Computer Vision

CSC-455

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Today's Lecture

- Image Enhancement
- Histogram Equalization
- Image filtering

Image Enhancement

Image Enhancement

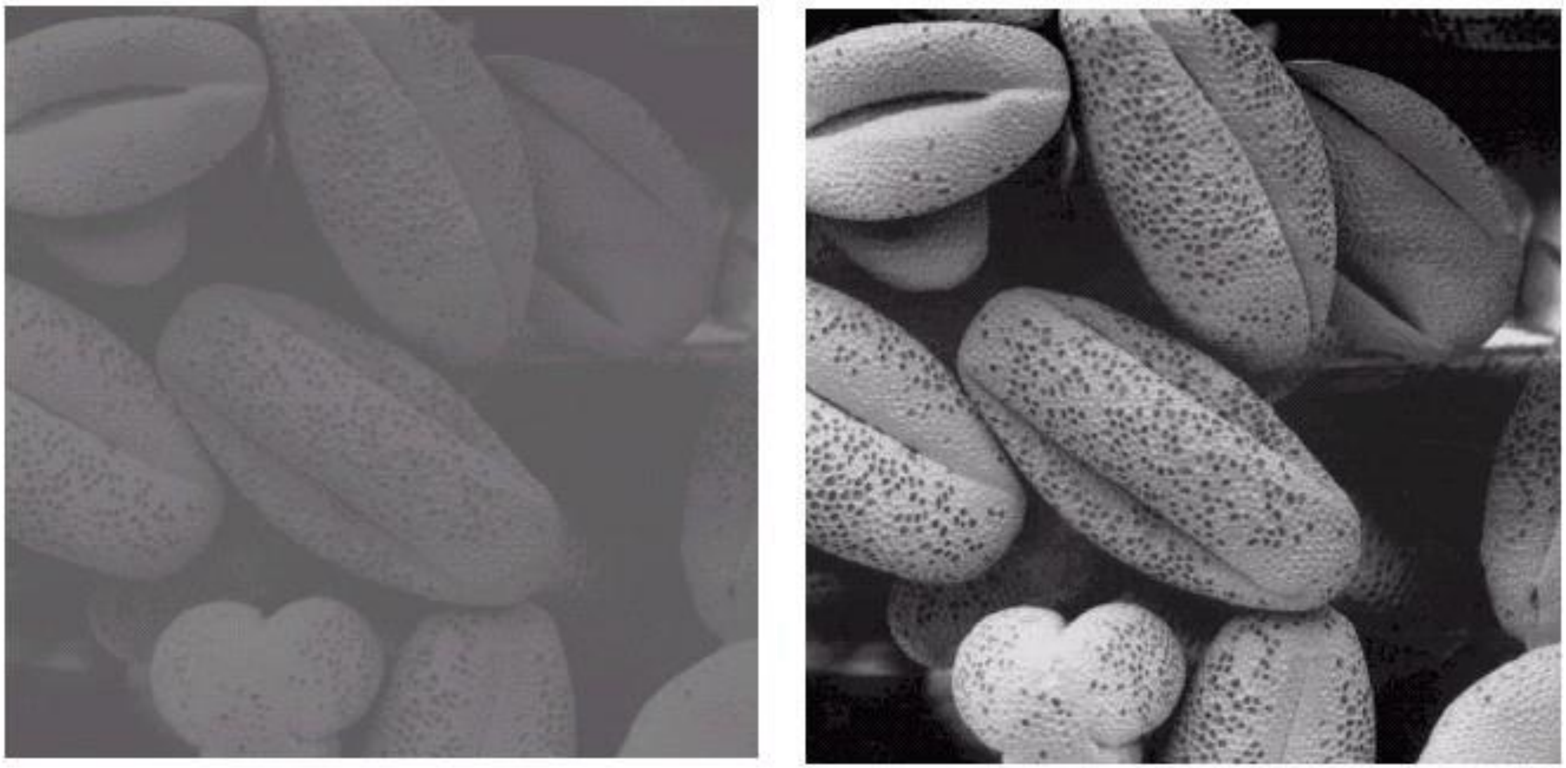


Image Enhancement

Process an image so that the result is more suitable than the original image for a specific application

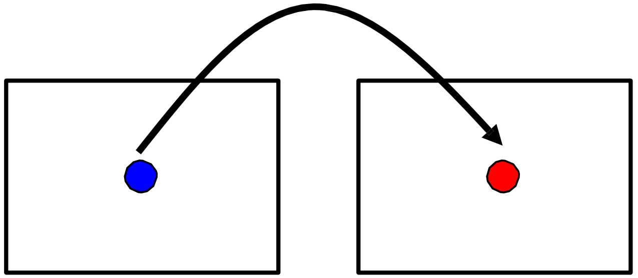
- Image Enhancement Methods
  - Spatial Domain: Direct manipulation of pixels in an image
  - Frequency Domain: Process the image by modifying the Fourier transform of an image

This Chapter – Spatial Domain

Types of image enhancement operations

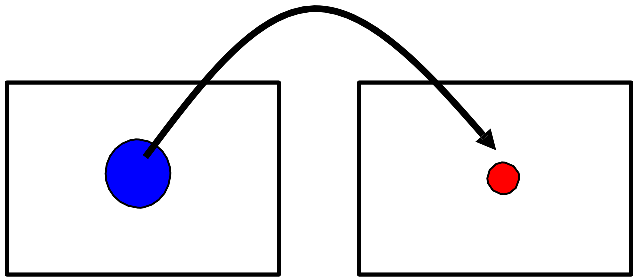
- Point/Pixel operations

  Output value at specific coordinates *(x,y)* is dependent only on the input value at *(x,y)*



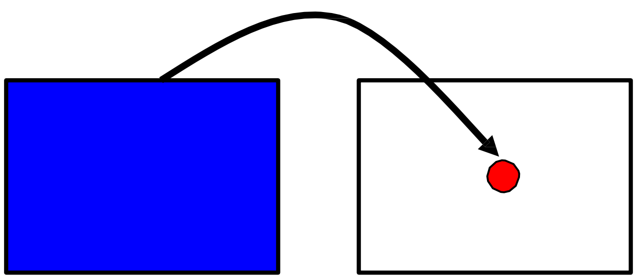
- Local operations

  The output value at *(x,y)* is dependent on the input values in the neighborhood of *(x,y)*



- Global operations

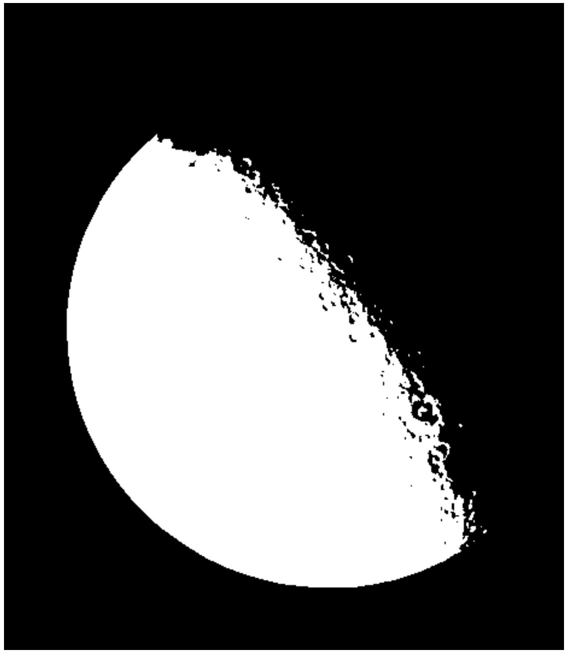
  The output value at *(x,y)* is dependent on all the values in the input image



Point Processing Example: Thresholding

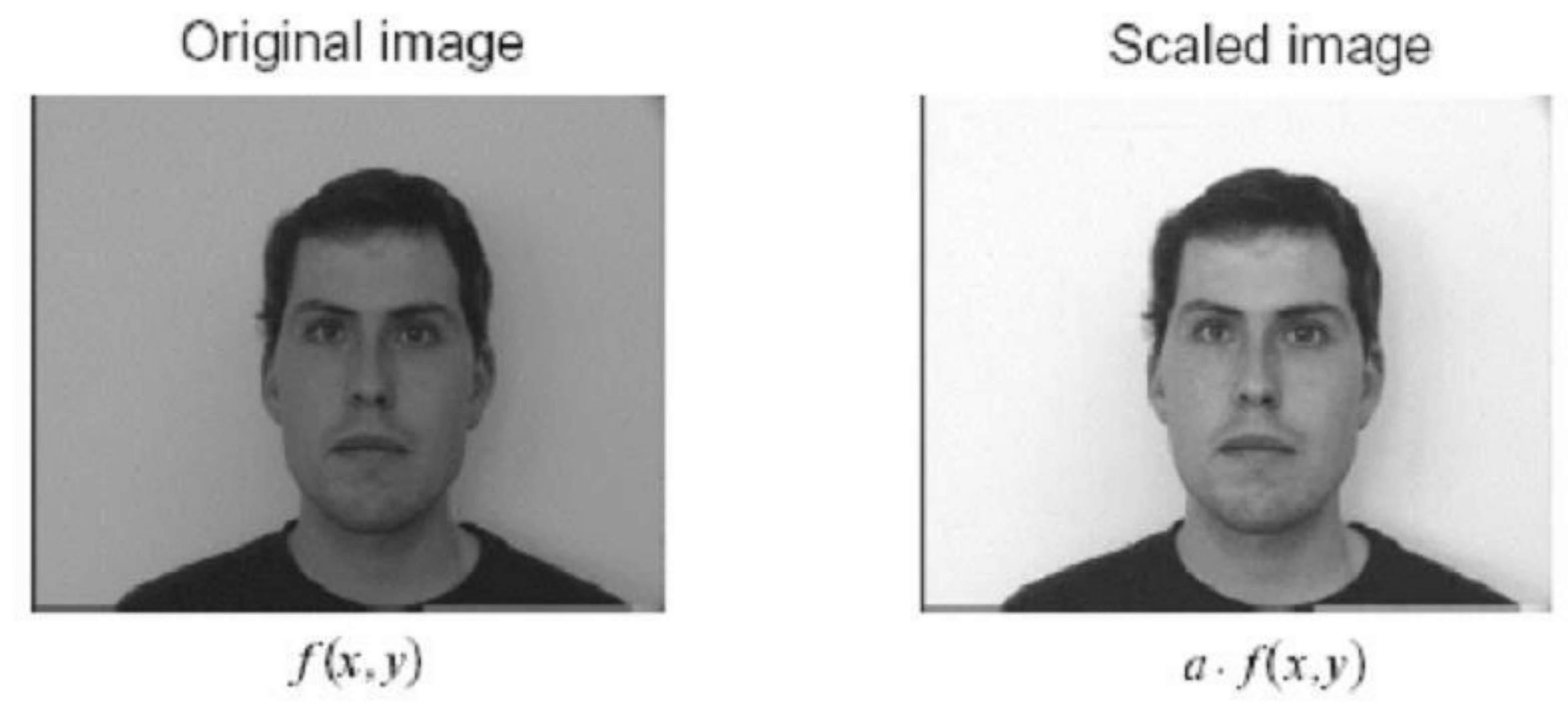
- Segmentation of an object of interest from a background

$$s = \begin{cases} 1.0 & r > \text{threshold} \\ 0.0 & r <= \text{threshold} \end{cases}$$



Point Processing Example: Intensity Scaling

$$s = T(r) = a.r$$



Point Processing Example: Negative Images

- Reverses the gray level order
- For L gray levels, the transformation has the form:

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

  - Negative images are useful for enhancing white or grey detail embedded in dark regions of an image

Point Processing Example: Negative Images

Input image (X-ray image)

Output image (negative)

Logarithmic Transformations

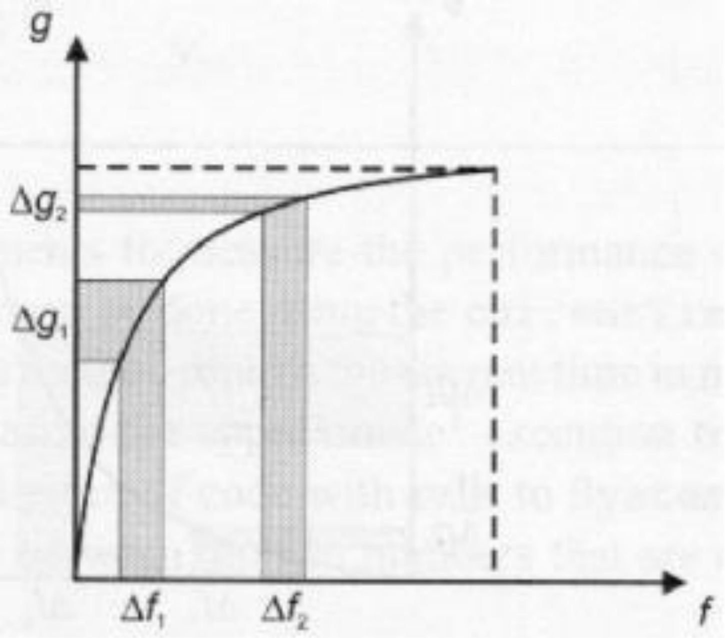
- The general form of the log transformation is

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

- The log transformation maps a **narrow range of low input grey level values** into **a wider range of output values**
- The inverse log transformation performs the opposite transformation

Logarithmic Transformations

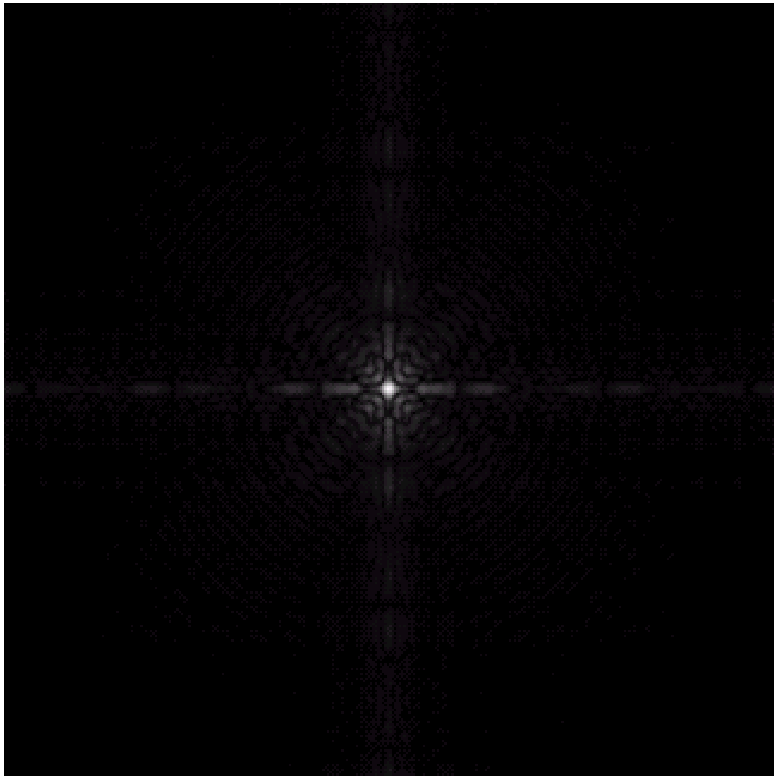
- **Properties**
  - For lower amplitudes of input image the range of gray levels is expanded
  - For higher amplitudes of input image the range of gray levels is compressed



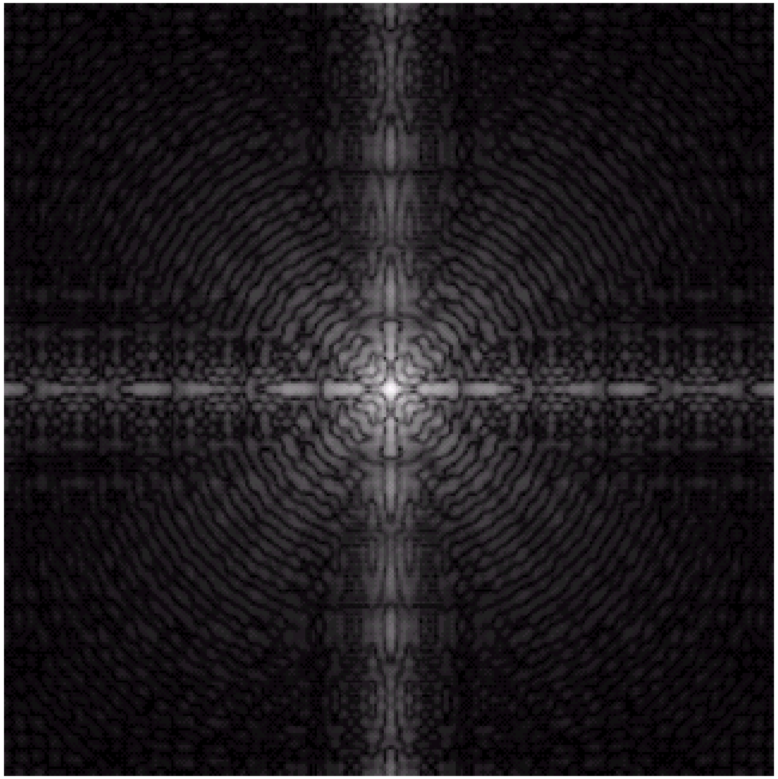
Logarithmic Transformations

- **Application**
  - This transformation is suitable for the case when the dynamic range of a processed image far exceeds the capability of the display device (e.g. display of the Fourier spectrum of an image)
  - Also called "dynamic-range compression / expansion"

Logarithmic Transformations



Fourier spectrum: image values ranging from 0 to 1.5×10^6



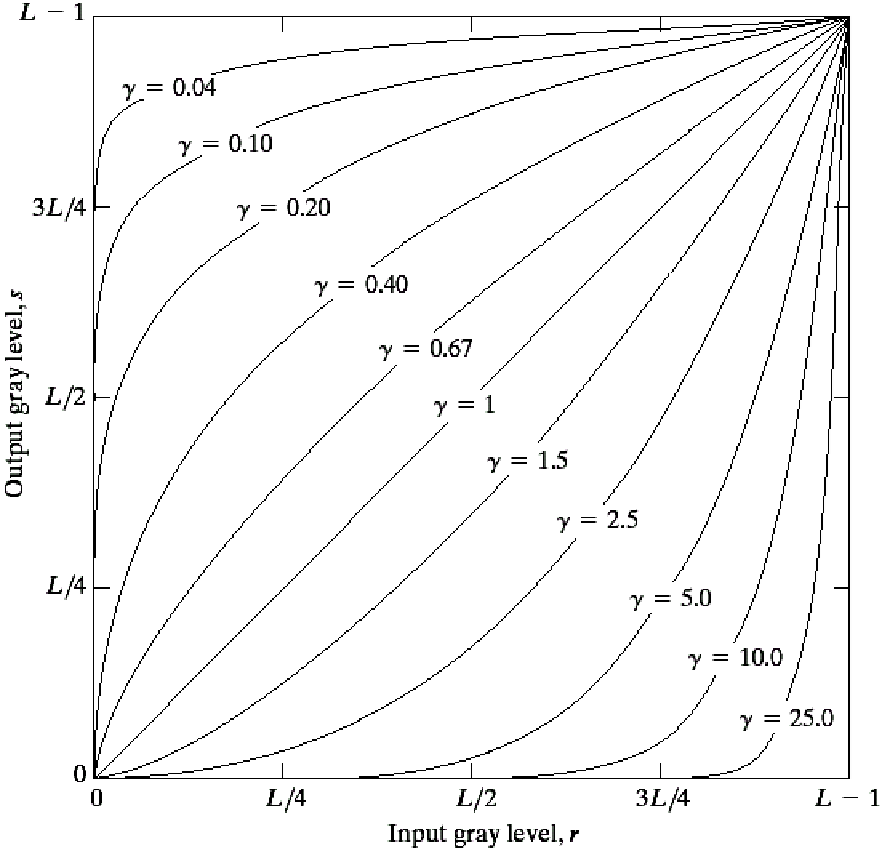
The result of log transformation with c = 1

Power Law Transformations

- Power law transformations have the following form

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

- Map a narrow range of dark input values into a wider range of output values or vice versa
- Varying γ gives a whole family of curves

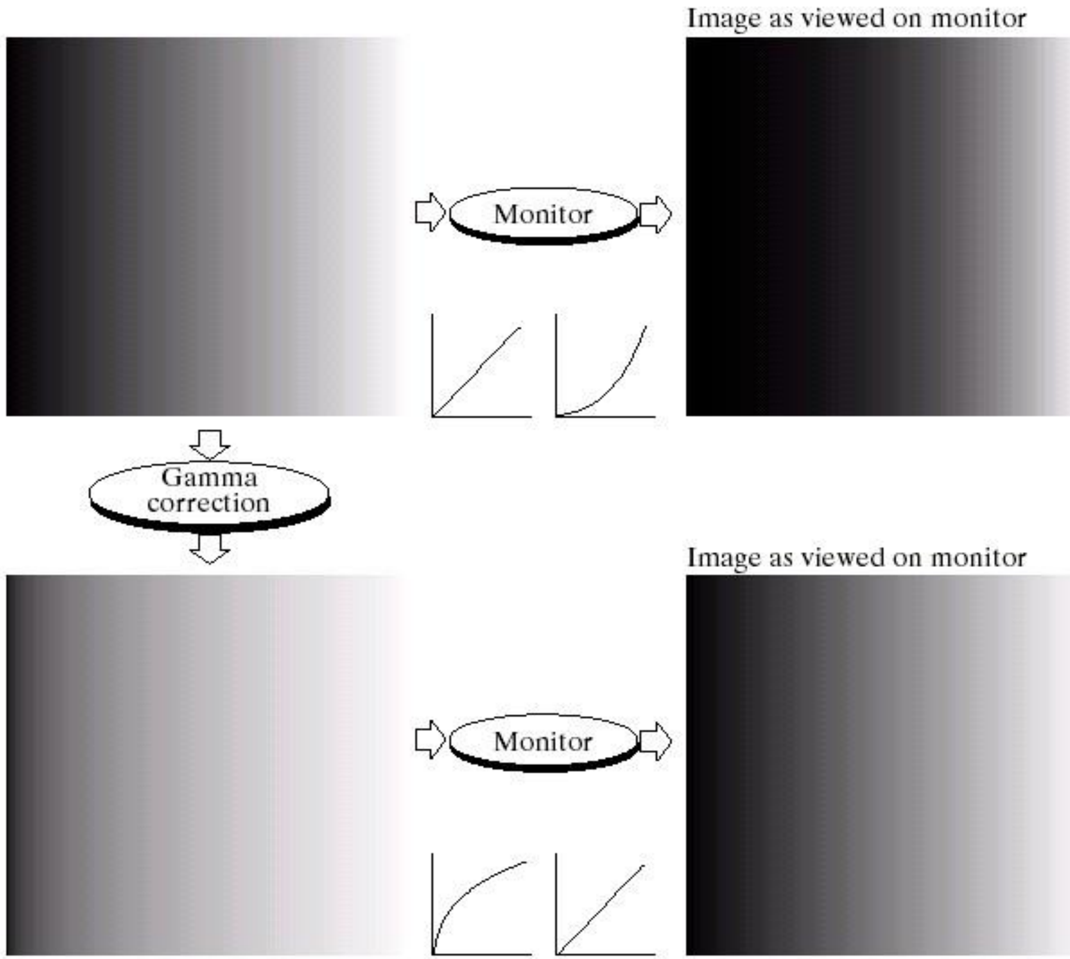


Power Law Transformations

- For $\gamma < 1$: Expands values of dark pixels, compress values of brighter pixels
- For $\gamma > 1$: Compresses values of dark pixels, expand values of brighter pixels
- If $\gamma=1$ & $c=1$: Identity transformation ($s = r$)

- A variety of devices (image capture, printing, display) respond according to a power law and need to be corrected

Power Law Transformations: Gamma Correction



a b
c d

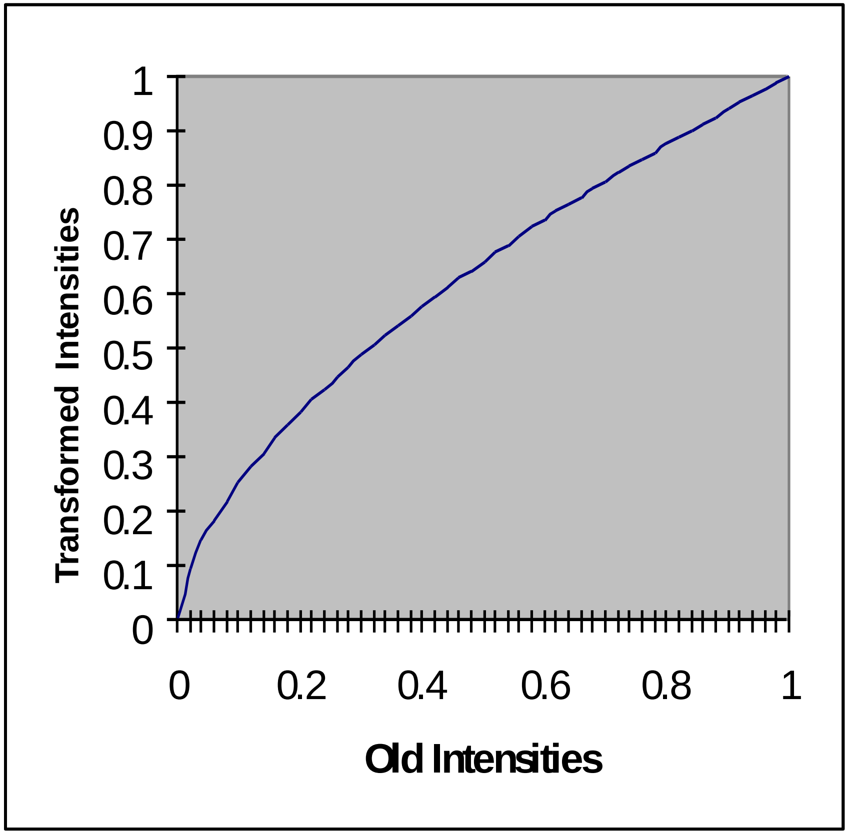
FIGURE 3.7
(a) Linear-wedge gray-scale image.
(b) Response of monitor to linear wedge.
(c) Gamma-corrected wedge.
(d) Output of monitor.

Power Law Transformations
Contrast Enhancement

The images to the right show a magnetic resonance (MR) image of a fractured human spine

Power Law Transformations
Contrast Enhancement

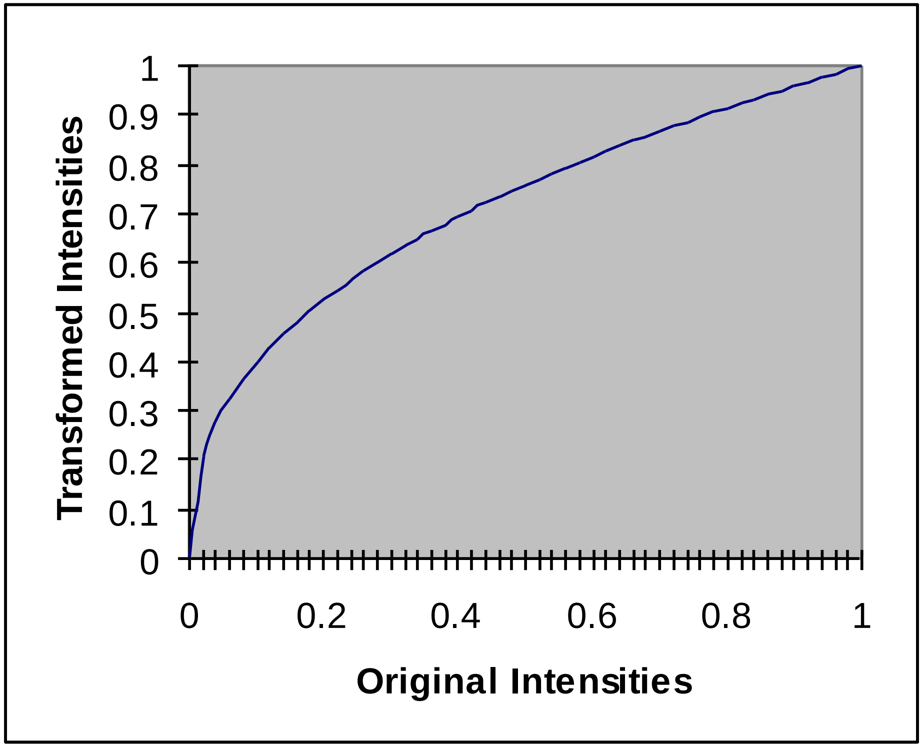
$\gamma = 0.6$



Power Law Transformations

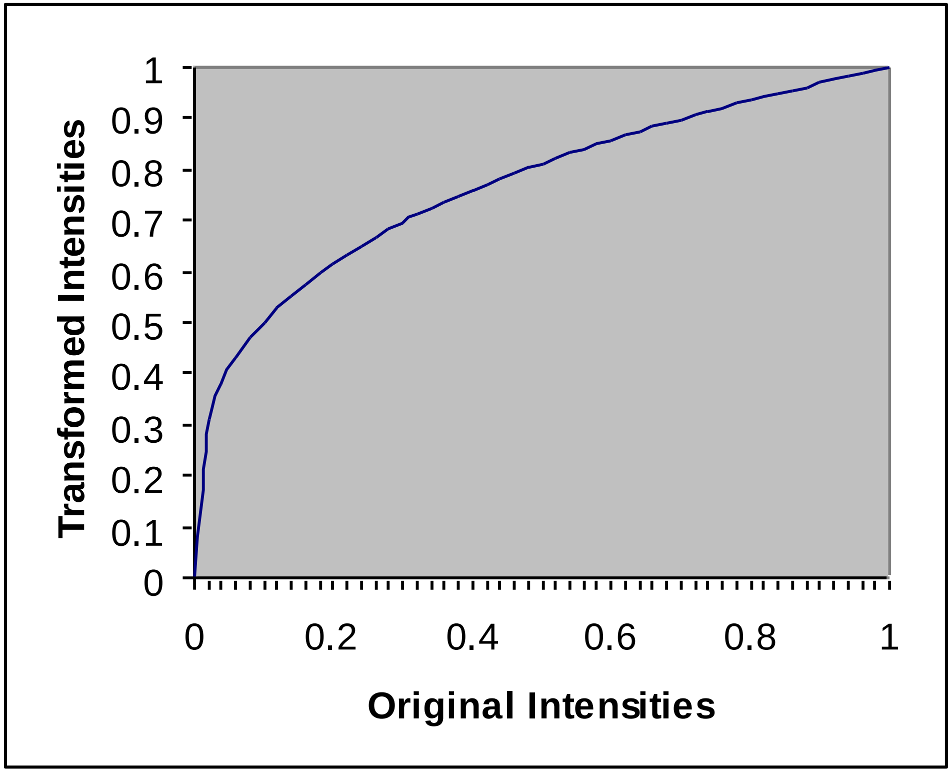
Contrast Enhancement

$\gamma = 0.4$



Power Law Transformations
Contrast Enhancement

$\gamma = 0.3$



Power Law Transformations
Contrast Enhancement

MR image of

fractured human spine

Result after

Power law transformation

c = 1, γ = 0.6

Result after

Power law transformation

c = 1, γ = 0.4

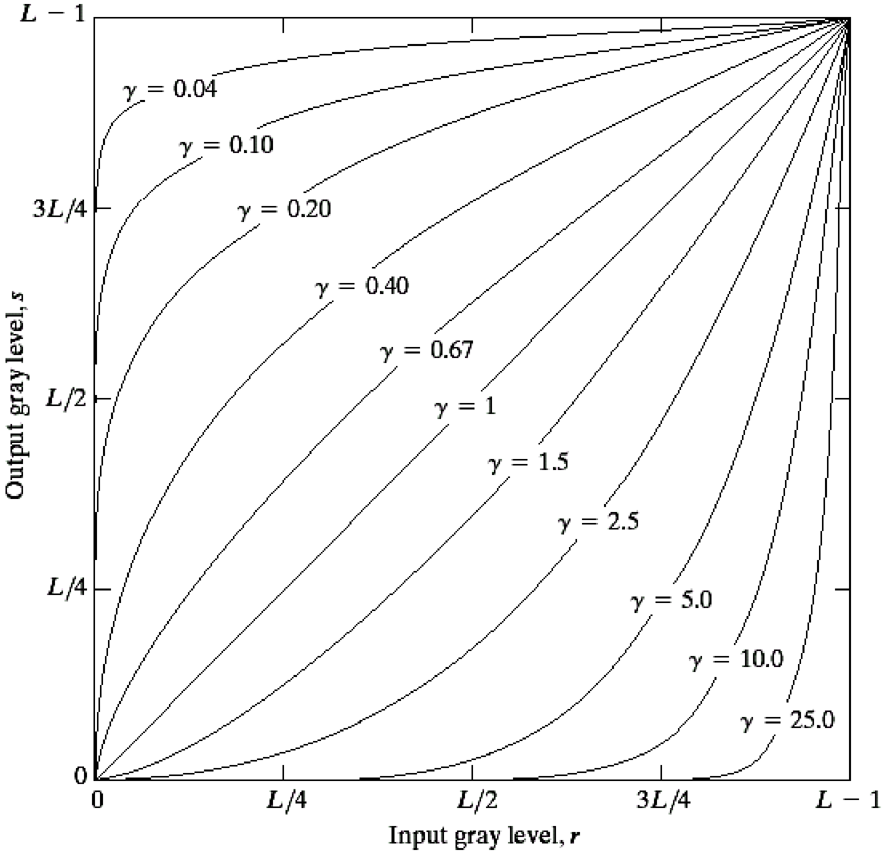
Result after

Power law transformation

c = 1, γ = 0.3

Power Law Transformations
Contrast Enhancement

When the γ is reduced too much, the image begins to reduce contrast to the point where the image started to have very slight "wash-out" look.



Power Law Transformations
Contrast Enhancement

Image has a washed-out appearance – needs $\gamma > 1$

Power Law Transformations
Contrast Enhancement

Aerial Image

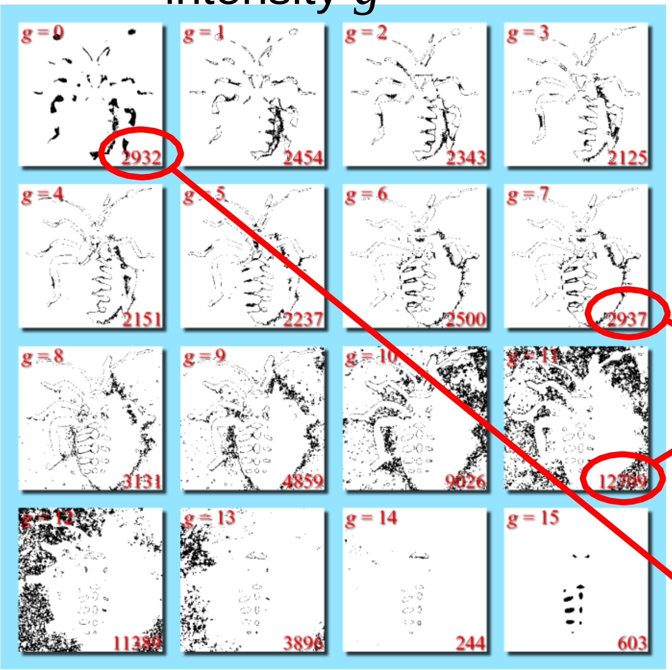
Result of Power law transformation c = 1, γ = 3.0 (suitable)

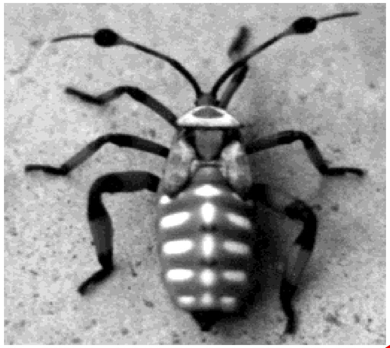
Result of Power law transformation c = 1, γ = 4.0 (suitable)

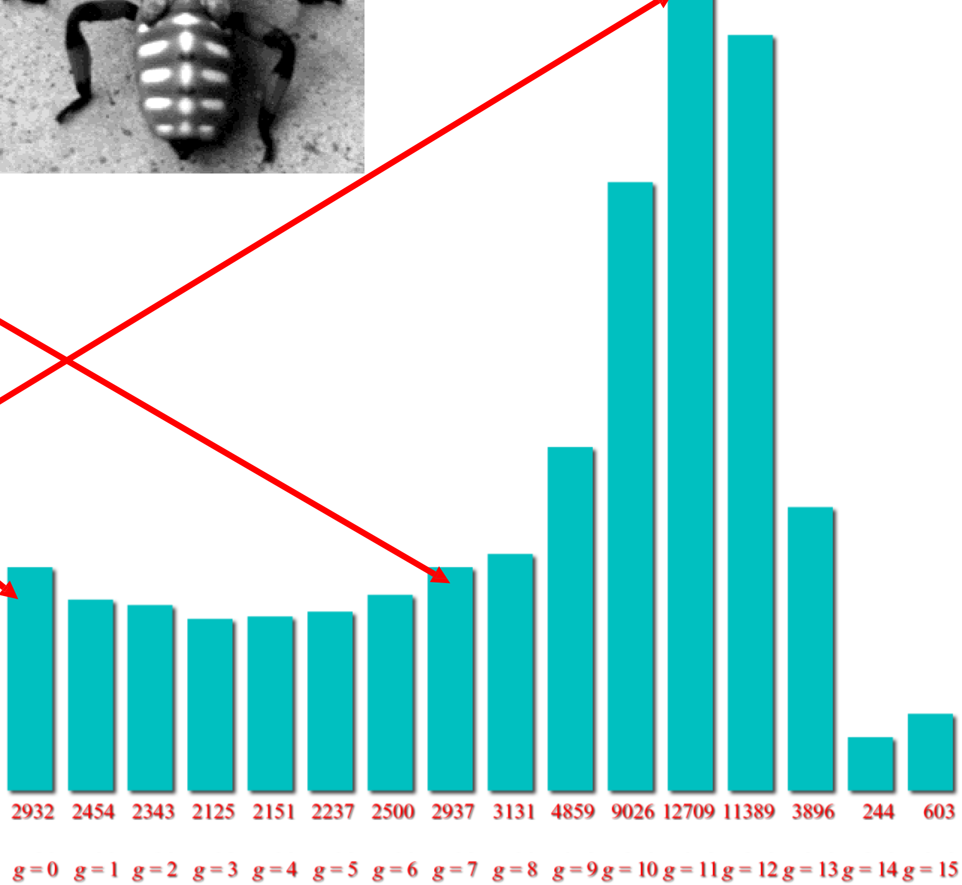
Result of Power law transformation c = 1, γ = 5.0 (high contrast, some regions are too dark)

Histogram of a Grayscale Image

Black marks pixels with intensity g

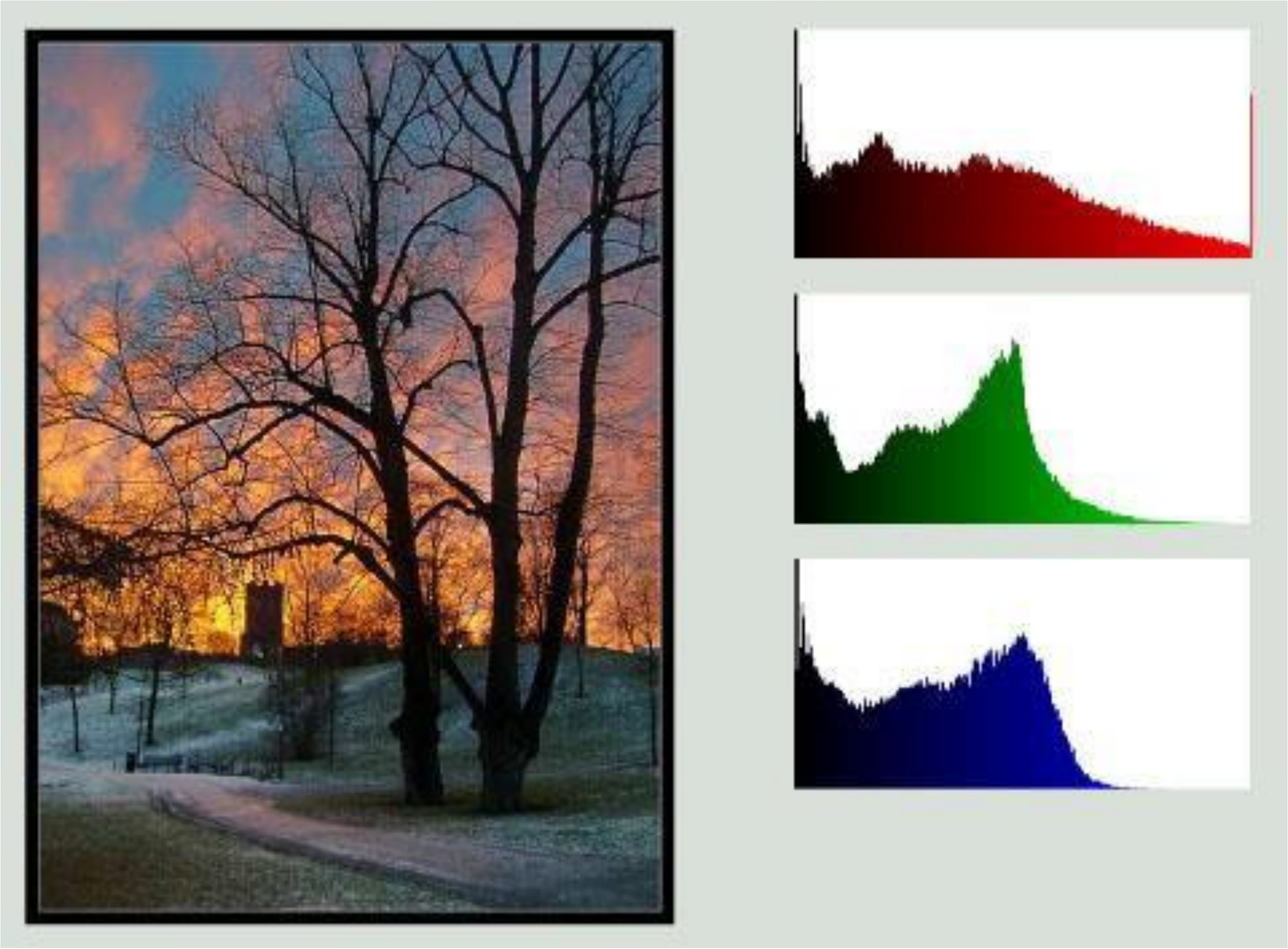




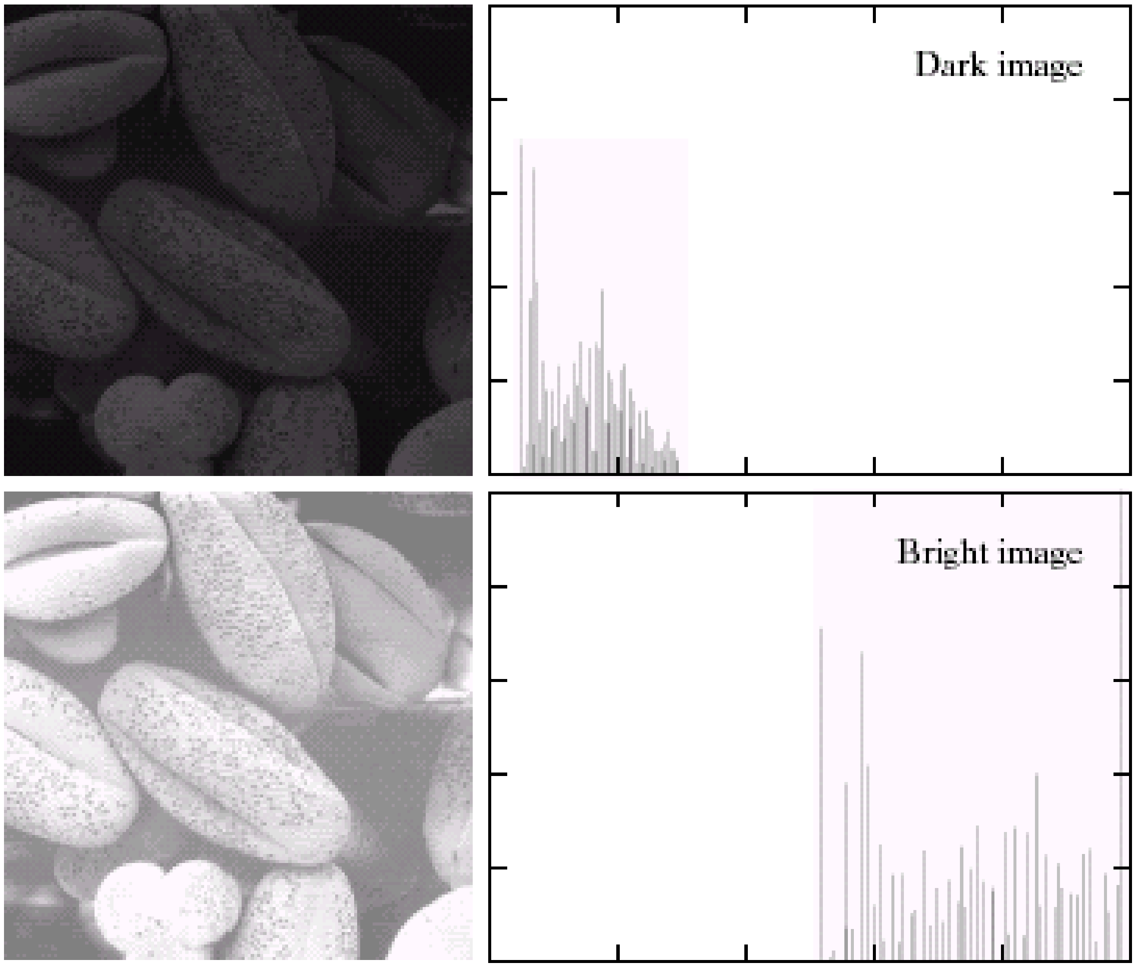


Plot of histogram:
number of pixels with intensity g

Histogram of a Color Image



Histogram: Example



Dark image

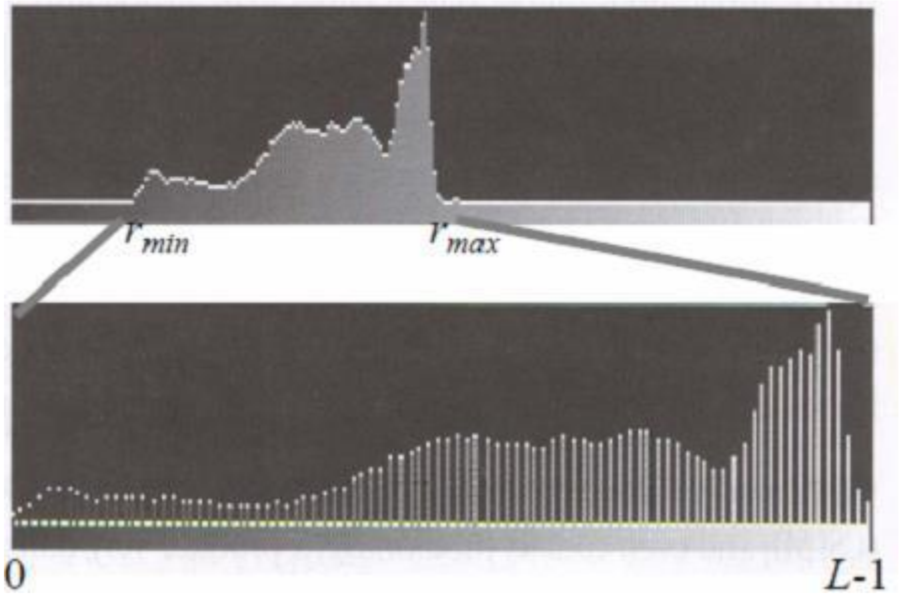
Components of histogram are concentrated on the low side of the gray scale

Bright image

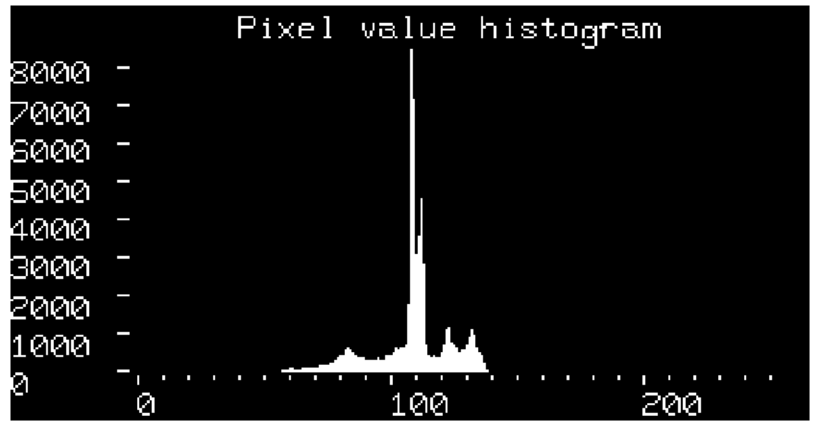
Components of histogram are concentrated on the high side of the gray scale

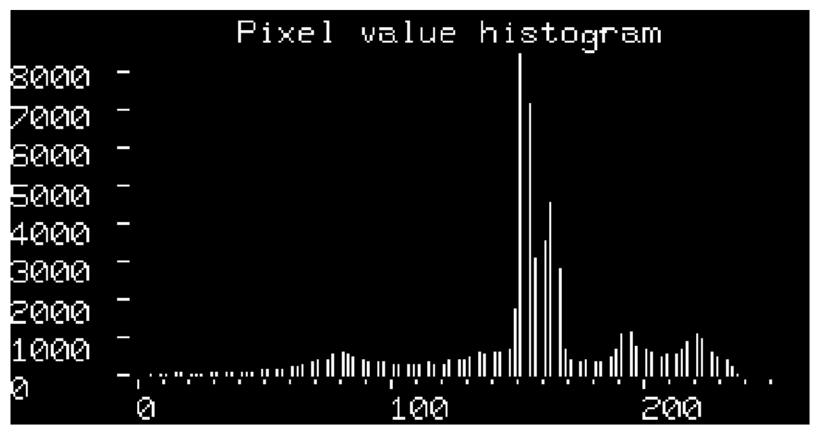
Contrast Stretching

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 the full range of pixel values



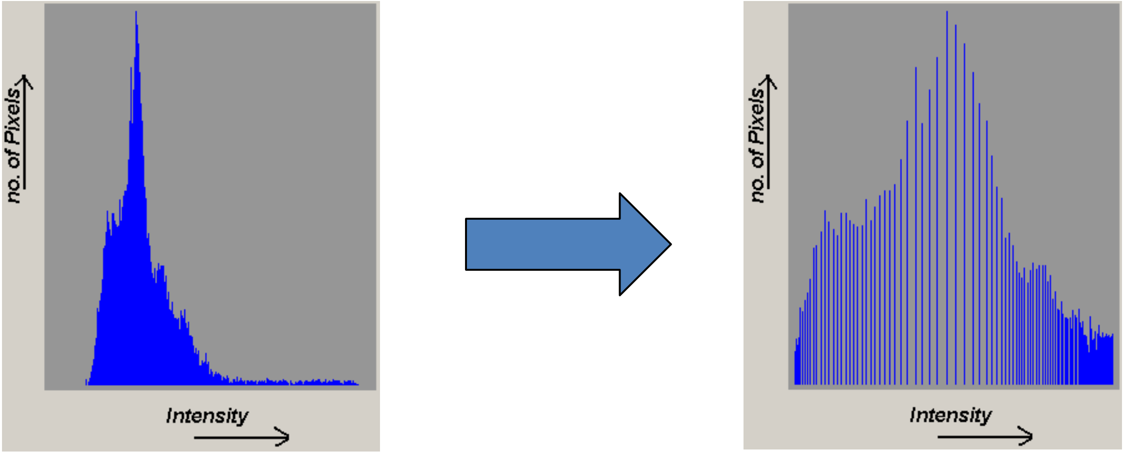
Contrast Stretching



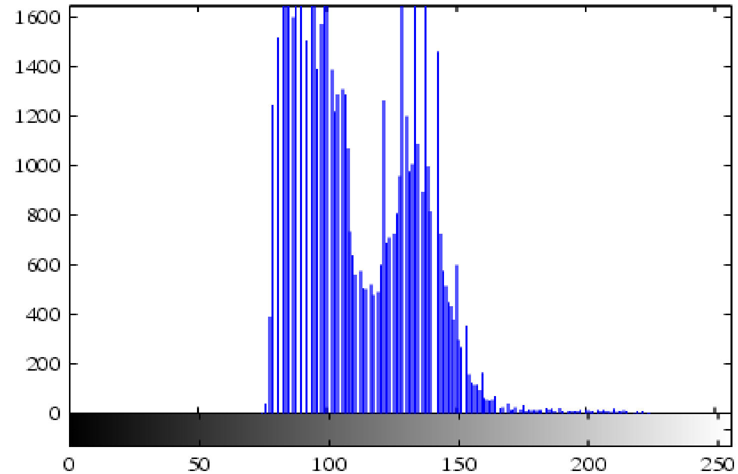


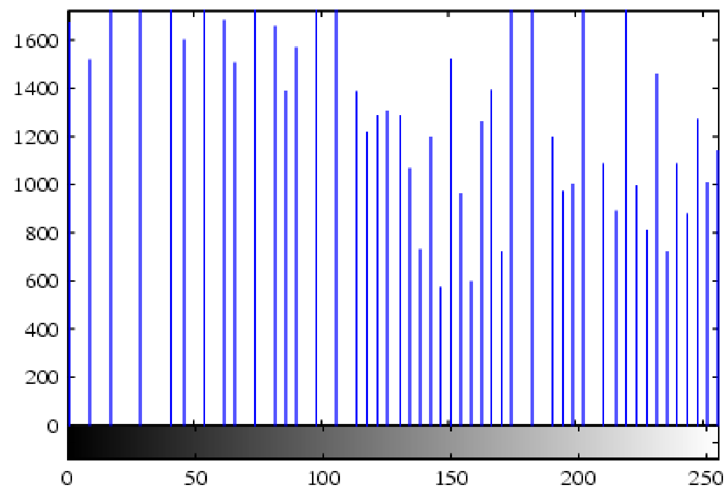
Histogram Equalization

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

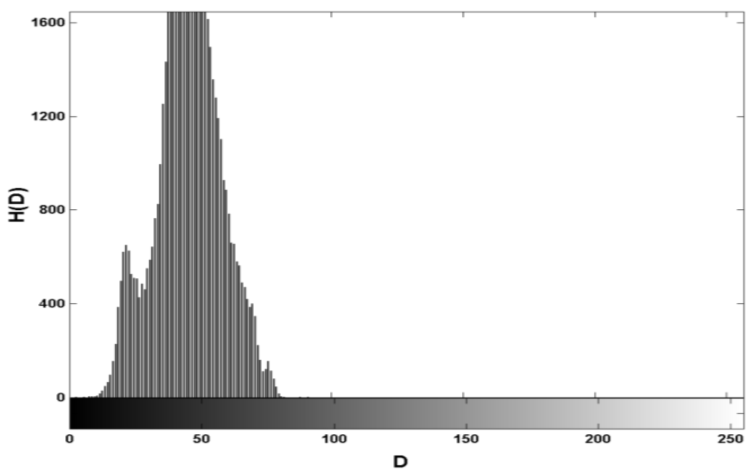


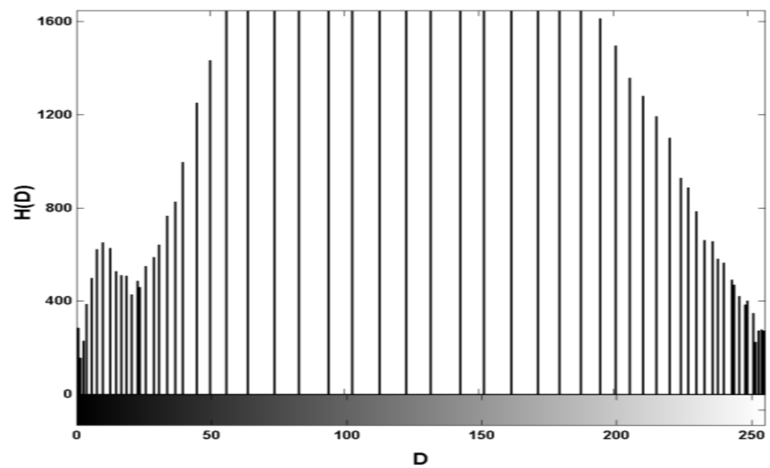
HISTOGRAM EQUALIZATION





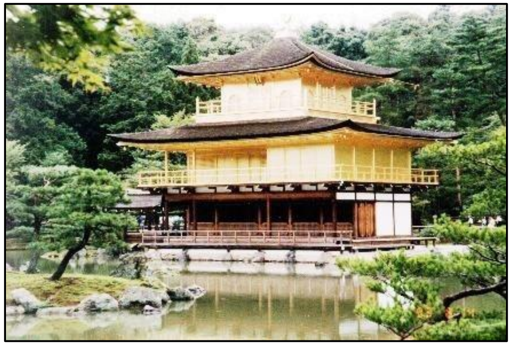
AERIAL PHOTOGRAPH OF THE PENTAGON

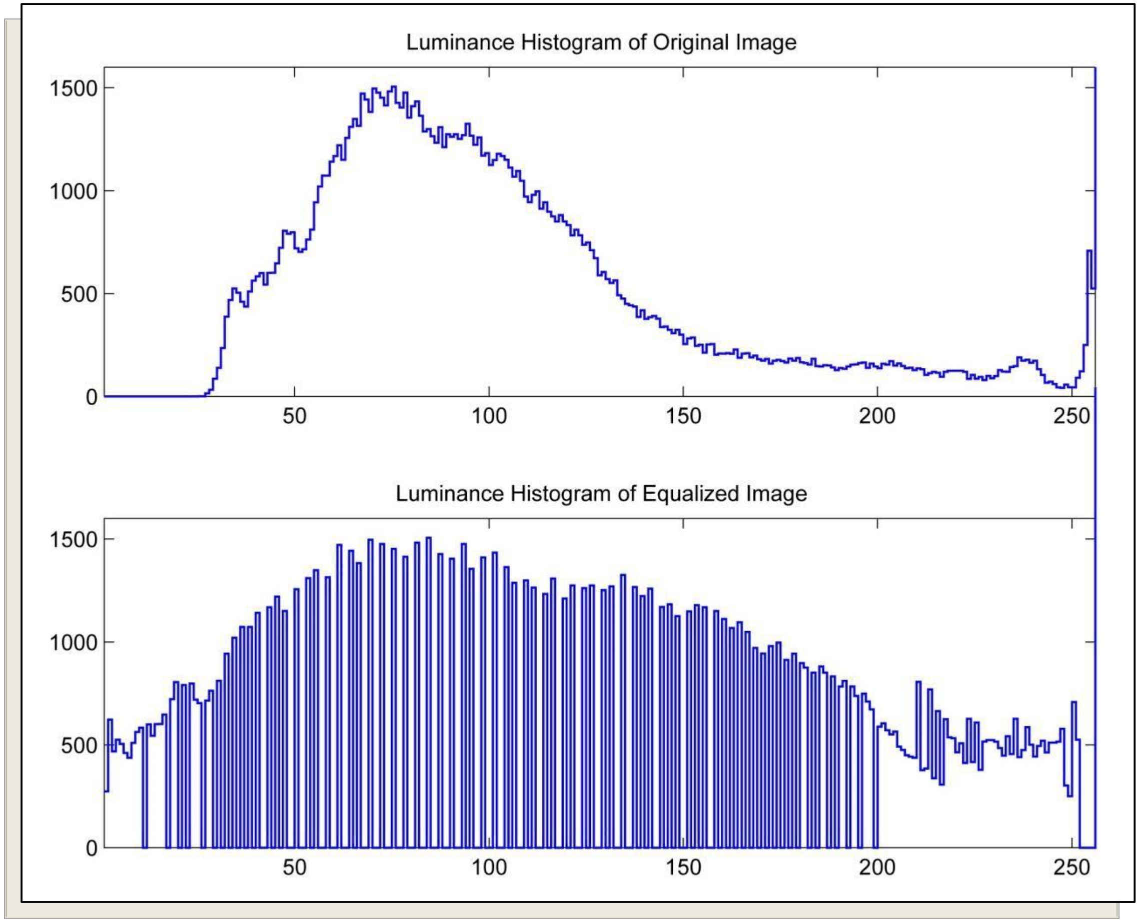




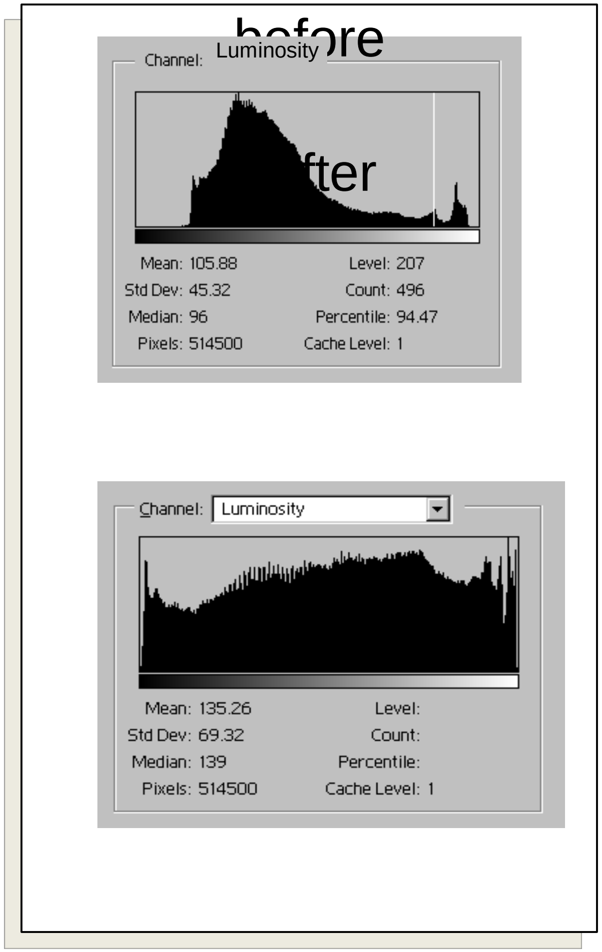
Resulting image uses more of dynamic range.
Resulting histogram almost, but not completely, flat.

Histogram Equalization



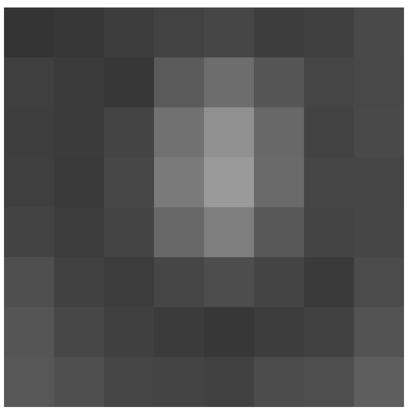


Histogram Equalization



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

Histogram Equalization: Example



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

An 8x8 image

Histogram Equalization: Example

Fill in the following table/histogram

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
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			

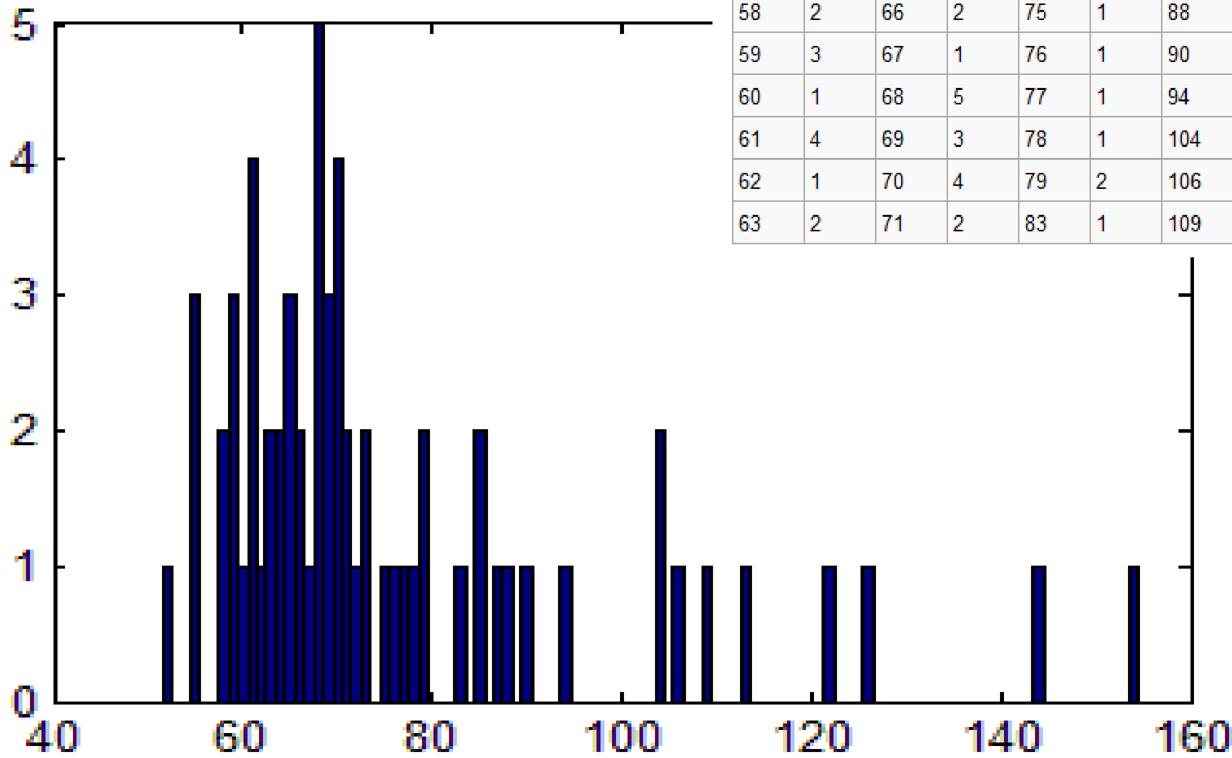
Image Histogram (Non-zero values)

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



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

Cumulative Distribution Function (cdf)

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			

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		

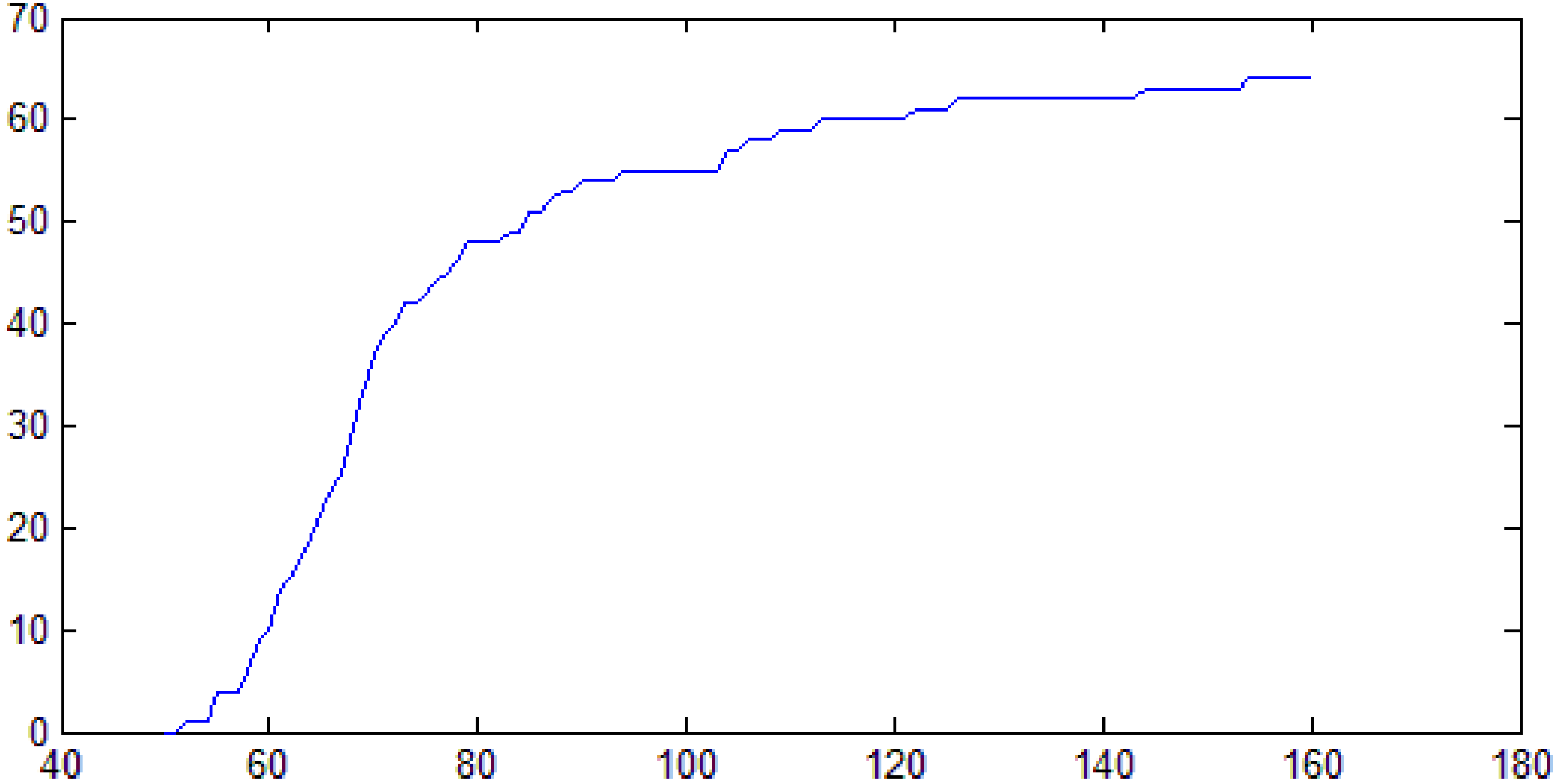
Histogram Equalization: Example

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		

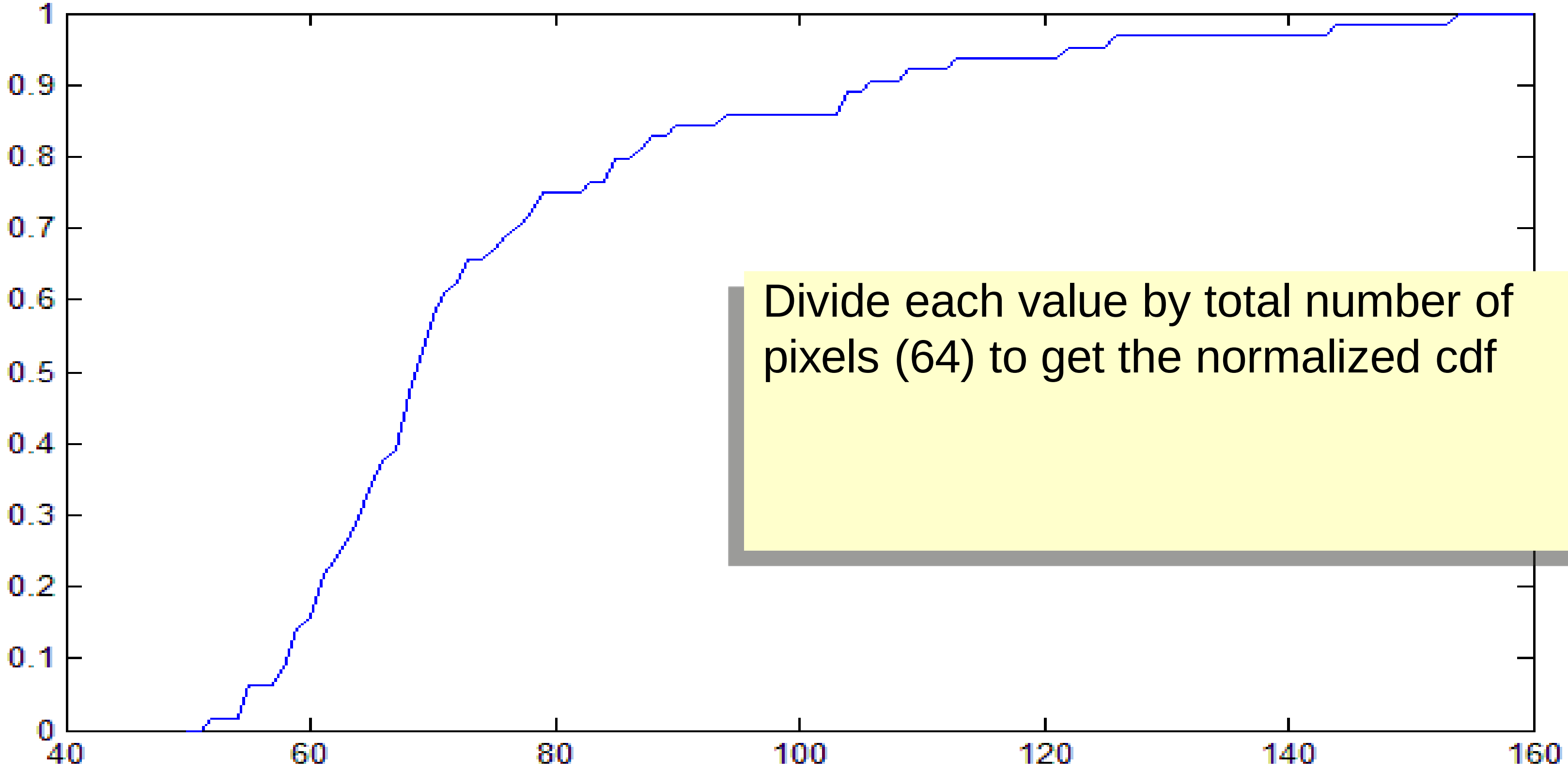
Histogram Equalization: Example

Cumulative Distribution Function (cdf)



Histogram Equalization: Example

Normalized Cumulative Distribution Function (cdf)



Divide each value by total number of pixels (64) to get the normalized cdf

Histogram Equalization: Example

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		

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

If cdf is normalized

$$s = round(255.cdf(r))$$

If cdf is NOT normalized

$$s = round(255.\frac{cdf(r)}{M \times N})$$

$$s = round(255.(46/64))$$

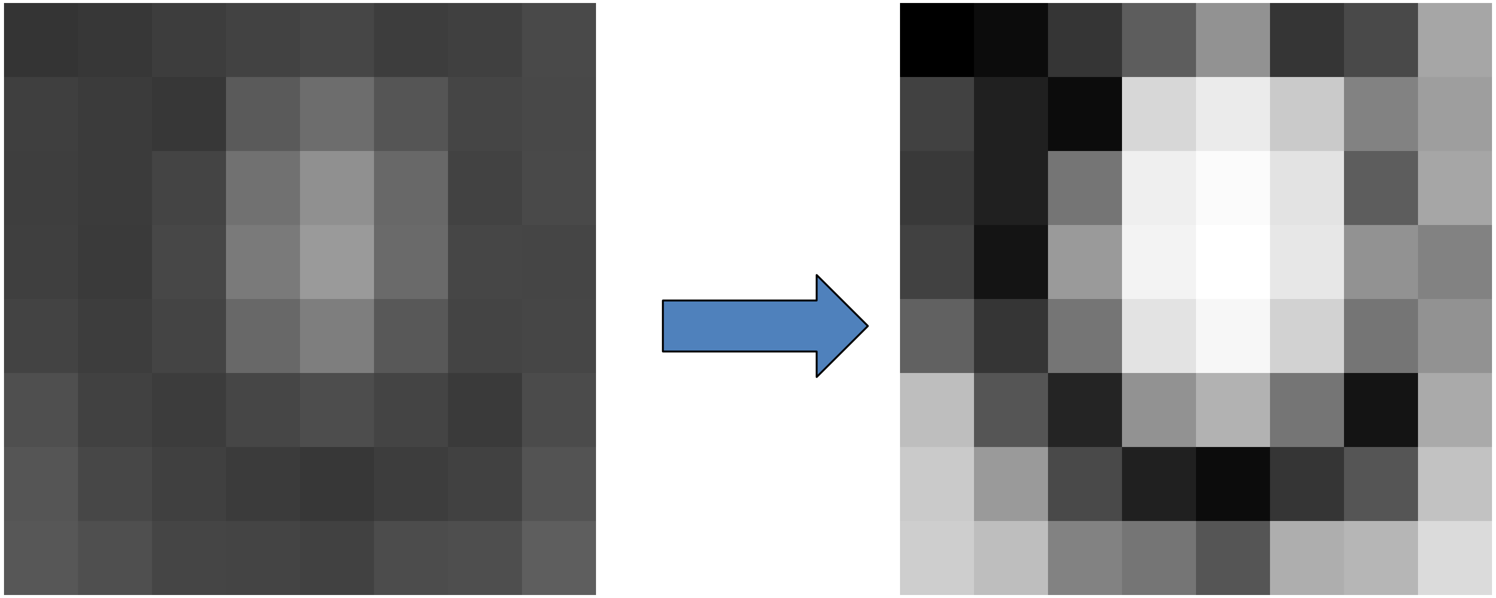
$$s = 183$$

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

Original Image

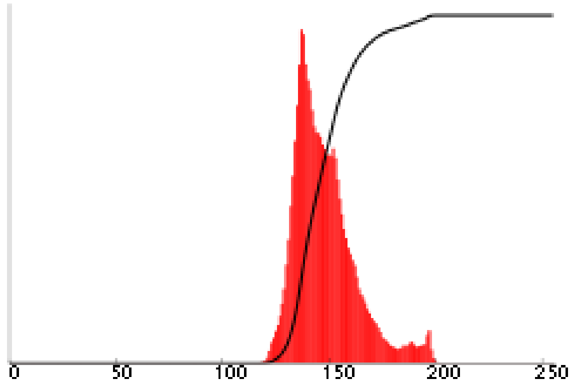
						183	

Histogram Equalization: Example



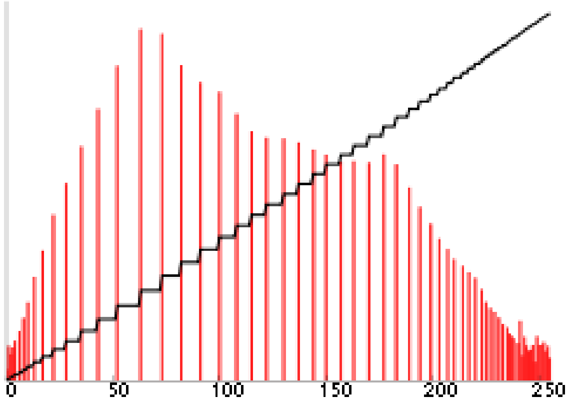
Histogram Equalization: Example

Original Image



Corresponding histogram (red) and cumulative histogram (black)

Image after histogram equalization



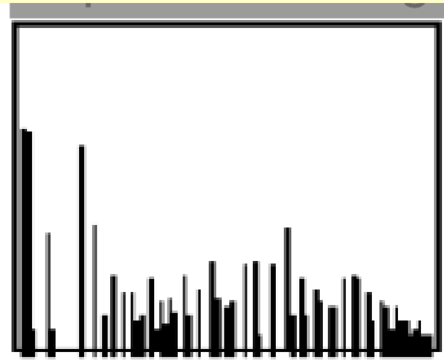
Corresponding histogram (red) and cumulative histogram (black)

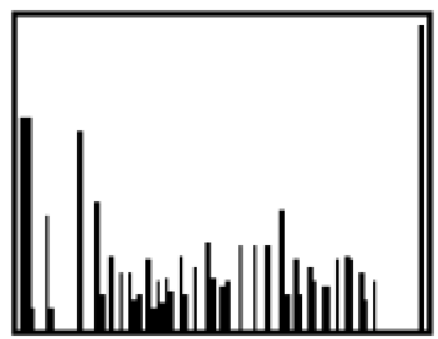
Histogram Equalization: Example

Dark image

Bright image

Equalized Histogram



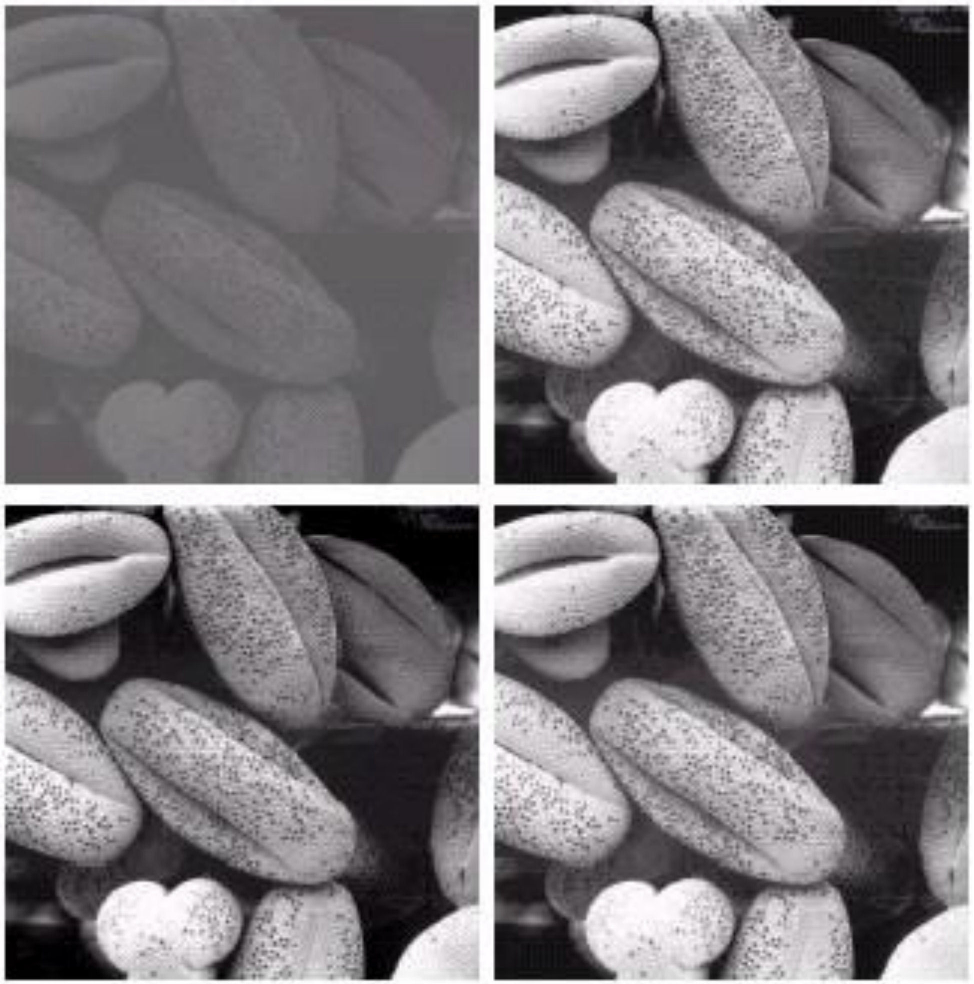


Equalized Histogram

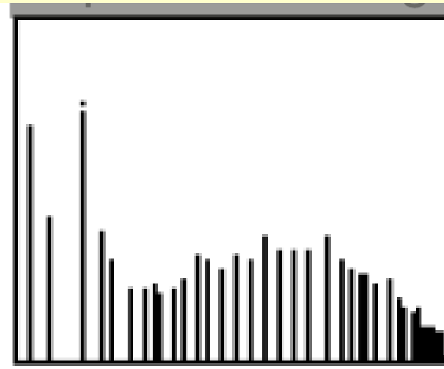
Histogram Equalization: Example

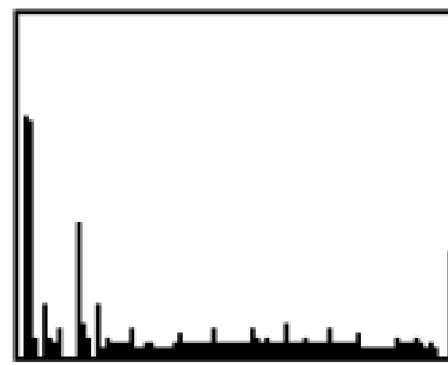
Low contrast

High Contrast



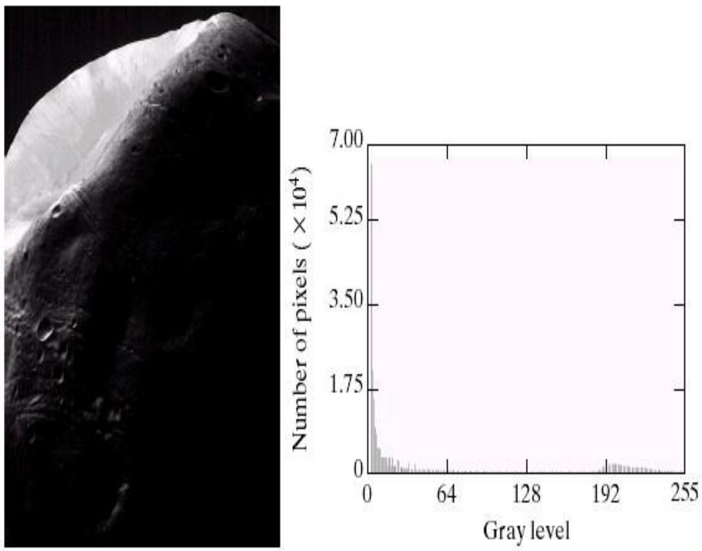
Equalized Histogram





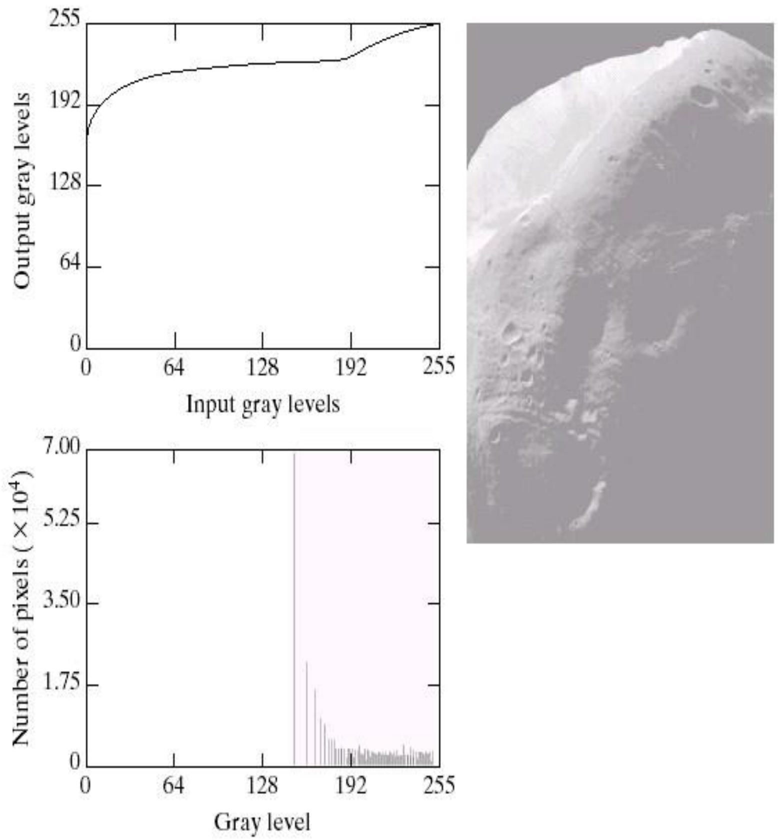
Equalized Histogram

IMAGE ENHANCEMENT IN THE SPATIAL DOMAIN



a b

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



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).

Poorly illuminated CCTV image and the result of histogram equalisation.

Common Distance Definitions

D_4 distance
(city-block distance)

4	3	2	3	4
3	2	1	2	3
2	1	0	1	2
3	2	1	2	3
4	3	2	3	4

D_8 distance
(checkboard distance)

2	2	2	2	2
2	1	1	1	2
2	1	0	1	2
2	1	1	1	2
2	2	2	2	2

Euclidean distance
(2-norm)

$$\mathrm{d}(\mathbf{p},\mathbf{q}) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2}.$$

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