	66	70	61	64	73
63	59	55	90	109	85	69	72
62	59	68	113	144	104	66	73
63	58	71	122	154	106	70	69
67	61	68	104	126	88	68	70
79	65	60	70	77	68	58	75
85	71	64	59	55	61	65	83
87	79	69	68	65	76	78	94

An 8x8 image



Histogram Equalization: Example

Fill in the following table/histogram

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
52	<input type="text"/>	64	<input type="text"/>	72	<input type="text"/>	85	<input type="text"/>	113	<input type="text"/>
55	<input type="text"/>	65	<input type="text"/>	73	<input type="text"/>	87	<input type="text"/>	122	<input type="text"/>
58	<input type="text"/>	66	<input type="text"/>	75	<input type="text"/>	88	<input type="text"/>	126	<input type="text"/>
59	<input type="text"/>	67	<input type="text"/>	76	<input type="text"/>	90	<input type="text"/>	144	<input type="text"/>
60	<input type="text"/>	68	<input type="text"/>	77	<input type="text"/>	94	<input type="text"/>	154	<input type="text"/>
61	<input type="text"/>	69	<input type="text"/>	78	<input type="text"/>	104	<input type="text"/>		
62	<input type="text"/>	70	<input type="text"/>	79	<input type="text"/>	106	<input type="text"/>		
63	<input type="text"/>	71	<input type="text"/>	83	<input type="text"/>	109	<input type="text"/>		

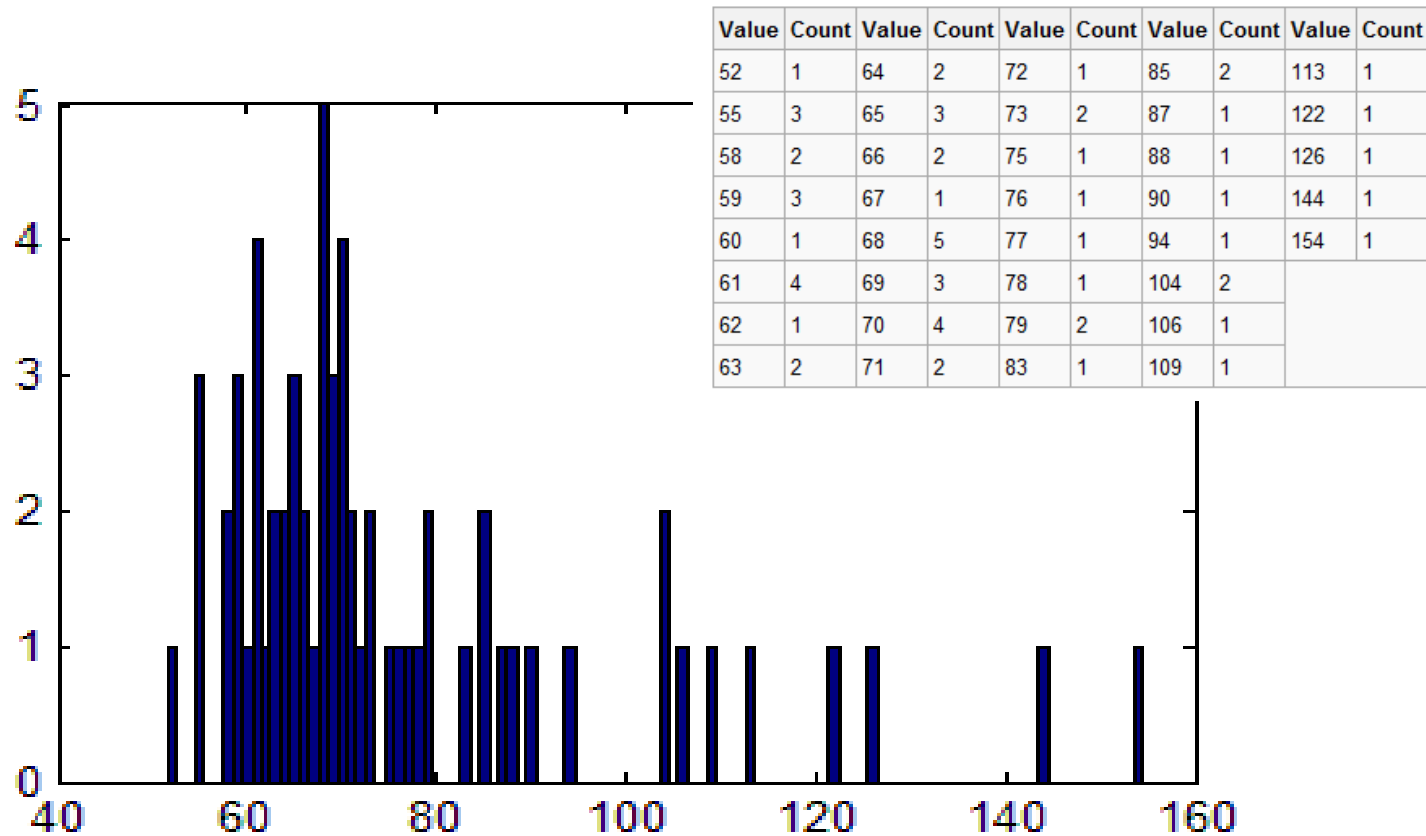
Image Histogram (Non-zero values)

Histogram Equalization: Example

Image Histogram (Non-zero values shown)

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
52	1	64	2	72	1	85	2	113	1
55	3	65	3	73	2	87	1	122	1
58	2	66	2	75	1	88	1	126	1
59	3	67	1	76	1	90	1	144	1
60	1	68	5	77	1	94	1	154	1
61	4	69	3	78	1	104	2		
62	1	70	4	79	2	106	1		
63	2	71	2	83	1	109	1		

Histogram Equalization: Example



Histogram Equalization: Example

Cumulative Distribution Function (cdf)

Image Histogram/Prob Mass Function

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
52	1	64	2	72	1	85	2	113	1
55	3	65	3	73	2	87	1	122	1
58	2	66	2	75	1	88	1	126	1
59	3	67	1	76	1	90	1	144	1
60	1	68	5	77	1	94	1	154	1
61	4	69	3	78	1	104	2		
62	1	70	4	79	2	106	1		
63	2	71	2	83	1	109	1		

Value	cdf	Value	cdf	Value	cdf	Value	cdf	Value	cdf
52	█	64	█	72	█	85	█	113	█
55	█	65	█	73	█	87	█	122	█
58	█	66	█	75	█	88	█	126	█
59	█	67	█	76	█	90	█	144	█
60	█	68	█	77	█	94	█	154	█
61	█	69	█	78	█	104	█		
62	█	70	█	79	█	106	█		
63	█	71	█	83	█	109	█		

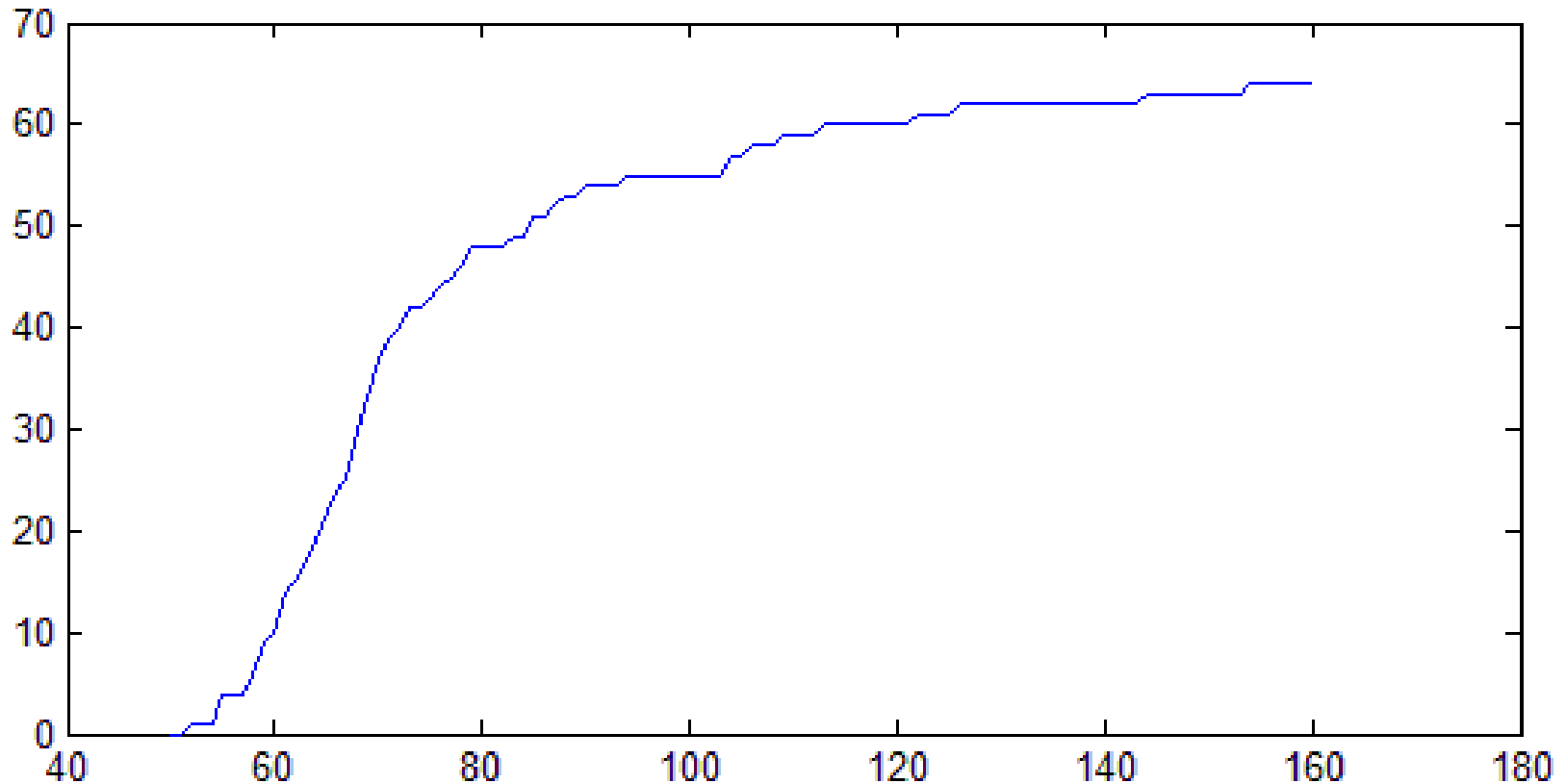
Histogram Equalization: Example

Cumulative Distribution Function (cdf)

Value	cdf	Value	cdf	Value	cdf	Value	cdf	Value	cdf
52	1	64	19	72	40	85	51	113	60
55	4	65	22	73	42	87	52	122	61
58	6	66	24	75	43	88	53	126	62
59	9	67	25	76	44	90	54	144	63
60	10	68	30	77	45	94	55	154	64
61	14	69	33	78	46	104	57		
62	15	70	37	79	48	106	58		
63	17	71	39	83	49	109	59		

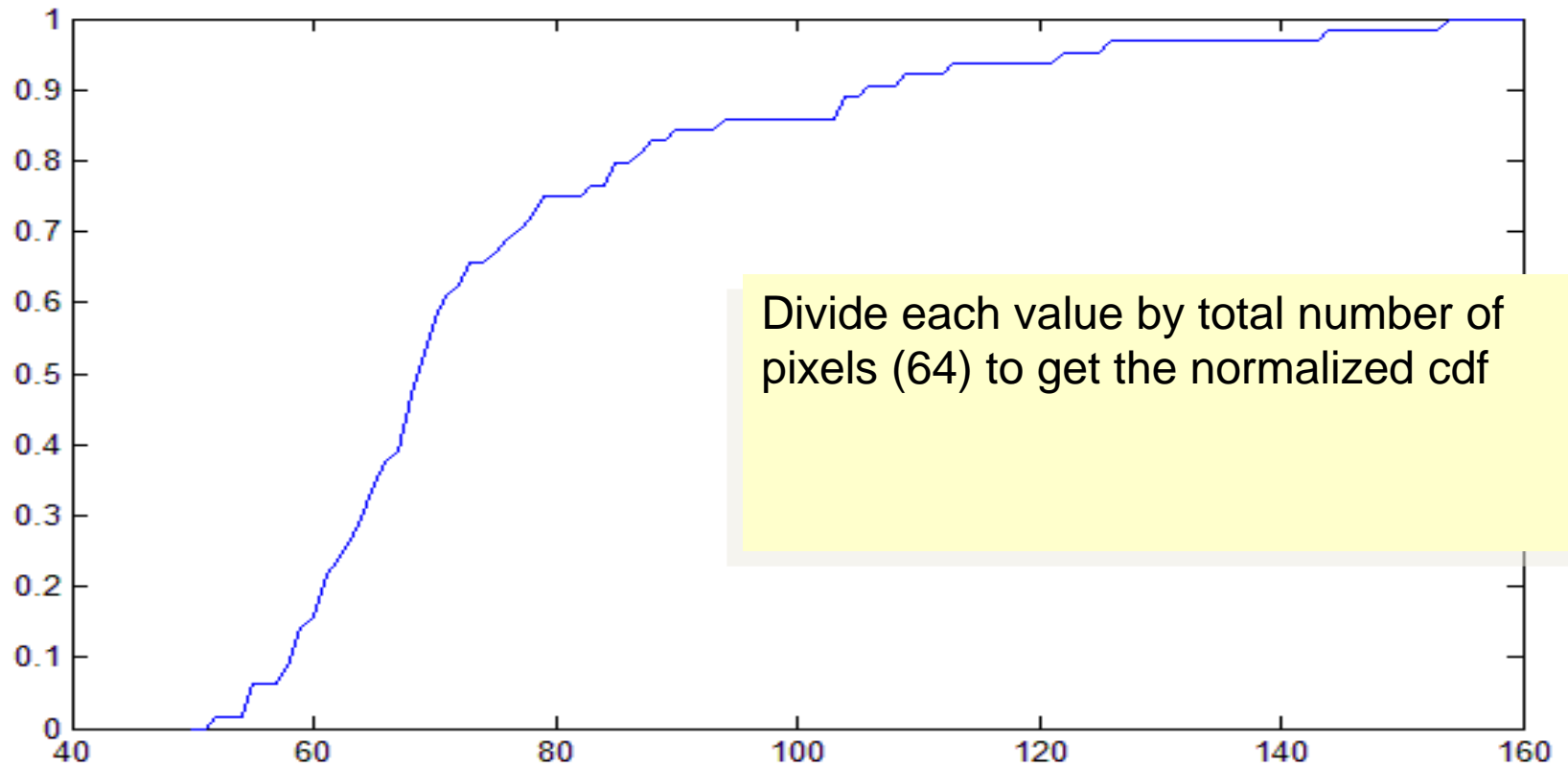
Histogram Equalization: Example

Cumulative Distribution Function (cdf)

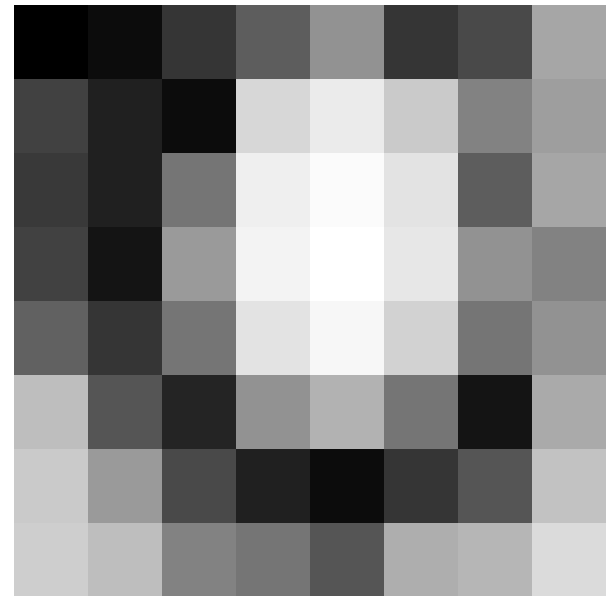
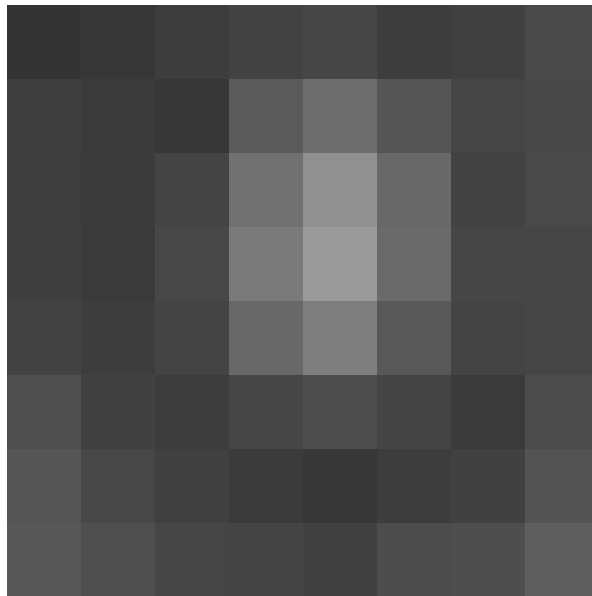


Histogram Equalization: Example

Normalized Cumulative Distribution Function (cdf)



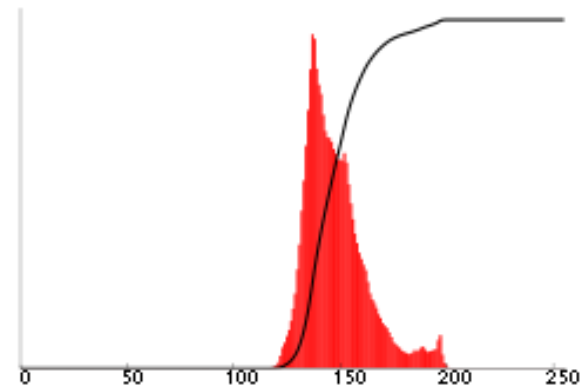
Histogram Equalization: Example



Histogram Equalization: Example



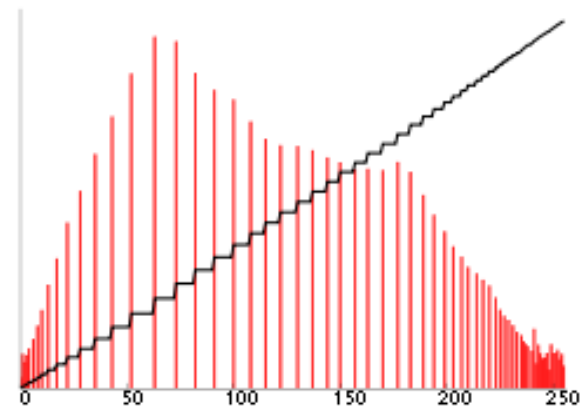
Original Image



Corresponding histogram (red) and cumulative histogram (black)



Image after histogram equalization



Corresponding histogram (red) and cumulative histogram (black)

Histogram Equalization: Example

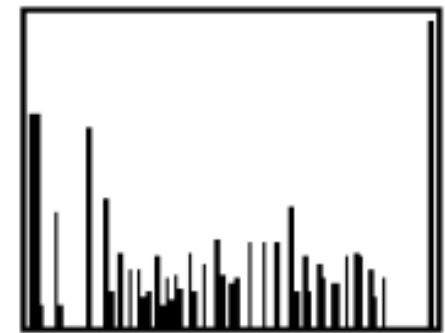
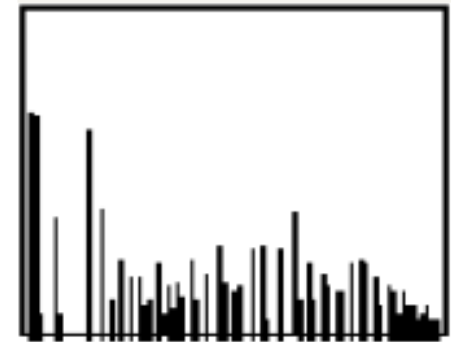
Dark image



Bright image



Equalized Histogram



Equalized Histogram

Histogram Equalization: Example

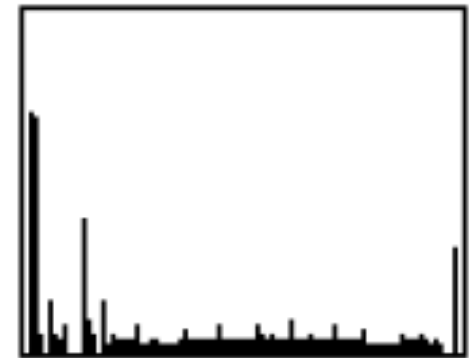
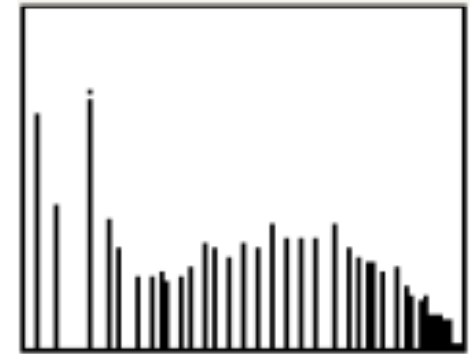
Low contrast



High Contrast



Equalized Histogram



Equalized Histogram

HISTOGRAM MATCHING (SPECIFICATION)

- HISTOGRAM EQUALIZATION DOES NOT ALLOW INTERACTIVE IMAGE ENHANCEMENT AND GENERATES ONLY ONE RESULT: AN APPROXIMATION TO A UNIFORM HISTOGRAM.
- SOMETIMES THOUGH, WE NEED TO BE ABLE TO SPECIFY PARTICULAR HISTOGRAM SHAPES CAPABLE OF HIGHLIGHTING CERTAIN GRAY-LEVEL RANGES.

HISTOGRAM SPECIFICATION

Suppose $s = T(r) = \int_0^r p_r(w) dw$

$p_r(r) \rightarrow$ Original histogram ; $p_z(z) \rightarrow$ Desired histogram

Let $v = G(z) = \int_0^z p_z(w) dw$ and $z = G^{-1}(v)$

But s and v are identical p.d.f.

$\therefore z = G^{-1}(v) = G^{-1}(s) = G^{-1}(T(r))$

HISTOGRAM SPECIFICATION

- THE PROCEDURE FOR HISTOGRAM-SPECIFICATION BASED ENHANCEMENT IS:
 - EQUALIZE THE LEVELS OF THE ORIGINAL IMAGE USING:

$$s = T(r_k) = \sum_{j=0}^k \frac{n_j}{n}$$

n: total number of pixels,

n_j: number of pixels with gray level r_j,

L: number of discrete gray levels

HISTOGRAM SPECIFICATION

- SPECIFY THE DESIRED DENSITY FUNCTION AND OBTAIN THE TRANSFORMATION FUNCTION $G(z)$:

$$v_k = G(z_k) = \sum_{i=0}^k p_z(z_i) = s_k$$

p_z : specified desirable PDF for output

HISTOGRAM SPECIFICATION

- THE NEW, PROCESSED VERSION OF THE ORIGINAL IMAGE CONSISTS OF GRAY LEVELS CHARACTERIZED BY THE SPECIFIED DENSITY $p_z(z)$.

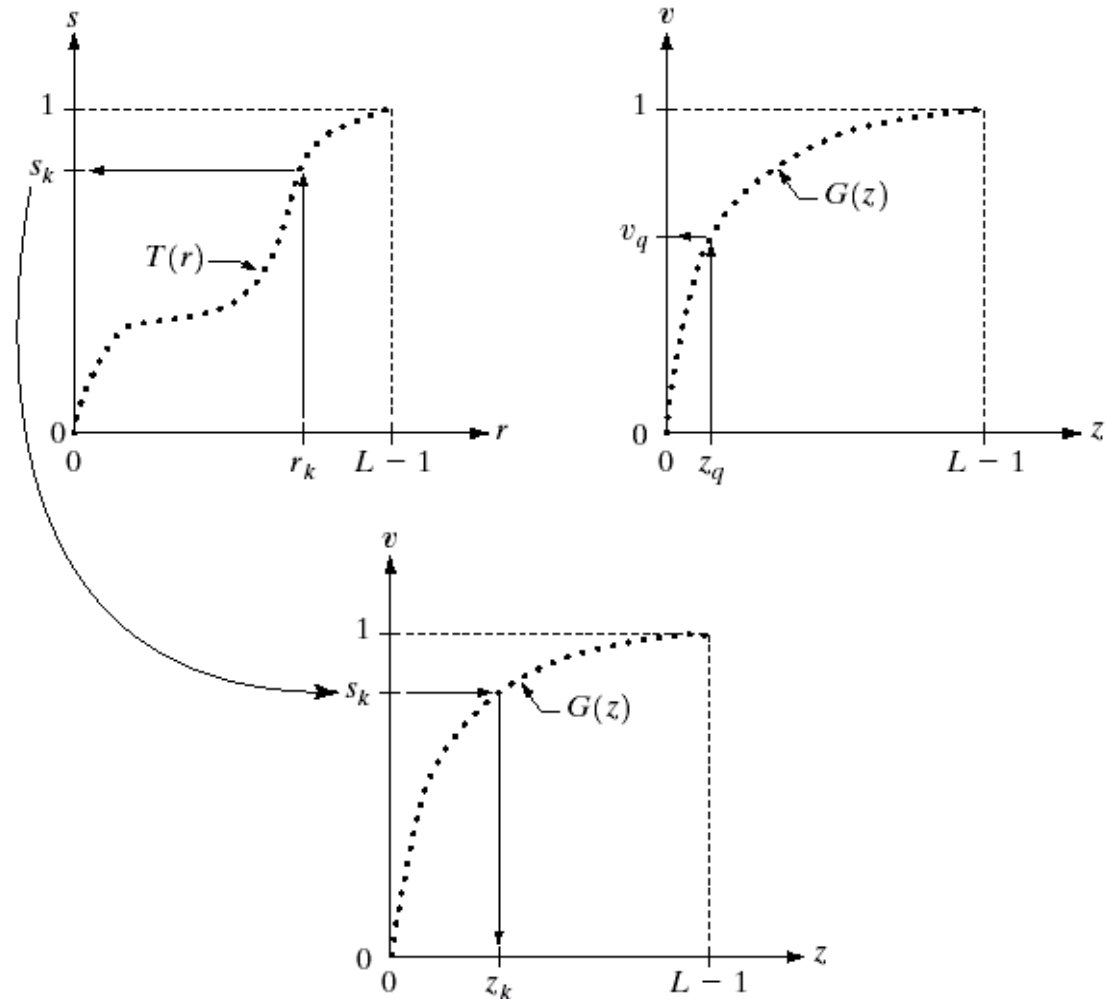
In essence: $z = G^{-1}(s) \rightarrow z = G^{-1}[T(r)]$

MAPPINGS

a b
c

FIGURE 3.19

(a) Graphical interpretation of mapping from r_k to s_k via $T(r)$.
 (b) Mapping of z_q to its corresponding value v_q via $G(z)$.
 (c) Inverse mapping from s_k to its corresponding value of z_k .



HISTOGRAM SPECIFICATION

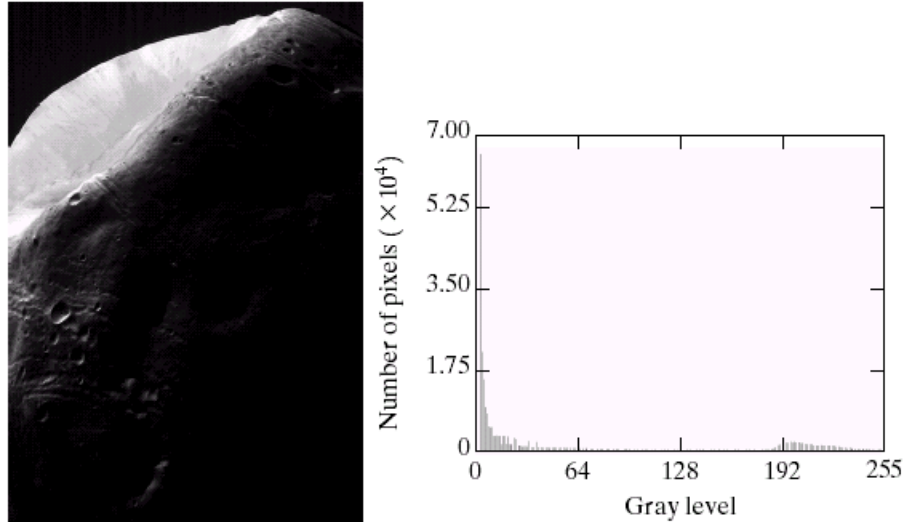
- OBTAIN THE HISTOGRAM OF THE GIVEN IMAGE
- MAP EACH LEVEL r_k TO A LEVEL S_k
- OBTAIN THE TRANSFORMATION FUNCTION G FROM THE GIVEN $P_z(z)$
- PRECOMPUTE Z_k FOR EACH VALUE OF S_k
- FOR EACH PIXEL IN THE ORIGINAL IMAGE, IF THE VALUE OF THAT PIXEL IS r_k MAP THIS VALUE TO ITS CORRESPONDING LEVEL S_k , THEN MAP LEVEL S_k INTO THE FINAL VALUE Z_k

HISTOGRAM SPECIFICATION

k	n_k	$p_r(r_k)$	s_k	$p_z(z_k)$	v_k	n_k
0	790	0.19	0.19	0	0	0
1	1023	0.25	0.44	0	0	0
2	850	0.21	0.65	0	0	0
3	656	0.16	0.81	0.15	0.15	790
4	329	0.08	0.89	0.2	0.35	1023
5	245	0.06	0.95	0.3	0.65	850
6	122	0.03	0.98	0.2	0.85	985
7	81	0.02	1.0	0.15	1.0	448

A 64X64 (4096 PIXELS) IMAGE WITH 8 GRAY LEVELS

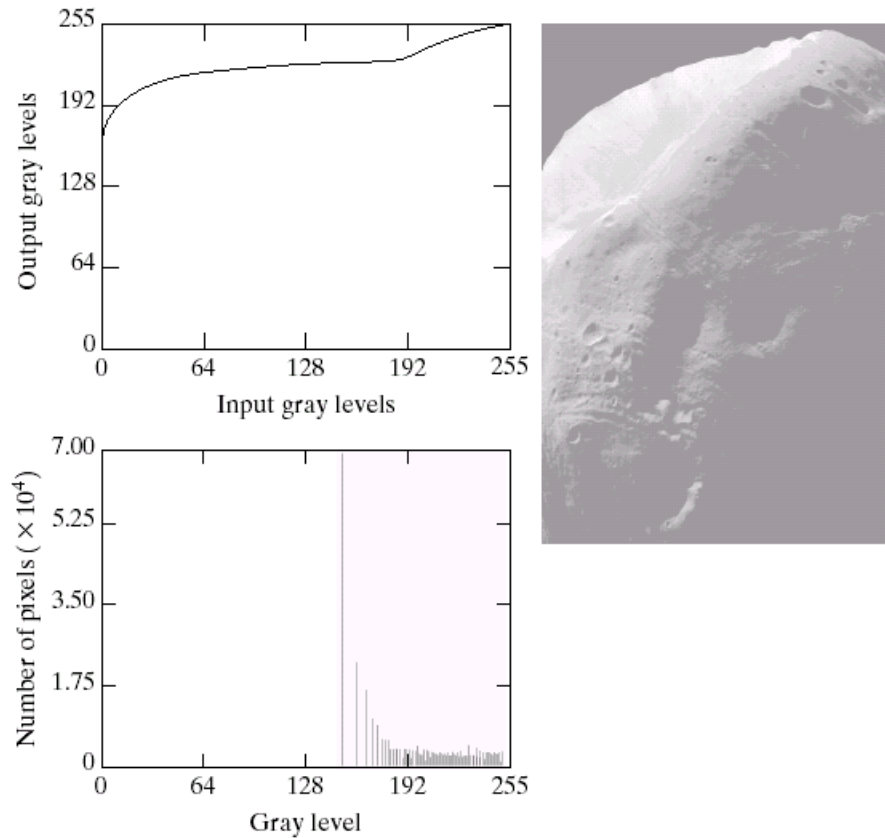
IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN



a b

FIGURE 3.20 (a) Image of the Mars moon Phobos taken by NASA's *Mars Global Surveyor*. (b) Histogram. (Original image courtesy of NASA.)

IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN



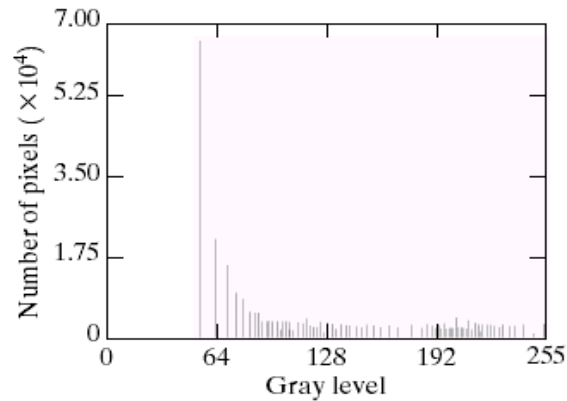
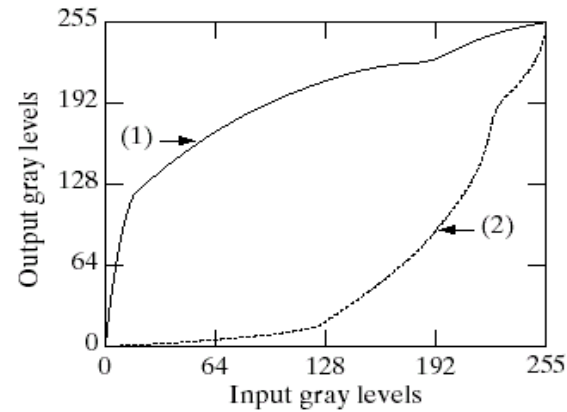
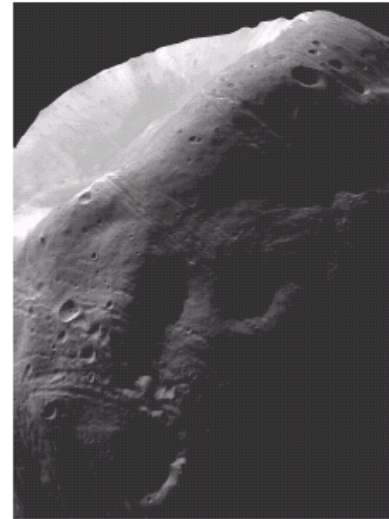
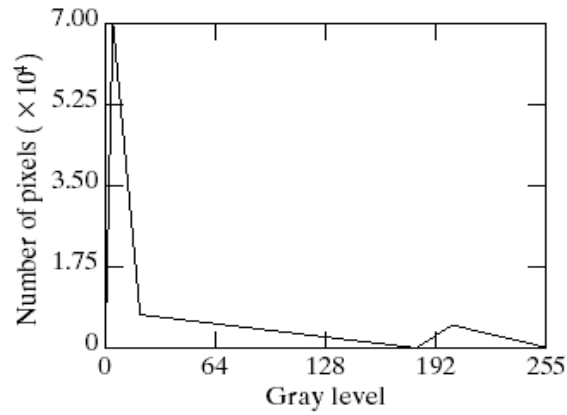
a b
c

FIGURE 3.21
(a) Transformation function for histogram equalization.
(b) Histogram-equalized image (note the washed-out appearance).
(c) Histogram of (b).

a c
b
d

FIGURE 3.22

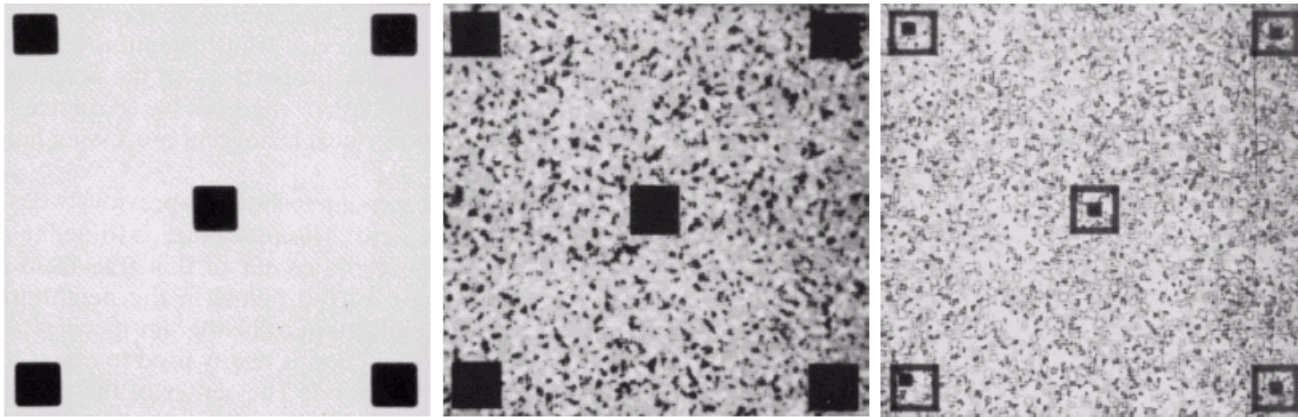
(a) Specified histogram.
(b) Curve (1) is from Eq. (3.3-14), using the histogram in (a); curve (2) was obtained using the iterative procedure in Eq. (3.3-17).
(c) Enhanced image using mappings from curve (2).
(d) Histogram of (c).



GLOBAL/LOCAL HISTOGRAM EQUALIZATION

- IT MAY BE NECESSARY TO ENHANCE DETAILS OVER SMALL AREAS IN THE IMAGE
- THE NUMBER OF PIXELS IN THESE AREAS MAY HAVE NEGLIGIBLE INFLUENCE ON THE COMPUTATION OF A GLOBAL TRANSFORMATION WHOSE SHAPE DOES NOT NECESSARILY GUARANTEE THE DESIRED LOCAL ENHANCEMENT
- DEVISE TRANSFORMATION FUNCTIONS BASED ON THE GRAY LEVEL DISTRIBUTION IN THE NEIGHBORHOOD OF EVERY PIXEL IN THE IMAGE
- THE PROCEDURE IS:
 - DEFINE A SQUARE (OR RECTANGULAR) NEIGHBORHOOD AND MOVE THE CENTER OF THIS AREA FROM PIXEL TO PIXEL.
 - AT EACH LOCATION, THE HISTOGRAM OF THE POINTS IN THE NEIGHBORHOOD IS COMPUTED AND EITHER A HISTOGRAM EQUALIZATION OR HISTOGRAM SPECIFICATION TRANSFORMATION FUNCTION IS OBTAINED.
 - THIS FUNCTION IS FINALLY USED TO MAP THE GRAY LEVEL OF THE PIXEL CENTERED IN THE NEIGHBORHOOD.
 - THE CENTER IS THEN MOVED TO AN ADJACENT PIXEL LOCATION AND THE PROCEDURE IS REPEATED.

GLOBAL/LOCAL HISTOGRAM EQUALIZATION



a b c

FIGURE 3.23 (a) Original image. (b) Result of global histogram equalization. (c) Result of local histogram equalization using a 7×7 neighborhood about each pixel.

USE OF HISTOGRAM STATISTICS FOR IMAGE ENHANCEMENT (Global)

- LET r REPRESENT A GRAY LEVEL IN THE IMAGE $[0, L-1]$, AND LET $p(r_i)$ DENOTE THE NORMALIZED HISTOGRAM COMPONENT CORRESPONDING TO THE i^{th} VALUE OF r .
- THE n^{th} MOMENT OF r ABOUT ITS MEAN IS DEFINED AS

$$\mu_n(r) = \sum_{i=0}^{L-1} (r_i - m)^n p(r_i)$$

- WHERE m IS THE MEAN VALUE OF r (AVERAGE GRAY LEVEL)

$$m = \sum_{i=0}^{L-1} r_i p(r_i)$$

USE OF HISTOGRAM STATISTICS FOR IMAGE ENHANCEMENT (Global)

- THE SECOND MOMENT IS GIVEN BY

$$\mu_2(r) = \sum_{i=0}^{L-1} (r_i - m)^2 p(r_i)$$

- WHICH IS THE VARIANCE OF r
- MEAN AS A MEASURE OF AVERAGE GRAY LEVEL IN THE IMAGE
- VARIANCE AS A MEASURE OF AVERAGE CONTRAST

USE OF HISTOGRAM STATISTICS FOR IMAGE ENHANCEMENT (Local)

- LET (x,y) BE THE COORDINATES OF A PIXEL IN AN IMAGE, AND LET $S_{x,y}$ DENOTE A NEIGHBORHOOD OF SPECIFIED SIZE, CENTERED AT (x,y)
- THE MEAN VALUE $m_{s_{xy}}$ OF THE PIXELS IN $S_{x,y}$ IS

$$m_{s_{xy}} = \sum_{(s,t) \in S_{xy}} r_{s,t} p(r_{s,t})$$

- THE GRAY LEVEL VARIANCE OF THE PIXELS IN REGION $S_{x,y}$ IS GIVEN BY

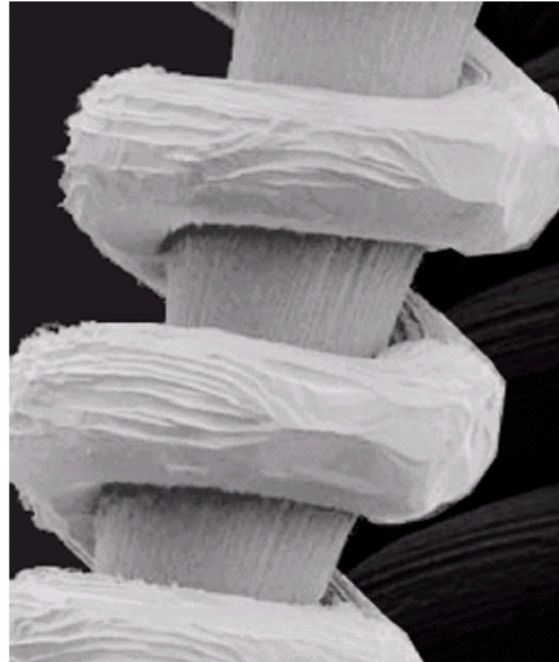
$$\sigma_{s_{xy}}^2 = \sum_{(s,t) \in S_{xy}} [r_{s,t} - m_{s_{xy}}]^2 p(r_{s,t})$$

USE OF HISTOGRAM STATISTICS FOR IMAGE ENHANCEMENT

- THE GLOBAL MEAN AND VARIANCE ARE MEASURED OVER AN ENTIRE IMAGE AND ARE USEFUL FOR GROSS ADJUSTMENTS OF OVERALL INTENSITY AND CONTRAST.
- A USE OF THESE MEASURES IN LOCAL ENHANCEMENT IS, WHERE THE LOCAL MEAN AND VARIANCE ARE USED AS THE BASIS FOR MAKING CHANGES THAT DEPEND ON IMAGE CHARACTERISTICS IN A PREDEFINED REGION ABOUT EACH PIXEL IN THE IMAGE.

TUNGSTEN FILAMENT IMAGE

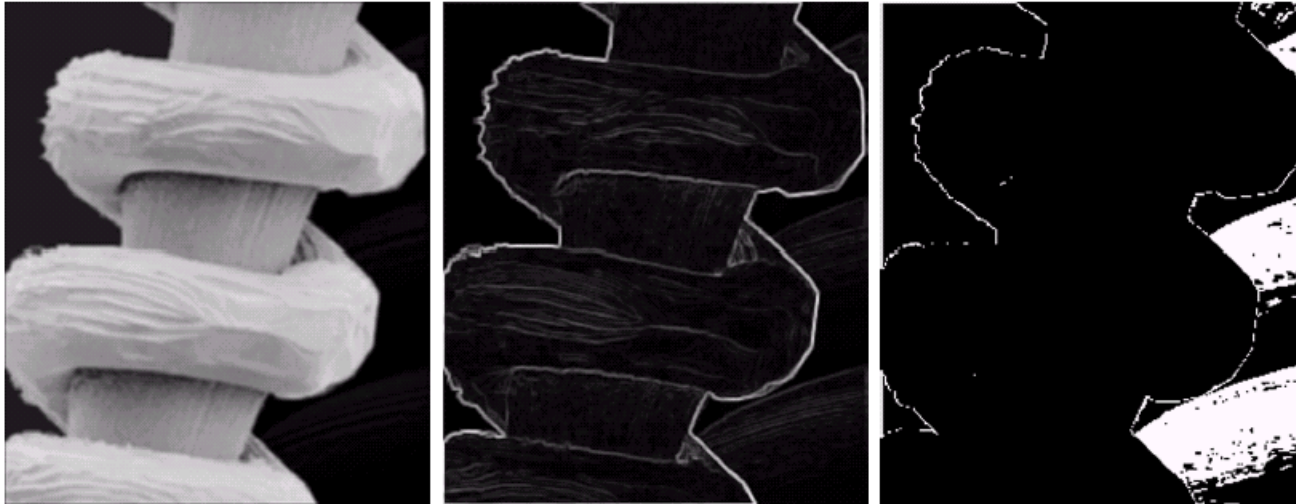
FIGURE 3.24 SEM image of a tungsten filament and support, magnified approximately 130 \times . (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene).



USE OF HISTOGRAM STATISTICS FOR IMAGE ENHANCEMENT

- A PIXEL AT POINT (x,y) IS CONSIDERED IF:
 - $m_{sxy} \leq k_0 M_G$, where k_0 is a positive constant less than 1.0, and M_G is global mean
 - $\sigma_{sxy} \leq k_2 D_G$, where D_G is the global standard deviation and k_2 is a positive constant
 - $k_1 D_G \leq \sigma_{sxy}$, with $k_1 < k_2$
- A PIXEL THAT MEETS ALL ABOVE CONDITIONS IS PROCESSED SIMPLY BY MULTIPLYING IT BY A SPECIFIED CONSTANT, E, TO INCREASE OR DECREASE THE VALUE OF ITS GRAY LEVEL RELATIVE TO THE REST OF THE IMAGE.
- THE VALUES OF PIXELS THAT DO NOT MEET THE ENHANCEMENT CONDITIONS ARE LEFT UNCHANGED.

IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN



a b c

FIGURE 3.25 (a) Image formed from all local means obtained from Fig. 3.24 using Eq. (3.3-21). (b) Image formed from all local standard deviations obtained from Fig. 3.24 using Eq. (3.3-22). (c) Image formed from all multiplication constants used to produce the enhanced image shown in Fig. 3.26.

IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN



FIGURE 3.26
Enhanced SEM
image. Compare
with Fig. 3.24. Note
in particular the
enhanced area on
the right side of
the image.

Readings from Book (3rd Edn.)

- Topics from 3rd chapter which we covered during lecture
- Bit plane slicing
- Histogram Matching/specification
- Local/global histogram equalization



Acknowledgements

- ◆ "Digital Image Processing", Rafael C. Gonzalez & Richard E. Woods, Addison-Wesley, 2009