BBM413 Fundamentals of Image Processing

Image Enhancement

Contents

- Point processing techniques
  - Negative images
  - Thresholding
  - Logarithmic transformation
  - Power law transforms
  - Grey level slicing
  - Bit plane slicing
- Histogram processing methods:
  - Histogram processing
  - Histogram Equalization
  - Histogram Matching

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A Note About Grey Levels

- When we have spoken about image grey level values we have said they are in the range [0, 255]
  - Where 0 is black and 255 is white
- There is no reason why we have to use this range
  - The range [0,255] stems from display technologies.
- For many of the image processing operations in this lecture grey levels are assumed to be given in the range [0.0, 1.0]

What Is Image Enhancement?

Image enhancement is the process of making images more useful

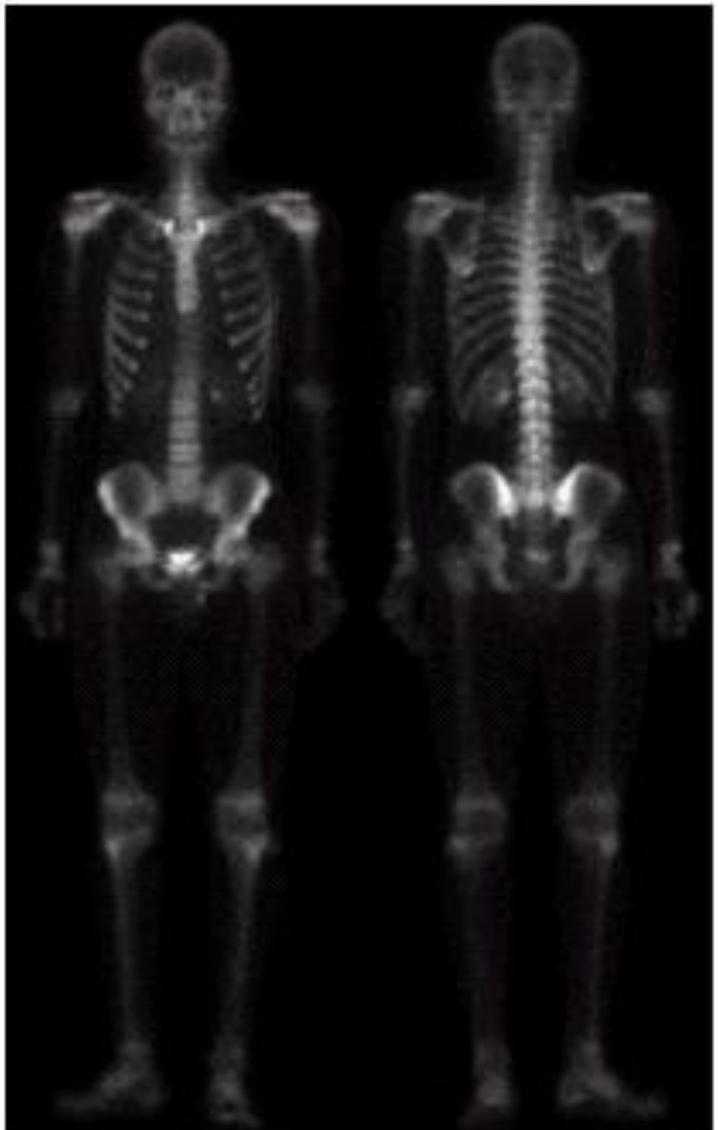
The reasons for doing this include:

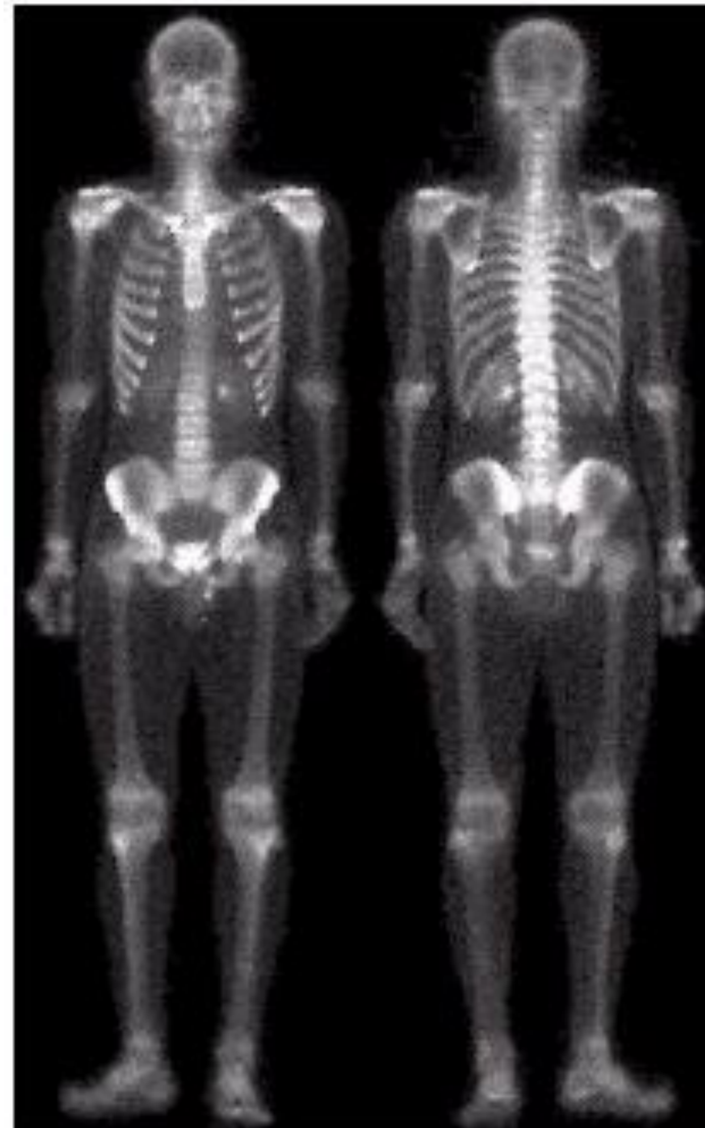
- Highlighting interesting detail in images
- Removing noise from images
- Making images more visually appealing

Image Enhancement Examples

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

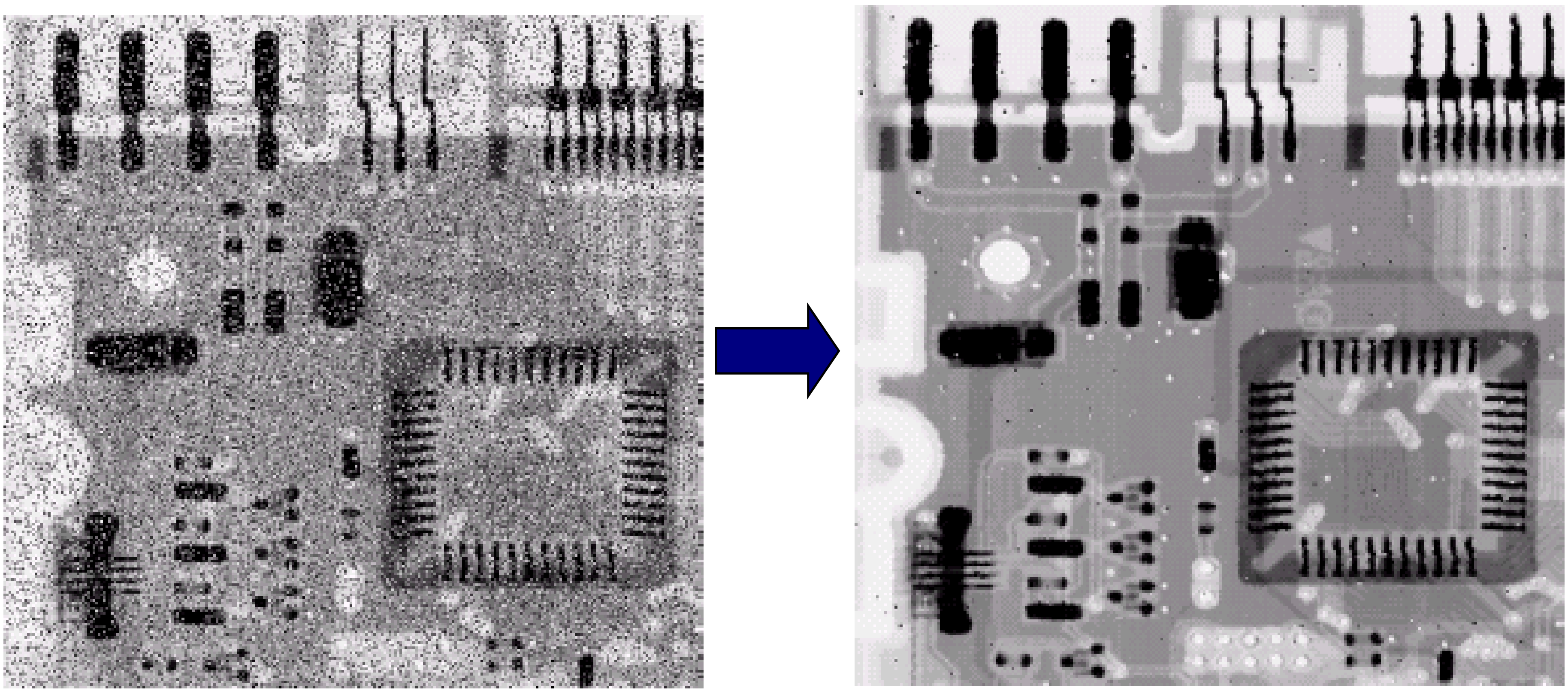
Image Enhancement Examples (cont…)





Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Enhancement Examples (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Image Enhancement Examples (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Spatial & Frequency Domains

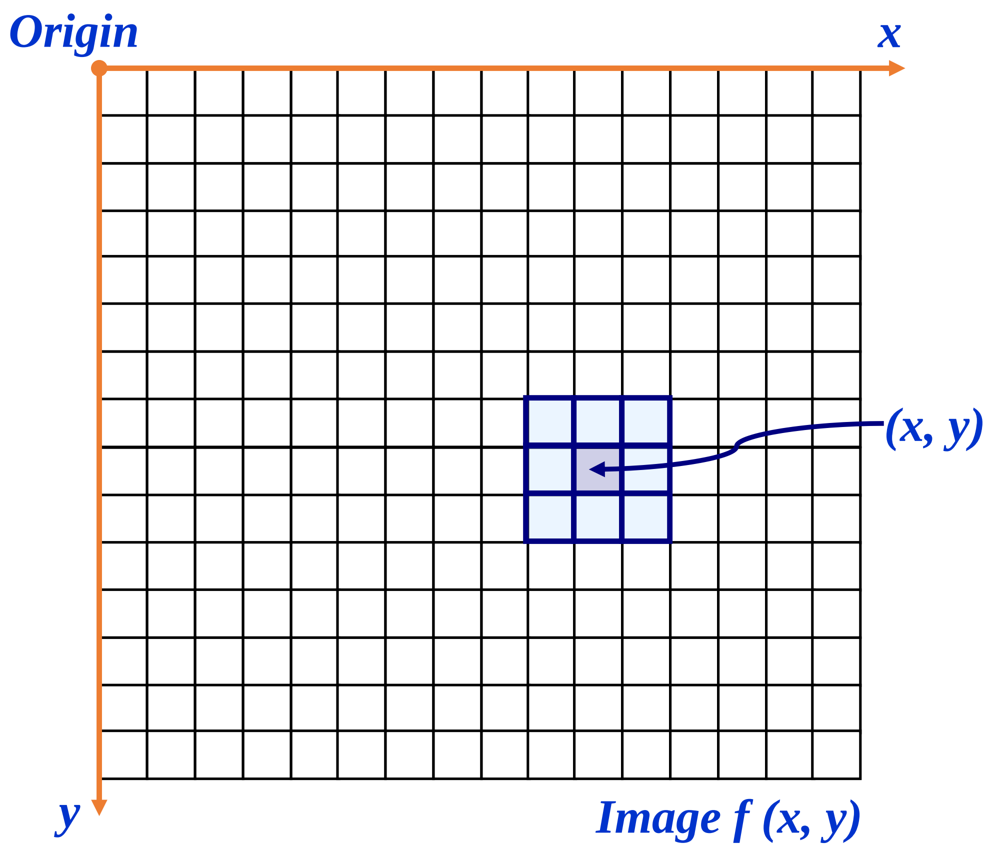
- There are two broad categories of image enhancement techniques
  - Spatial domain techniques
    - Direct manipulation of image pixels
  - Frequency domain techniques
    - Manipulation of Fourier transform or wavelet transform of an image
- For the moment we will concentrate on techniques that operate in the spatial domain

Basic Spatial Domain Image Enhancement

- Most spatial domain enhancement operations can be reduced to the form

$$g\ (x, y) = T[\ f\ (x, y)]$$

- where $f\ (x, y)$ is the input image, $g\ (x, y)$ is the processed image and T is some operator defined over some neighbourhood of (x, y)



Point Processing

•The simplest spatial domain operations occur when the neighbourhood is simply the pixel itself

•In this case T is referred to as a *grey level transformation function* or a *point processing operation*

•Point processing operations take the form

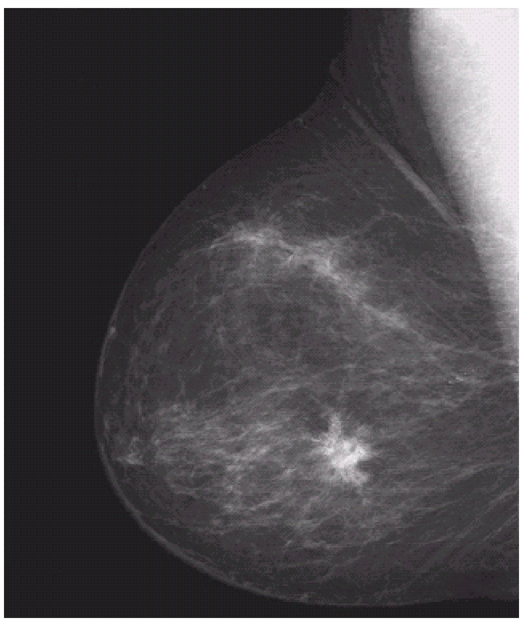
$$s = T(r)$$

•where s refers to the processed image pixel value and r refers to the original image pixel value

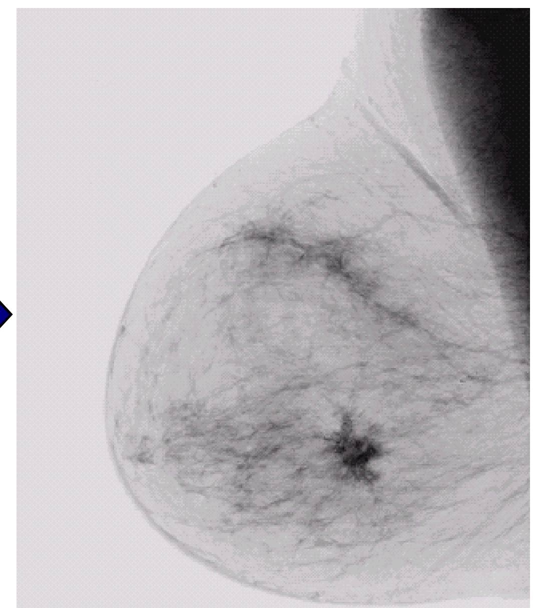
Point Processing Example: Negative Images

- Negative images are useful for enhancing white or grey detail embedded in dark regions of an image
  - Note how much clearer the tissue is in the negative image of the mammogram below

Original Image



$s = 1.0 - r$



Negative Image

$$s = intensity_{max} - r$$

Intensity Transformations

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

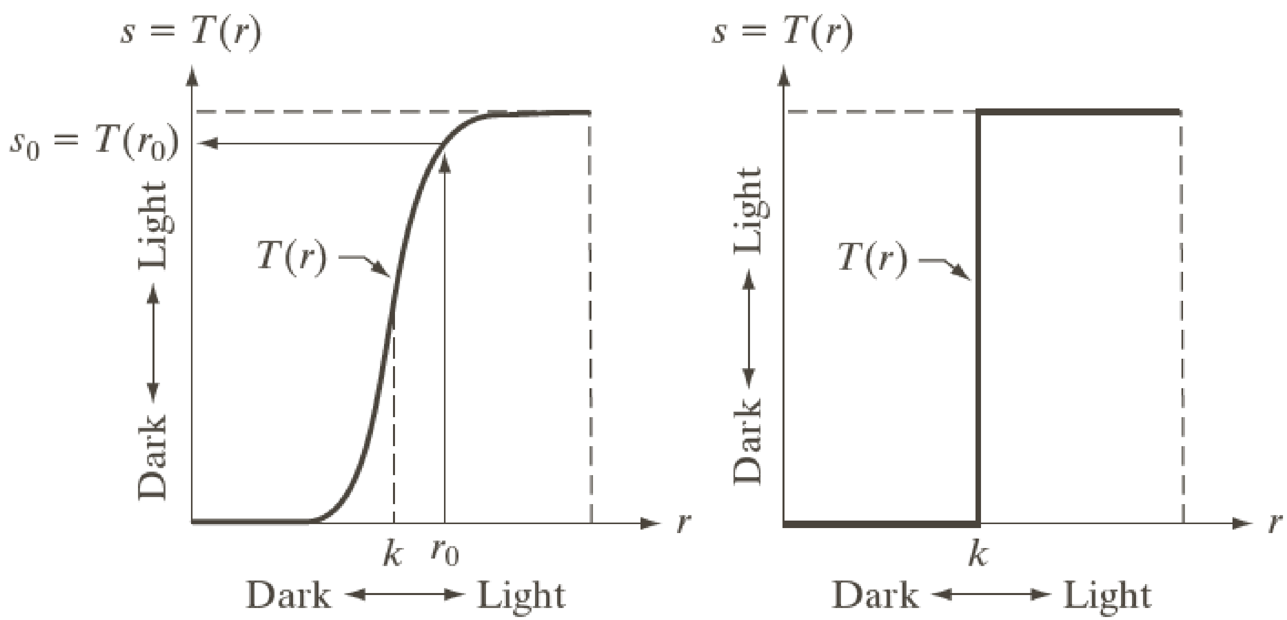


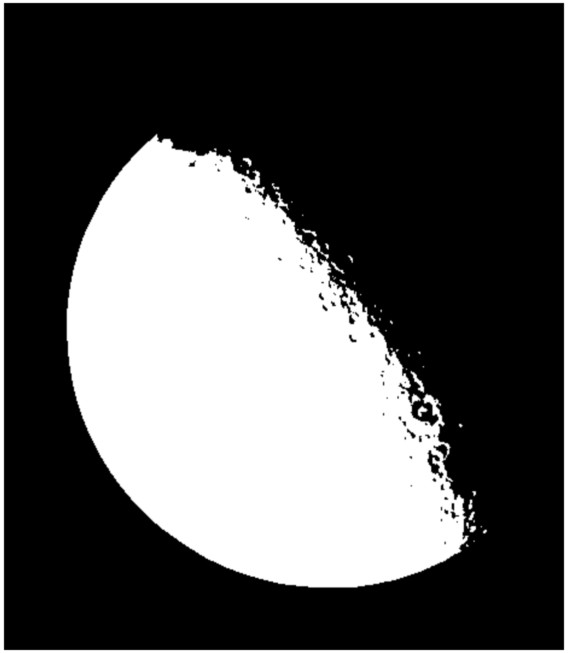
FIGURE 3.2 Intensity transformation functions. (a) Contrast-stretching function. (b) Thresholding function.

Point Processing Example: Thresholding

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- Thresholding transformations are particularly useful for segmentation in which we want to isolate an object of interest from a background

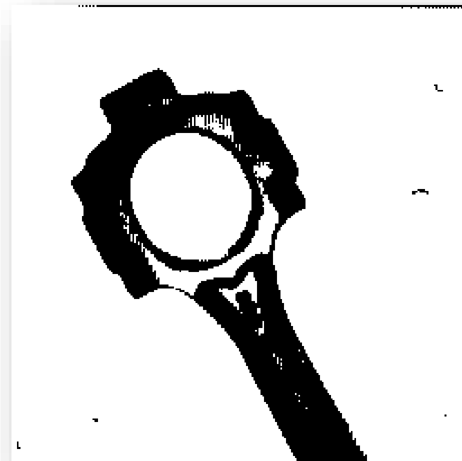
$$s = \begin{cases} 1.0 & r > \text{threshold} \\ 0.0 & r <= \text{threshold} \end{cases}$$

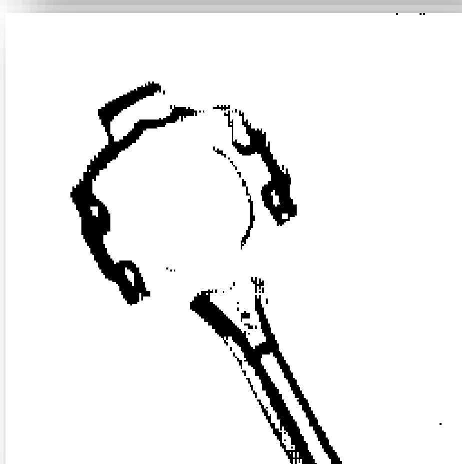


Threshold Selection

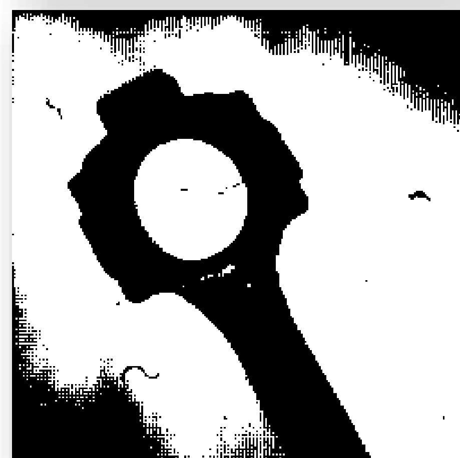
Original Image

Binary Image





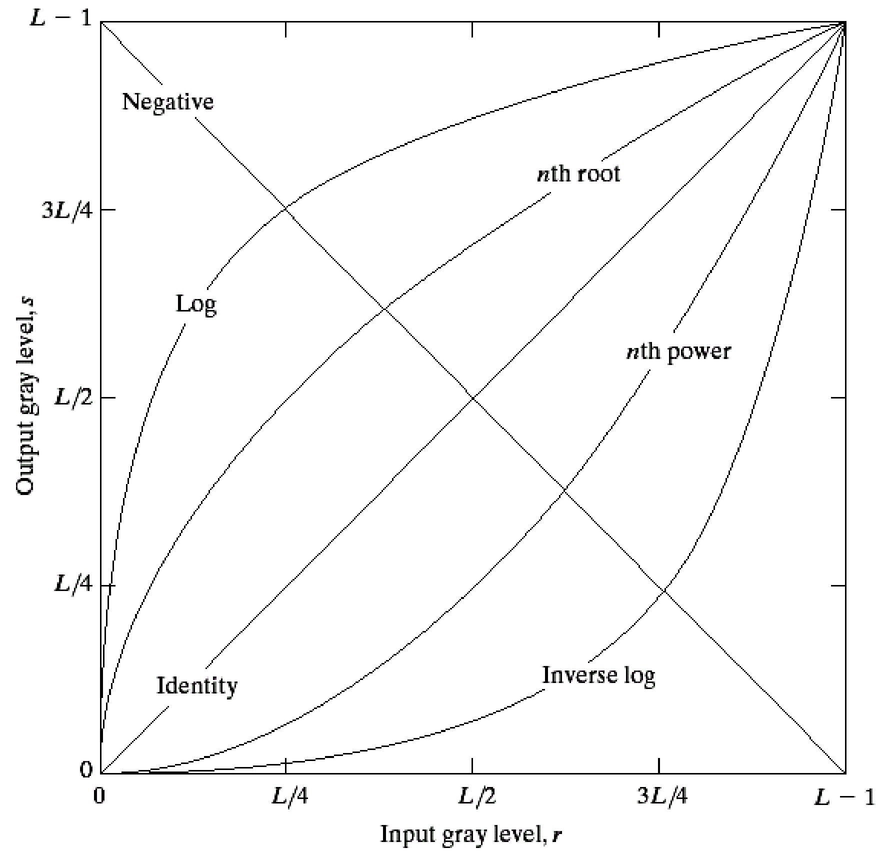
Threshold too low



Threshold too high

Basic Grey Level Transformations

- There are many different kinds of grey level transformations
- Three of the most common are shown here
  - Linear
    - Negative/Identity
  - Logarithmic
    - Log/Inverse log
  - Power law
    - n^{th} power/n^{th} root



Logarithmic Transformations

•The general form of the log transformation is

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

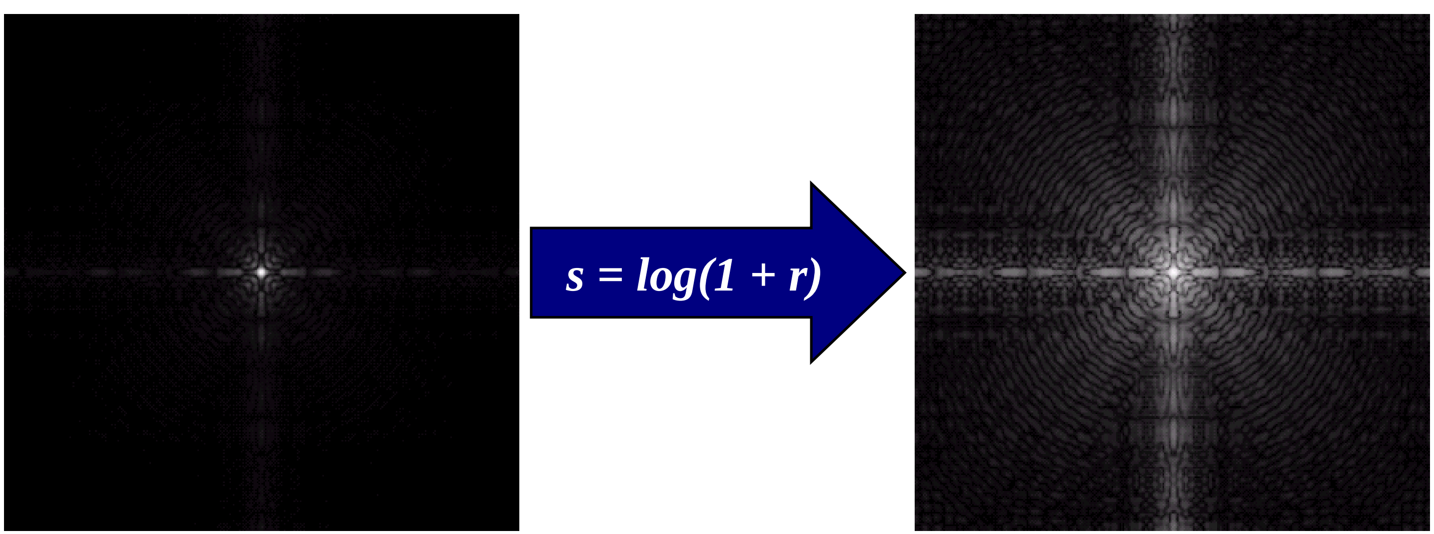
•The log transformation maps a narrow range of low input grey level values into a wider range of output values

•The inverse log transformation performs the opposite transformation

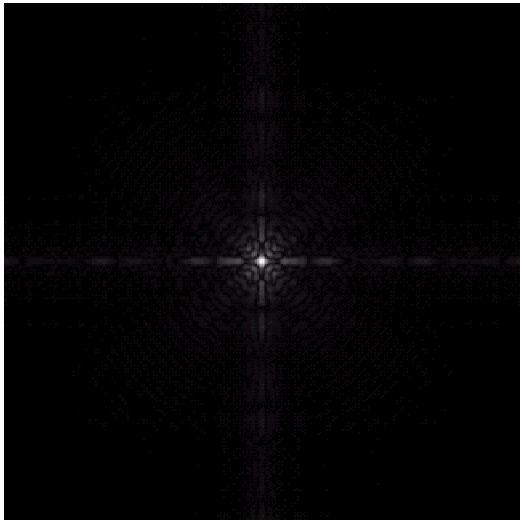
Logarithmic Transformations (cont)

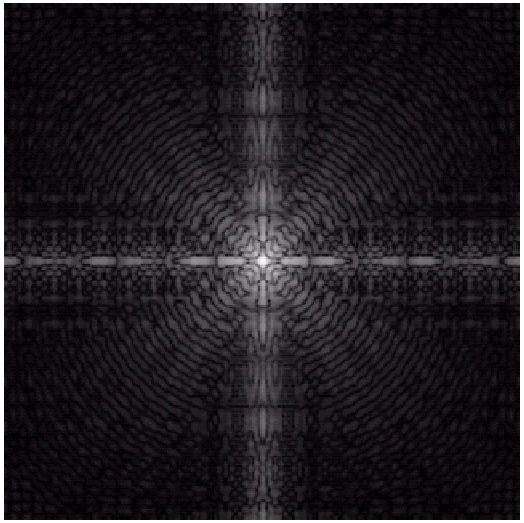
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

- Log functions are particularly useful when the input grey level values may have an extremely large range of values
- In the following example the Fourier transform of an image is put through a log transform to reveal more detail



Logarithmic Transformations (cont…)





$$s = log(1 + r)$$

We usually set c to 1

Grey levels must be in the range [0.0, 1.0]

Power Law (Gamma Correction) Transformations

- Power law transformations have the following form

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

- 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

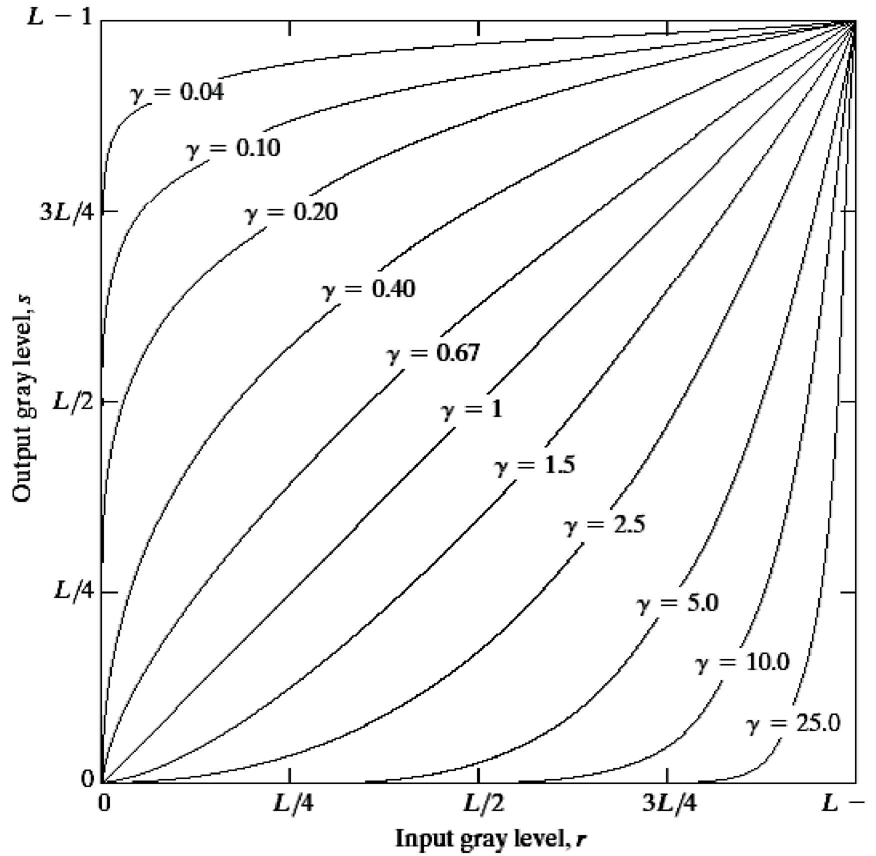
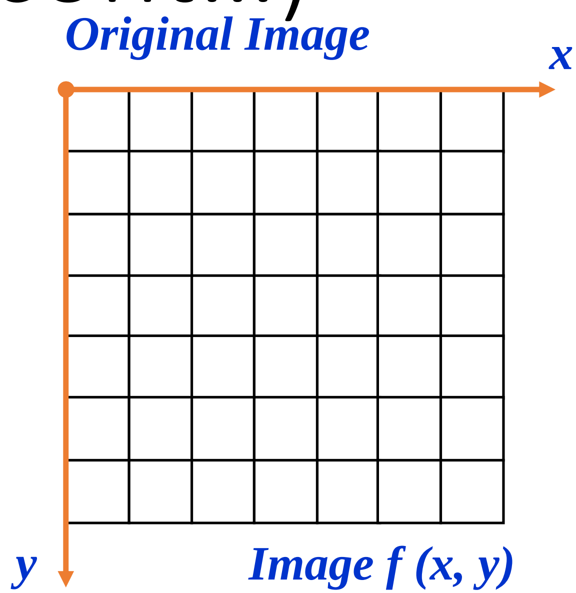
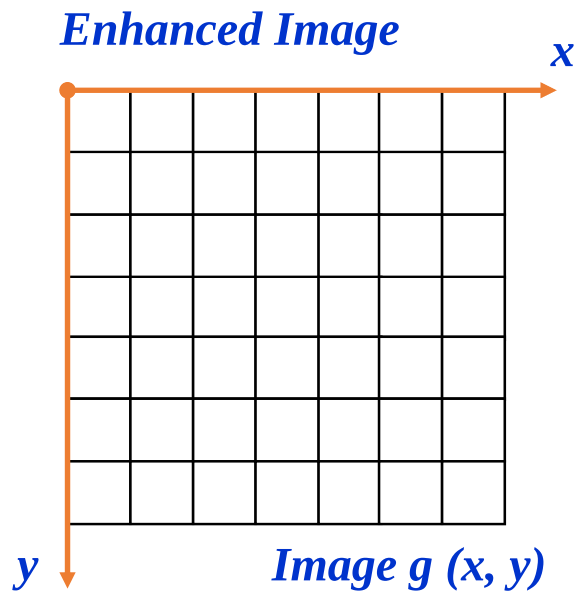


FIGURE 3.6 Plots of the equation $s = cr^{\gamma}$ for various values of γ ($c = 1$ in all cases). All curves were scaled to fit in the range shown.

Power Law Transformations (cont…)





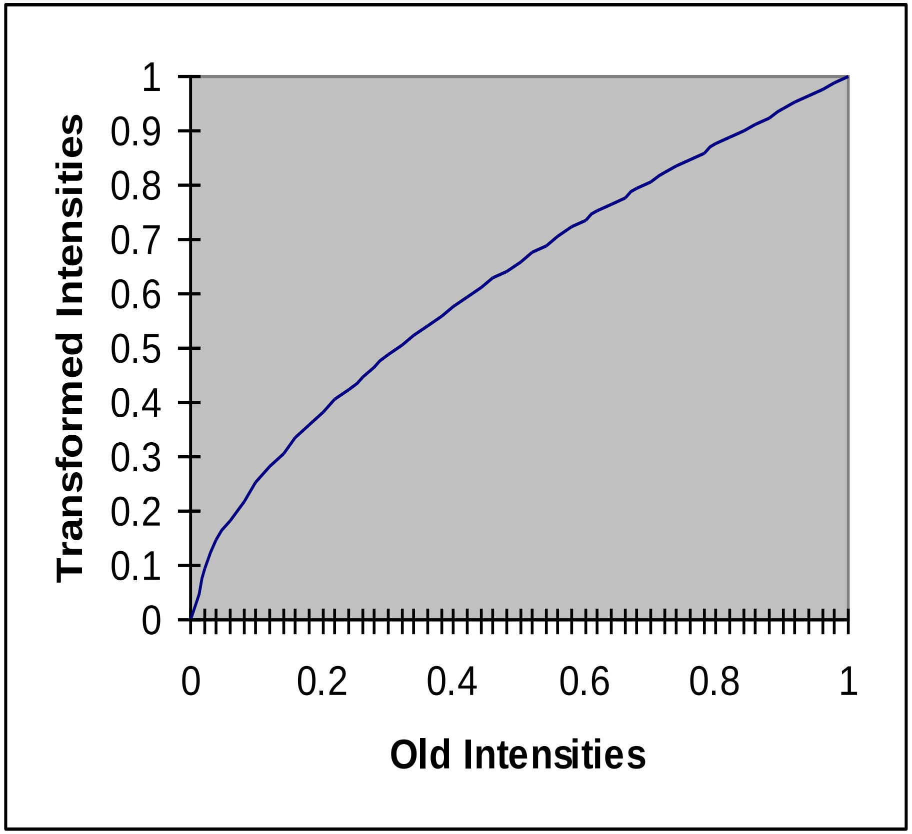
$$s = r^{\gamma}$$

- We usually set C to 1
- Grey levels must be in the range [0.0, 1.0]

Power Law Example

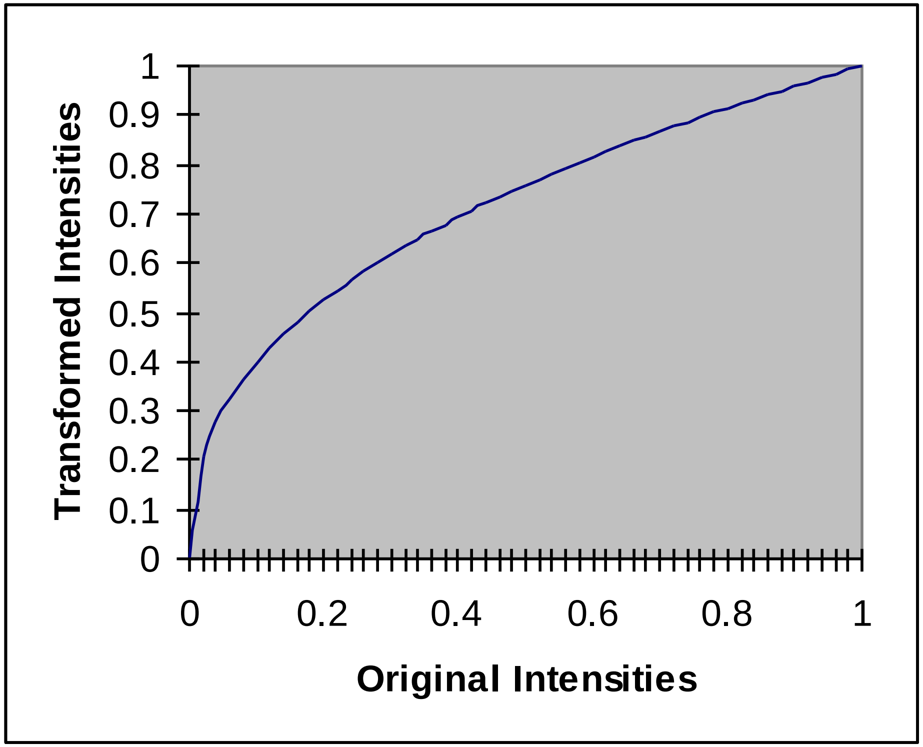
Power Law Example (cont…)

$\gamma = 0.6$



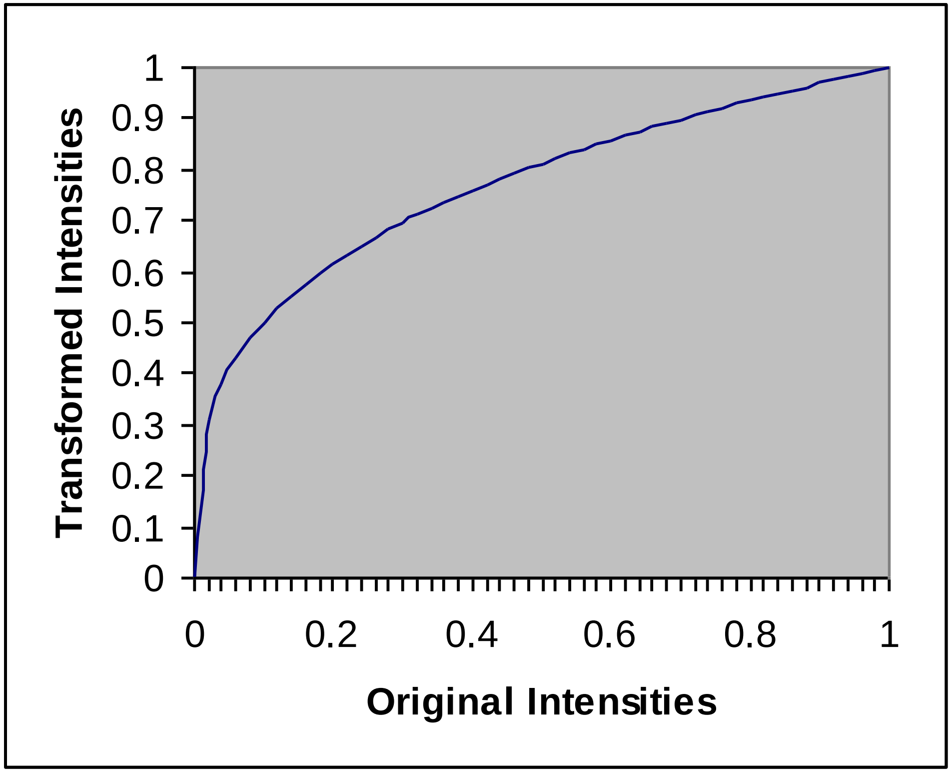
Power Law Example (cont…)

$\gamma = 0.4$



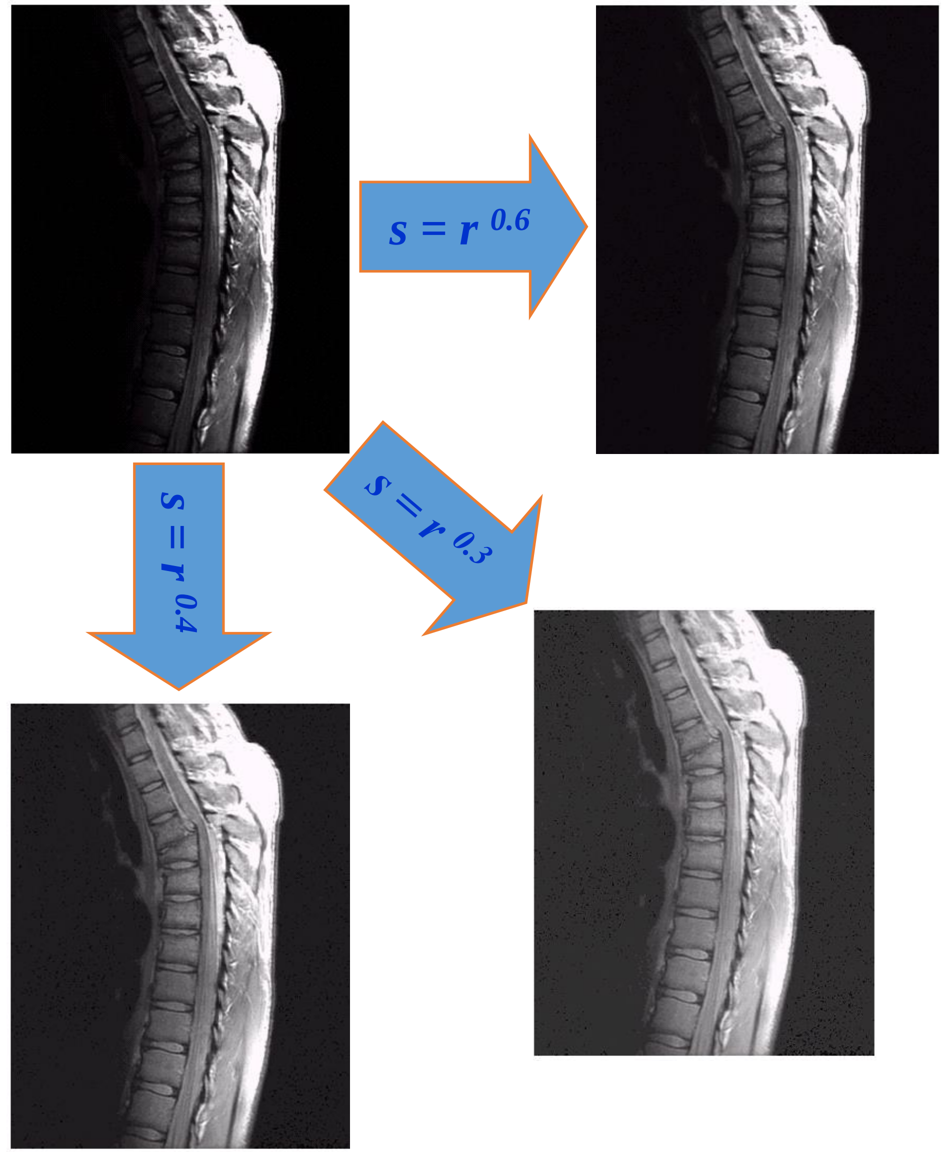
Power Law Example (cont…)

$\gamma = 0.3$



Power Law Example (cont…)

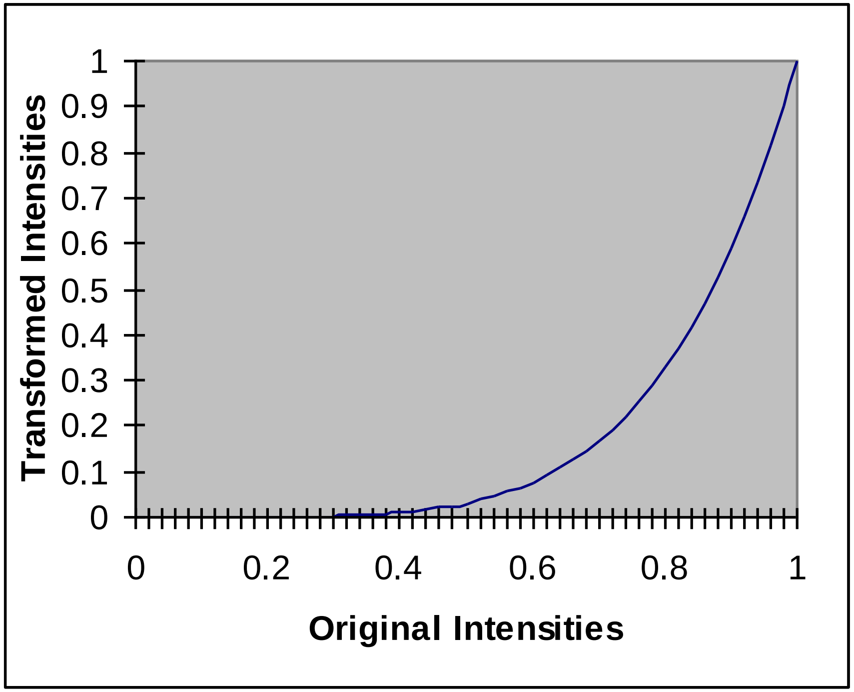
- The images to the right show a magnetic resonance (MR) image of a fractured human spine
- Different curves highlight different detail



Power Law Example

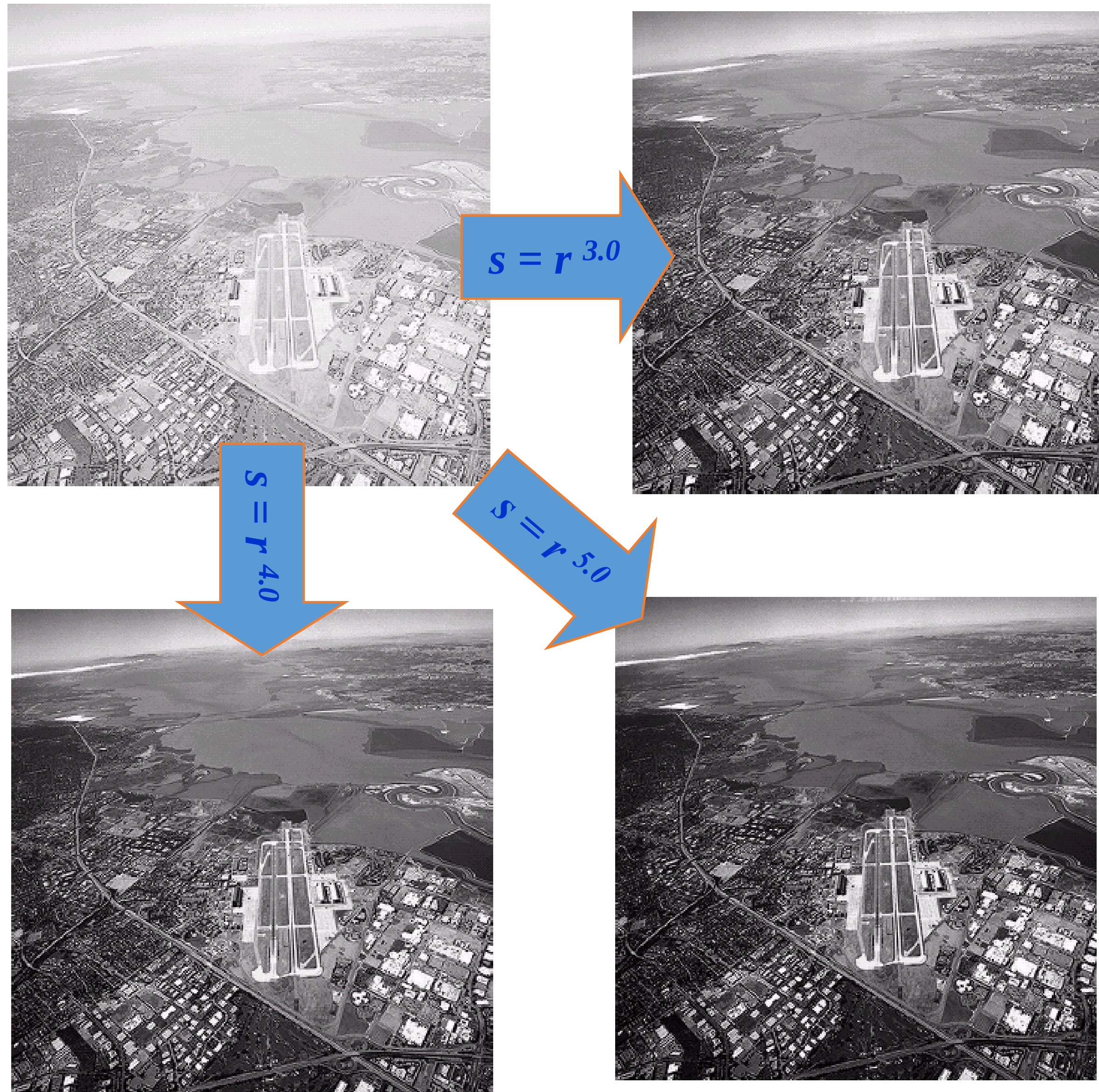
Power Law Example (cont…)

$\gamma = 5.0$



Power Law Transformations (cont…)

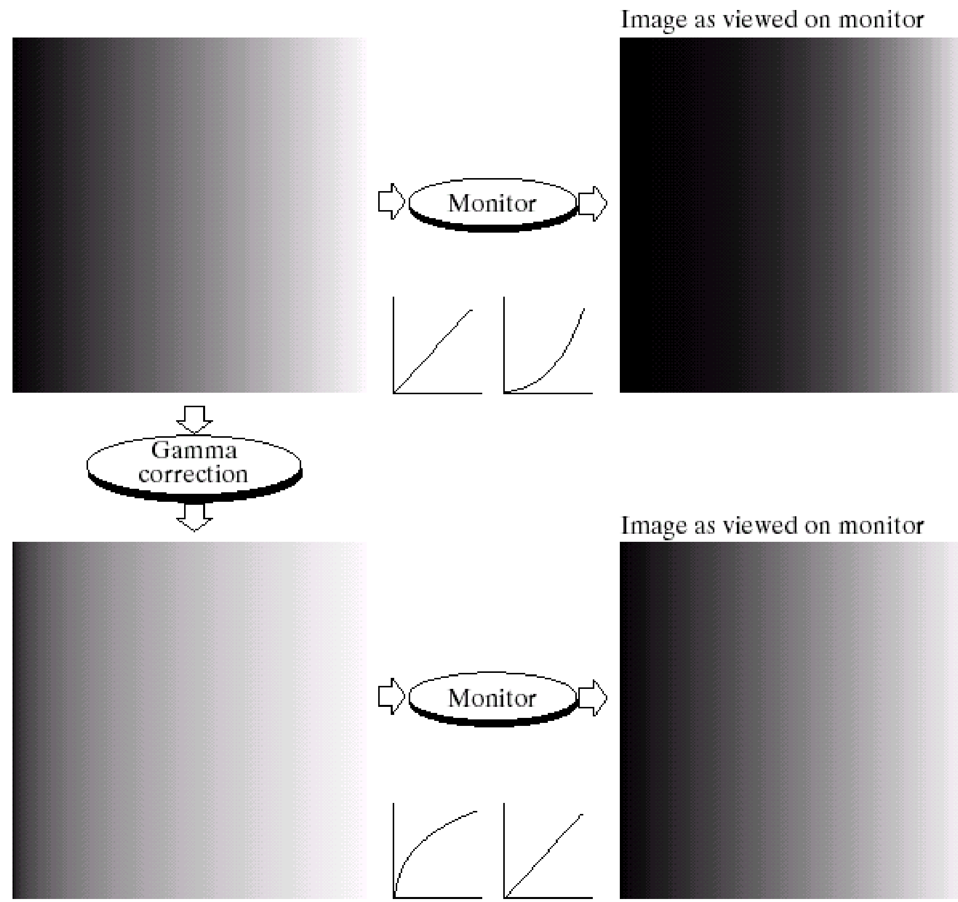
- An aerial photo of a runway is shown
- This time power law transforms are used to darken the image
- Different curves highlight different detail



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Gamma Correction

- Many of you might be familiar with gamma correction of computer monitors
- Problem is that display devices do not respond linearly to different intensities

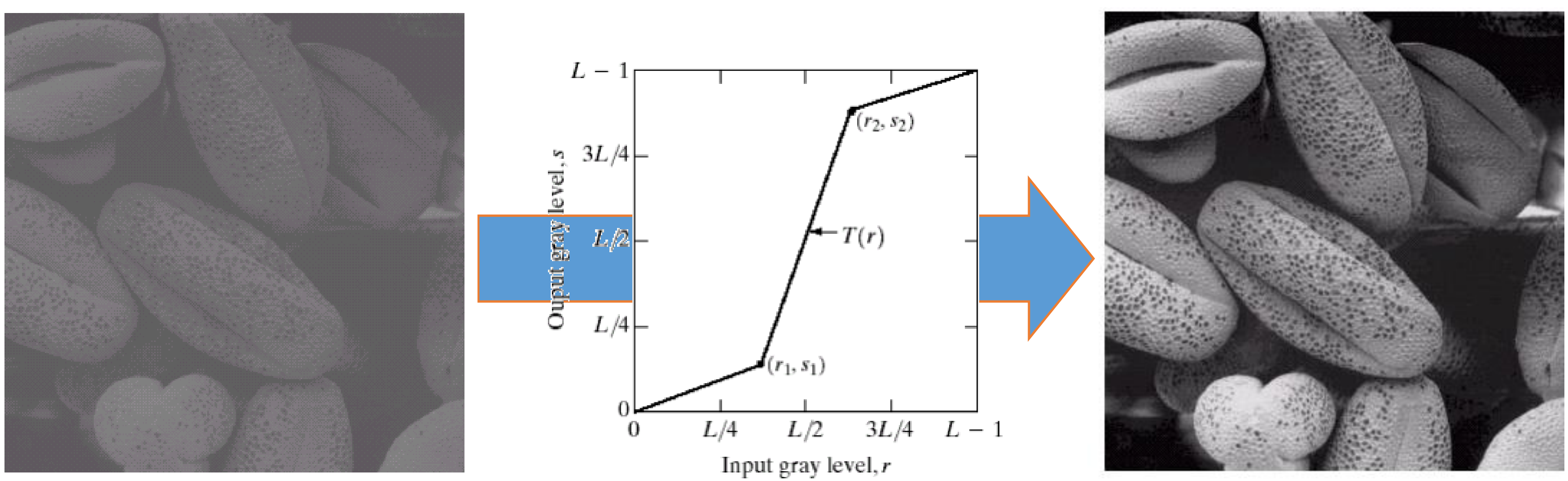


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Piecewise Linear Transformation Functions

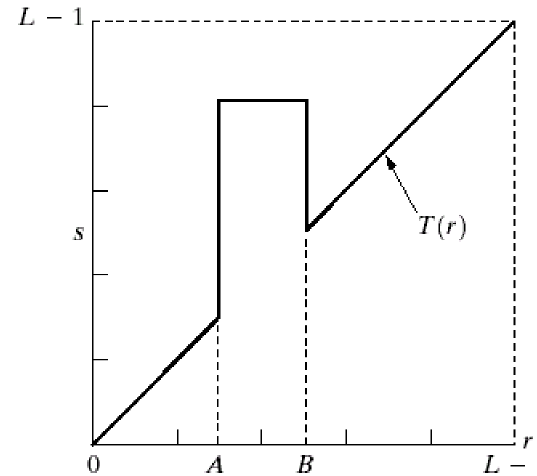
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

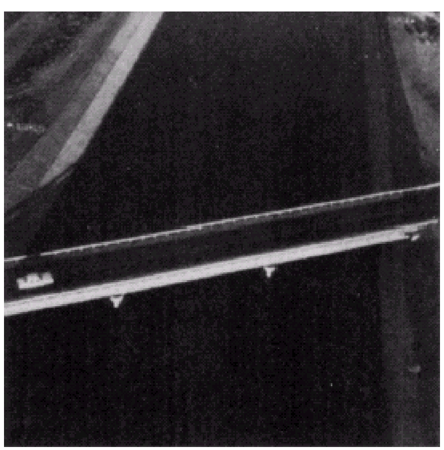
- Rather than using a well defined mathematical function we can use arbitrary user-defined transforms
- The images below show a contrast stretching linear transform to add contrast to a poor quality image

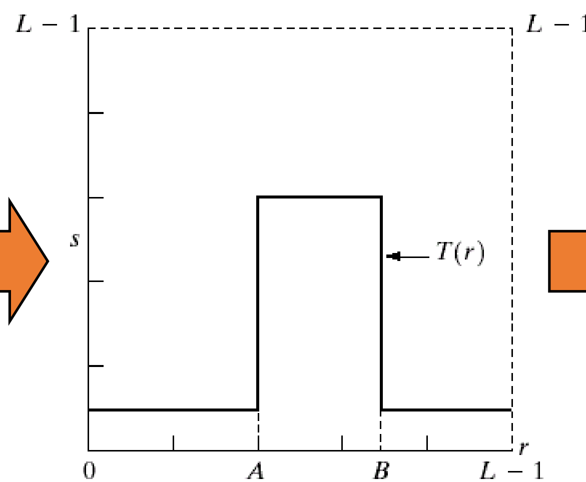


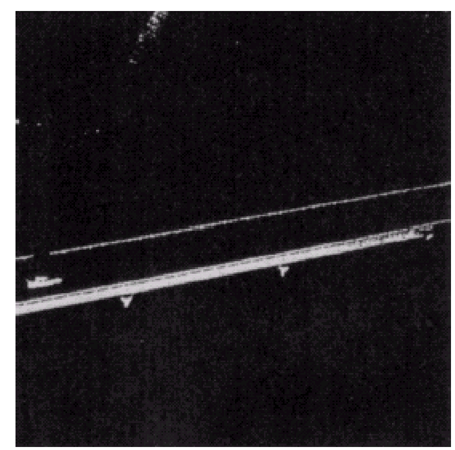
Gray Level Slicing

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







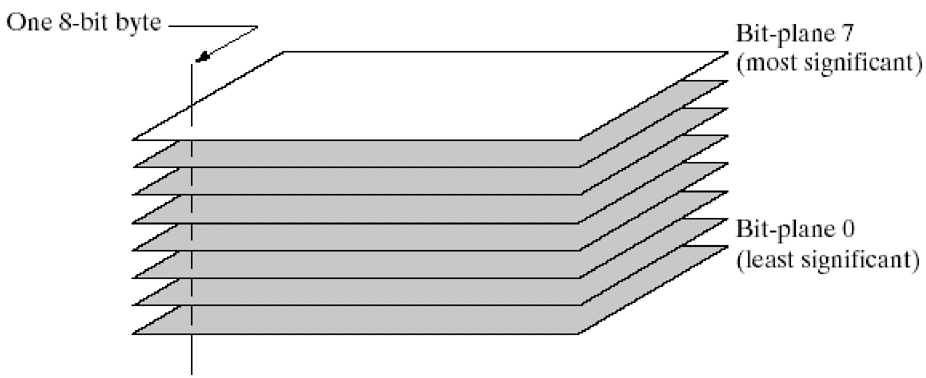


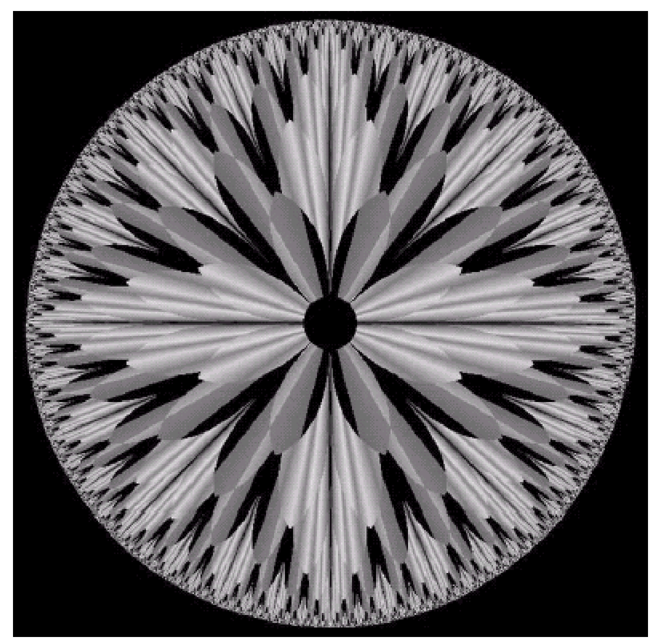
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing

•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





Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont...)

[10000000]

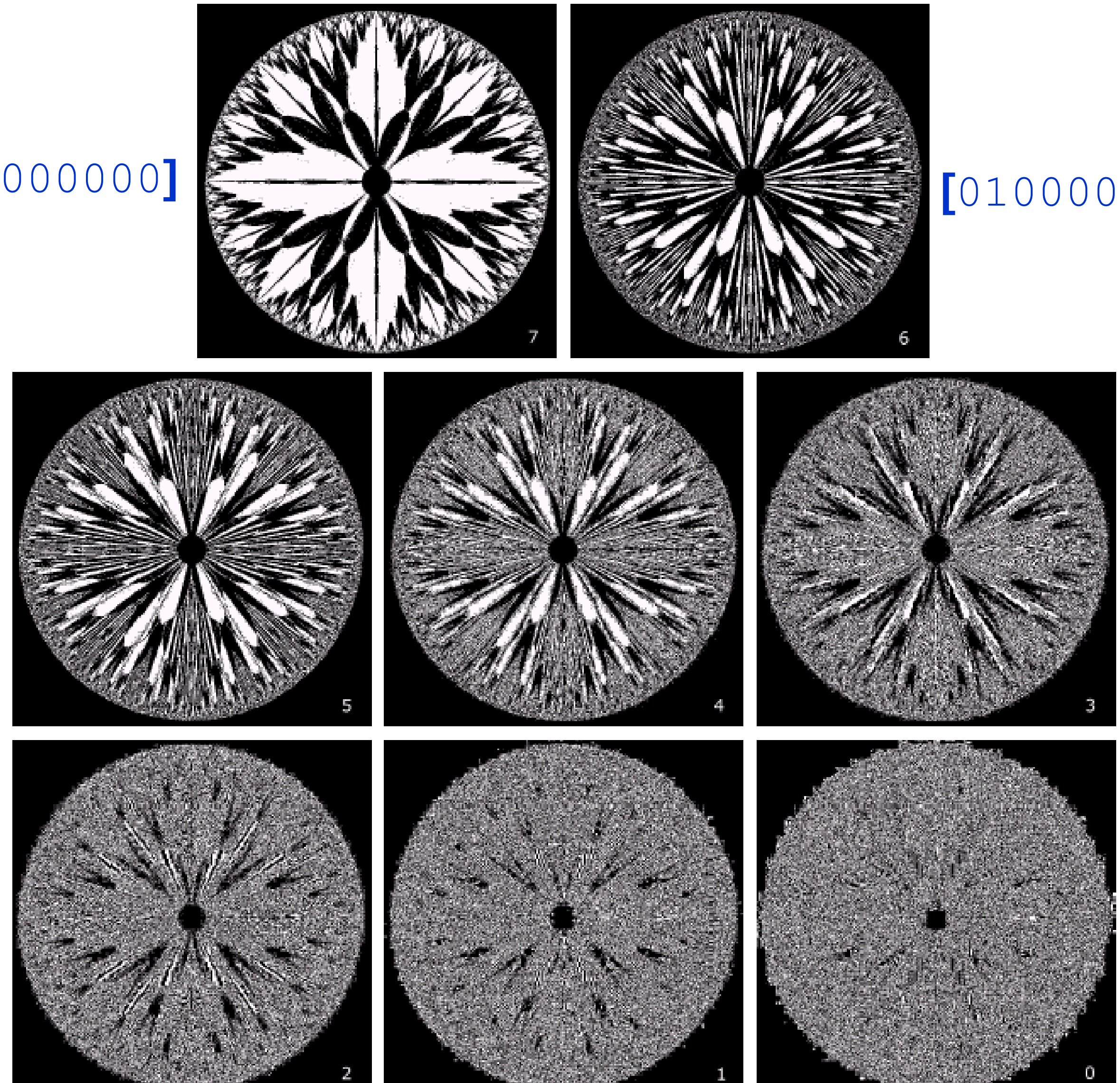
[01000000]

[00100000]

[00001000]

[00000100]

[00000001]



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

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…)

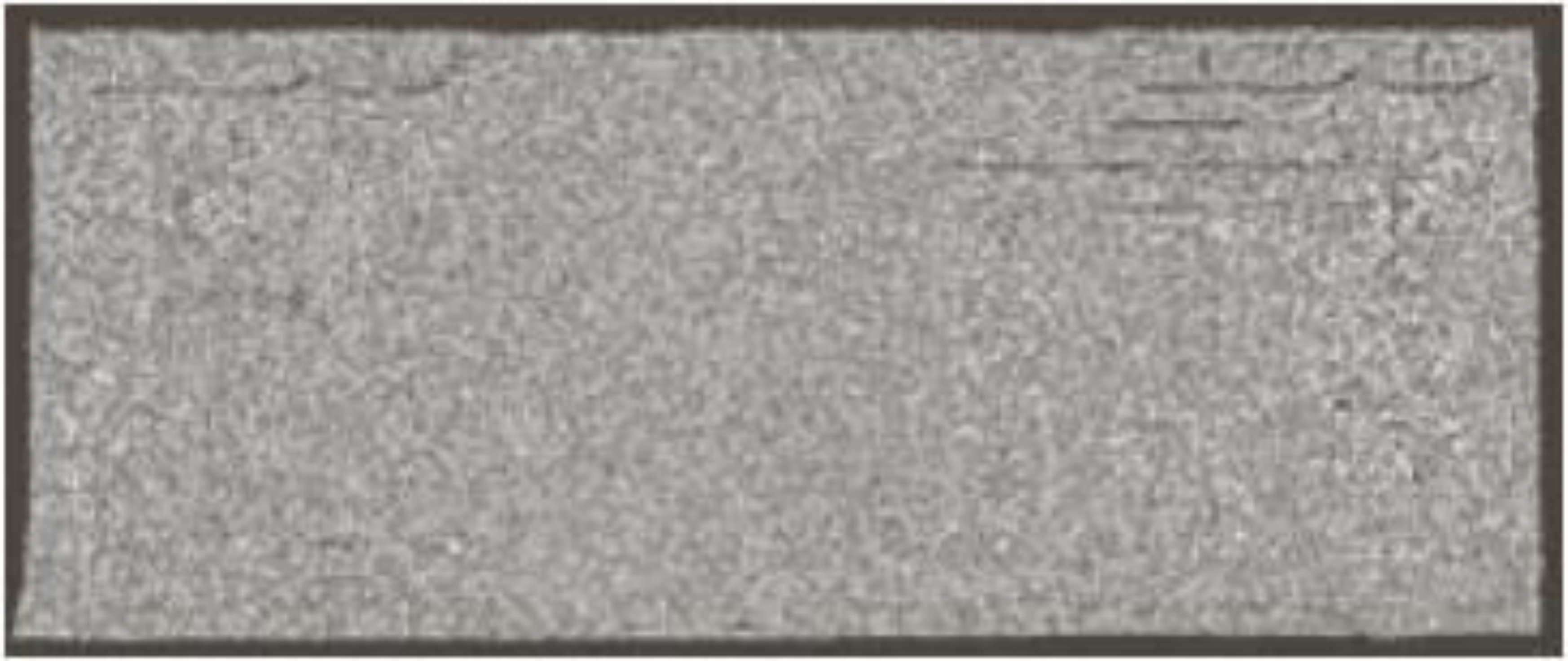
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont…)

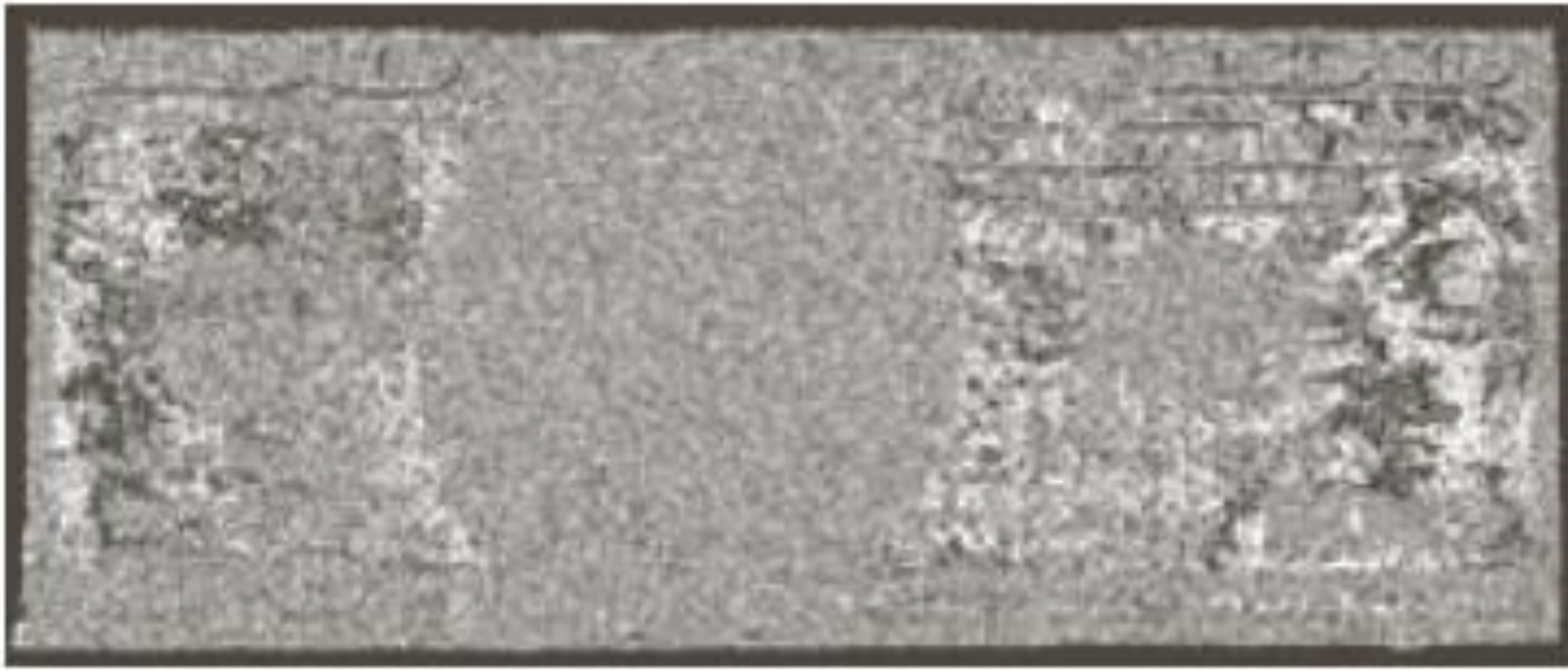
Bit Plane Slicing (cont...)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

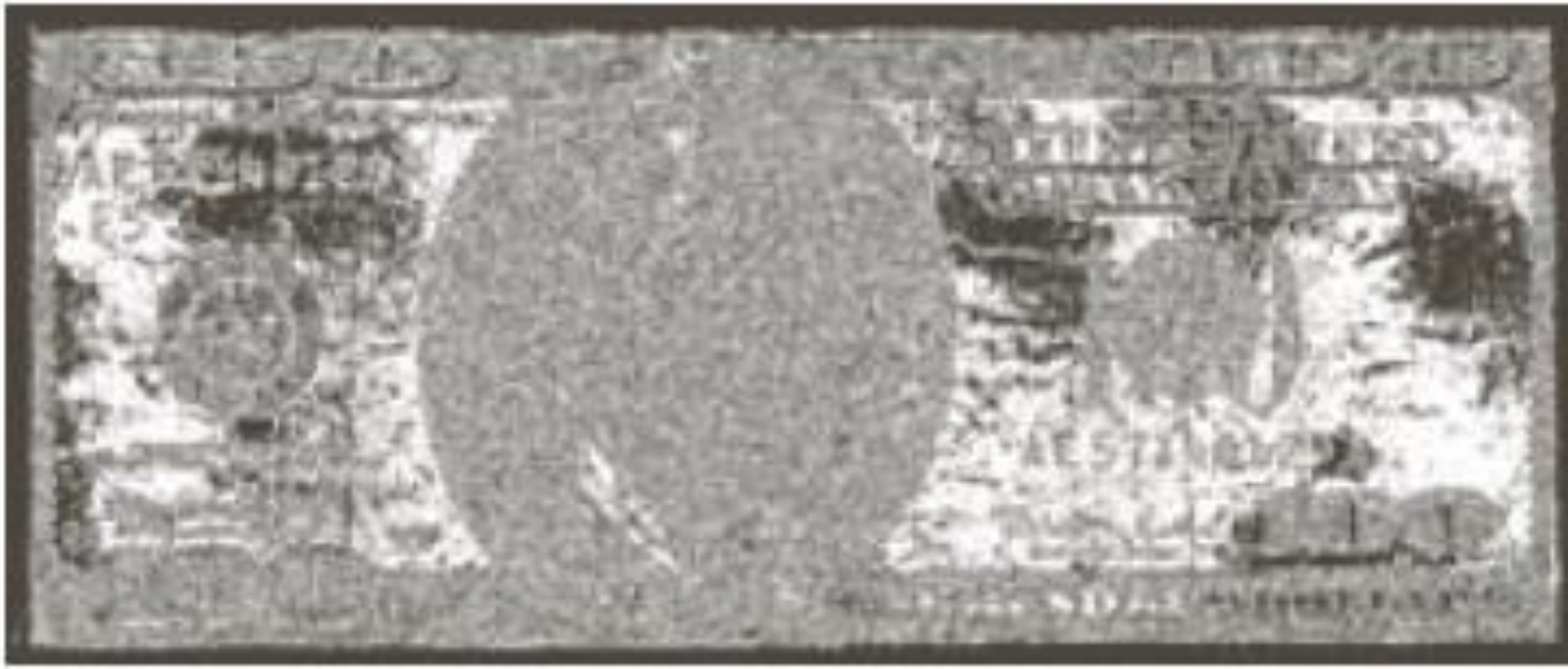
Bit Plane Slicing (cont…)



Bit Plane Slicing (cont…)



Bit Plane Slicing (cont…)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Bit Plane Slicing (cont…)

Reconstructed image using only bit planes 8 and 7

Bit Plane Slicing (cont…)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Reconstructed image using only bit planes 8, 7 and 6

Bit Plane Slicing (cont...)

Reconstructed image using only bit planes 7, 6 and 5

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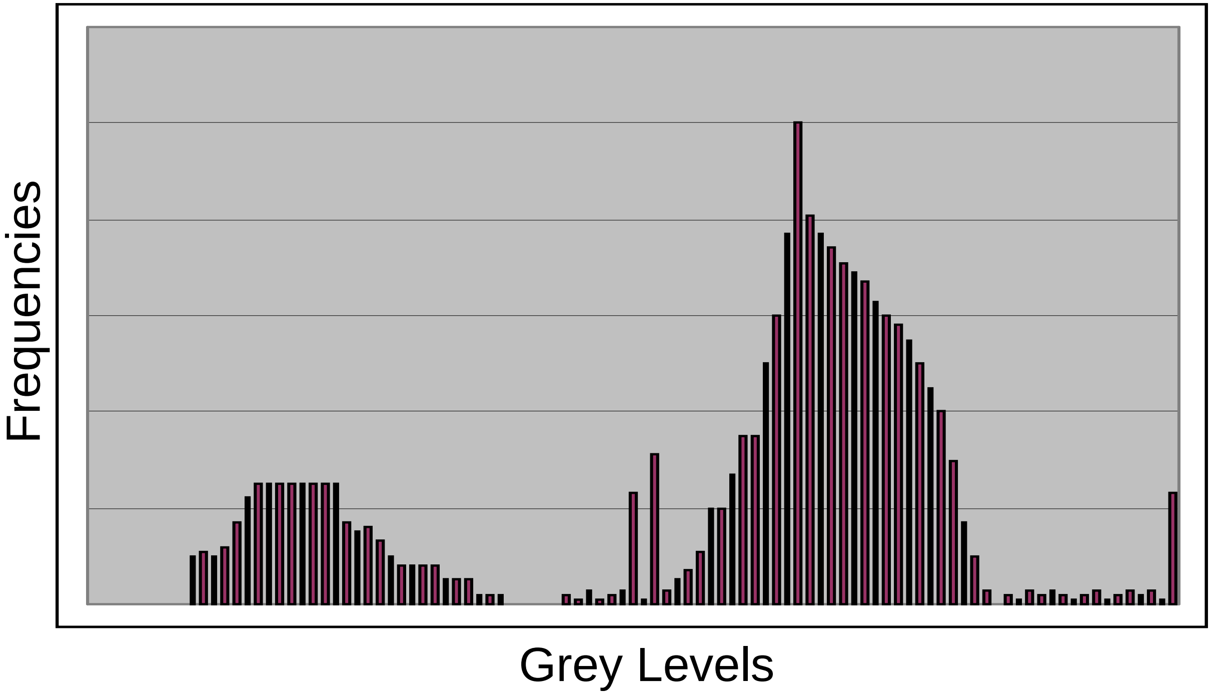
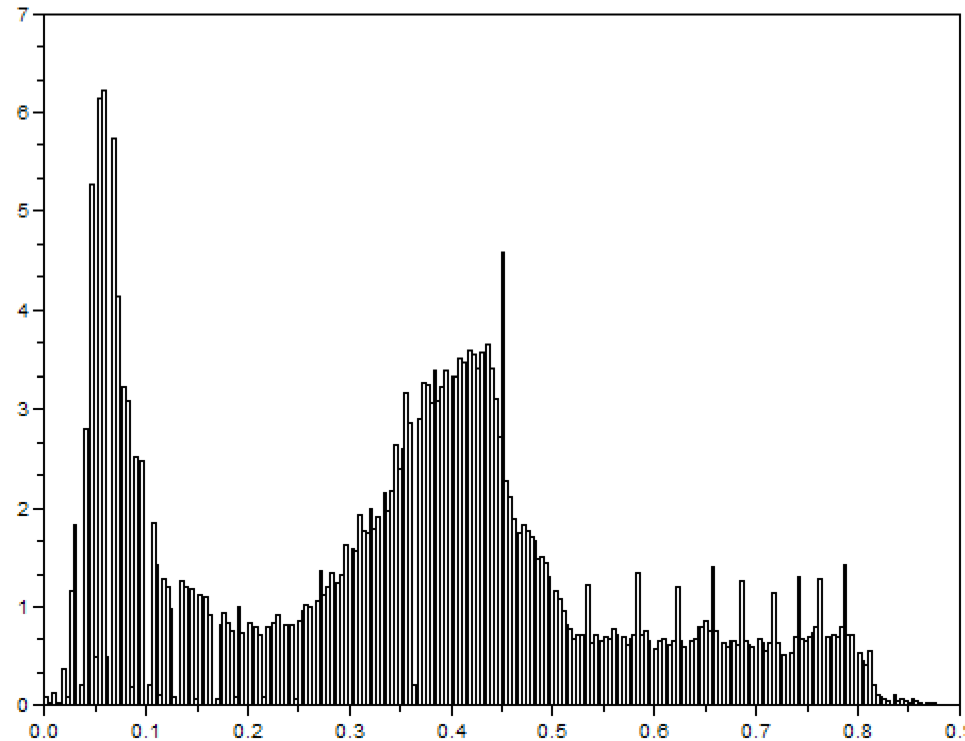
- Image enhancement techniques working in the spatial domain:
  - Histogram processing
  - Histogram Equalization
  - Histogram Matching

Image Histograms

- The histogram of an image shows us the distribution of grey levels in the image
- Massively useful in image processing, especially in segmentation and enhancement

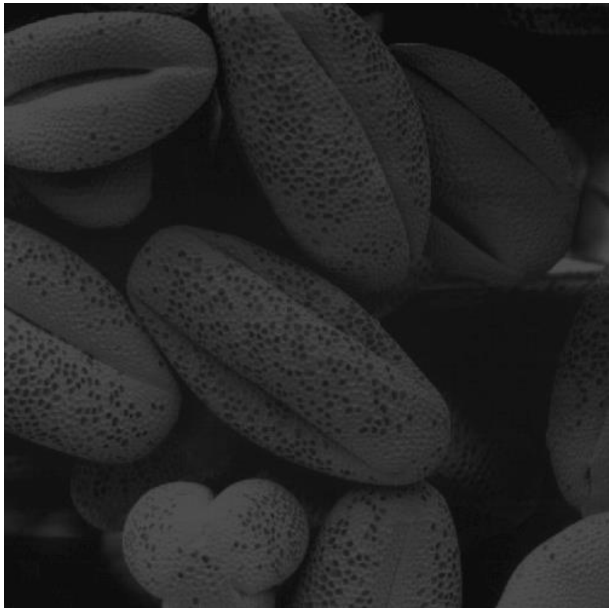


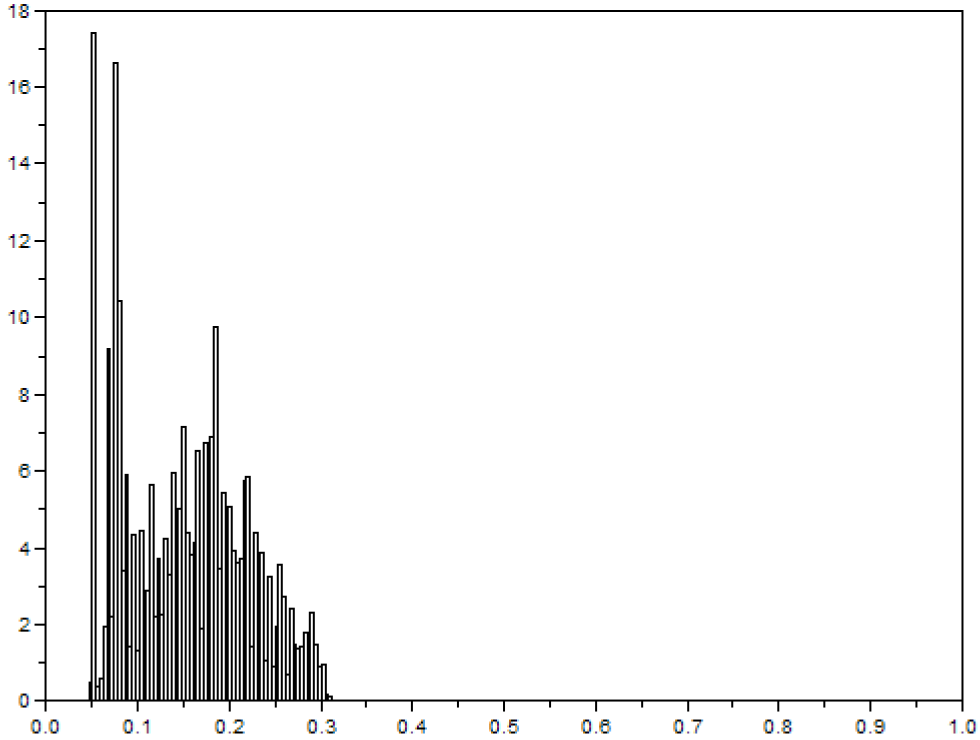
Histogram Examples



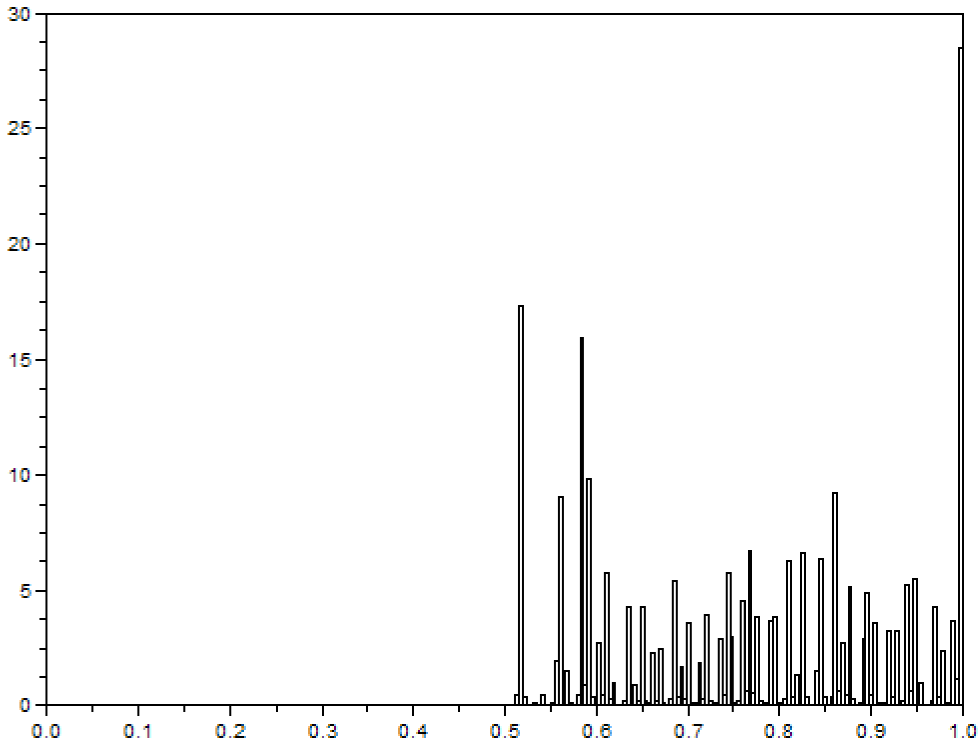
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Examples (cont…)

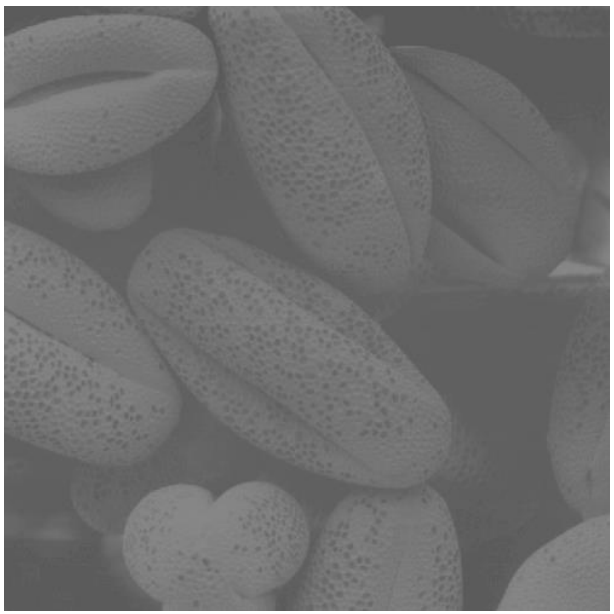


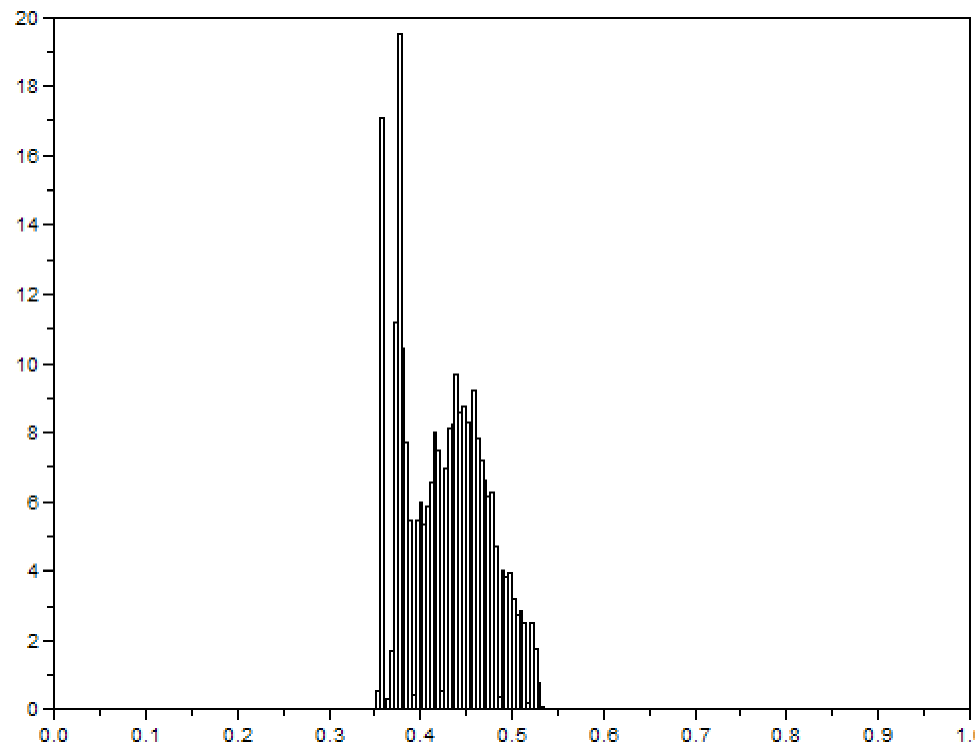


Histogram Examples (cont…)



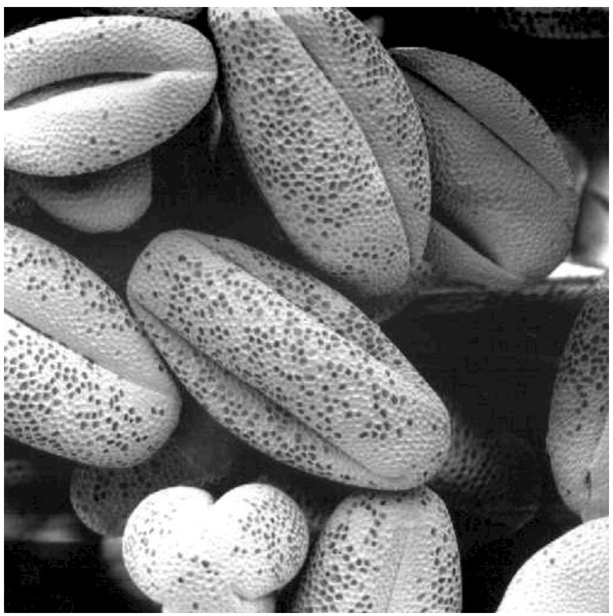
Histogram Examples (cont…)s

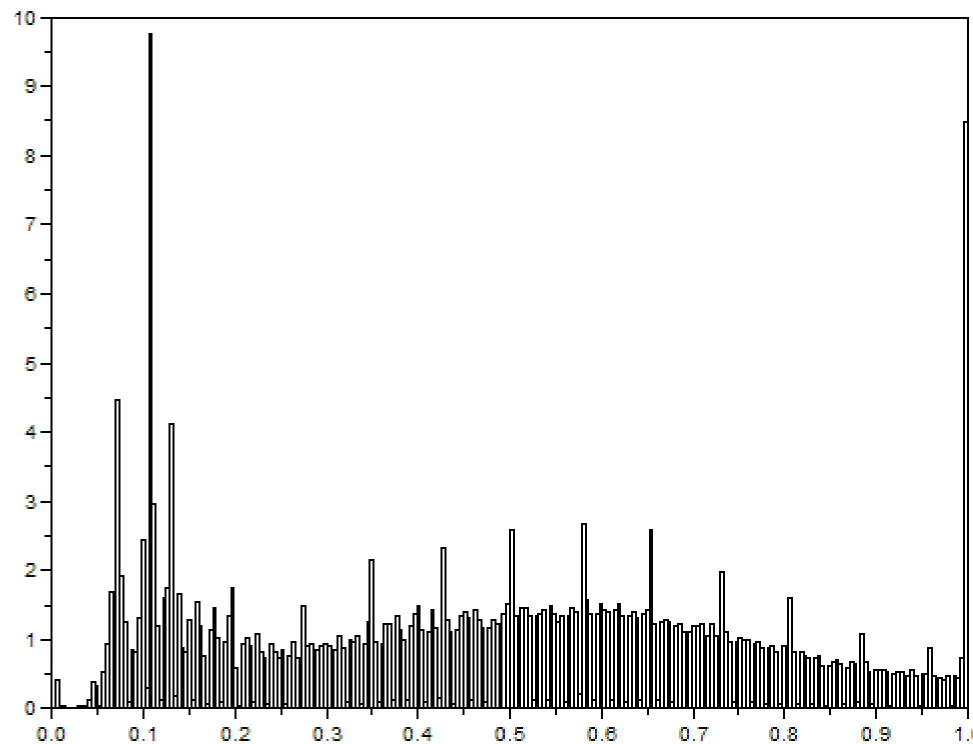




Images taken from Gonzalez & Woods, Digital Image Processing (2002)

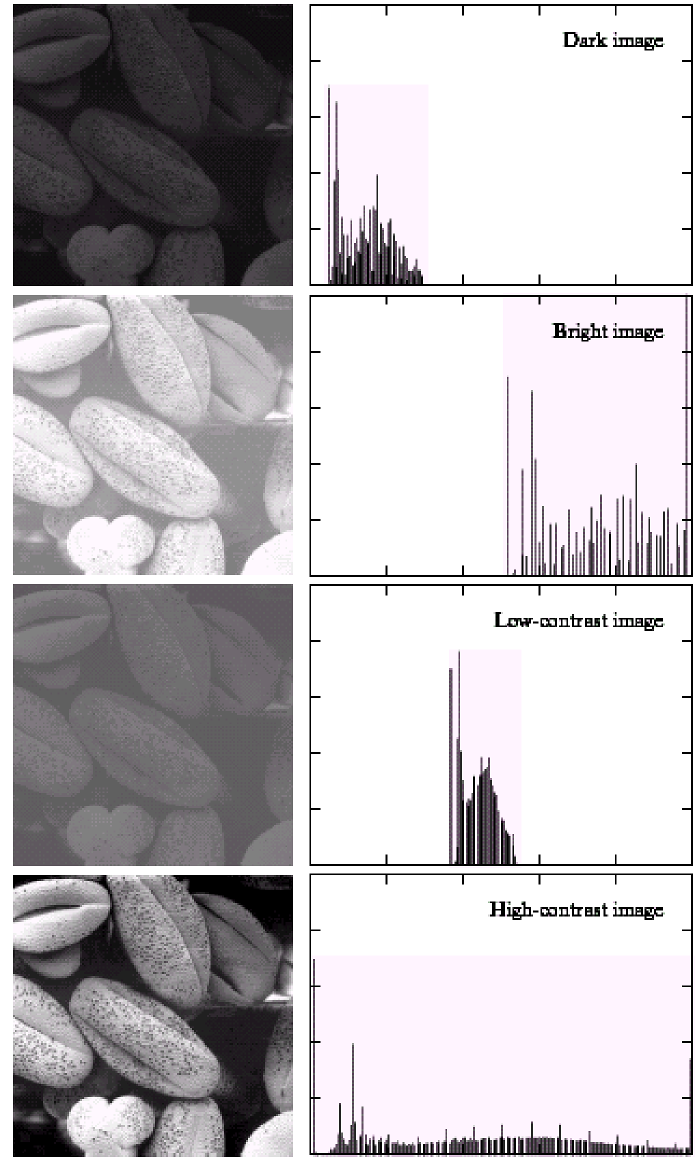
Histogram Examples (cont…)





Histogram Examples (cont…)

- A selection of images and their histograms
- Notice the relationships between the images and their histograms
- Note that the high contrast image has the most evenly spaced histogram



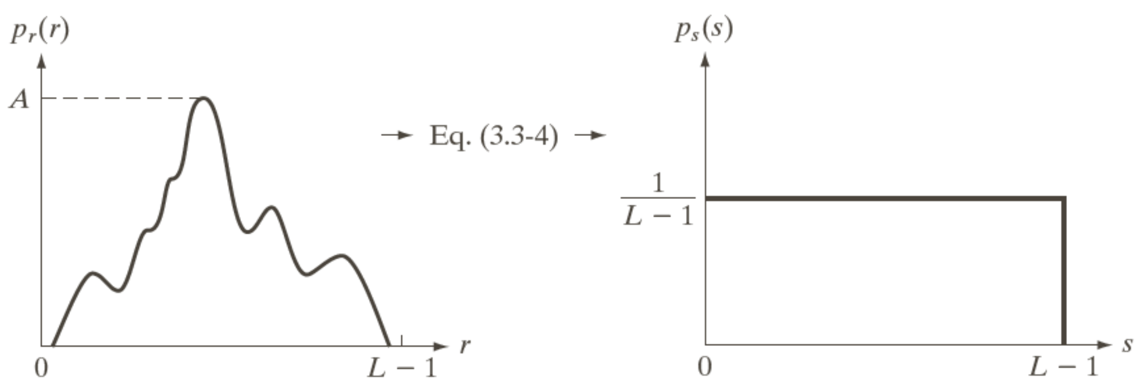
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Contrast Stretching

- We can fix images that have poor contrast by applying a pretty simple contrast specification
- The interesting part is how do we decide on this transformation function?

Histogram Equalisation

- Spreading out the frequencies in an image (or equalising the image) is a simple way to improve dark or washed out images

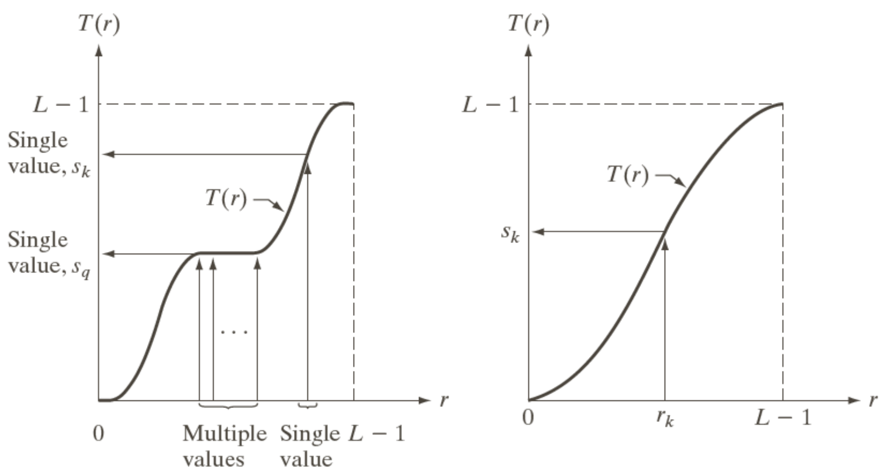


a b

FIGURE 3.18 (a) An arbitrary PDF. (b) Result of applying the transformation in Eq. (3.3-4) to all intensity levels, r. The resulting intensities, s, have a uniform PDF, independently of the form of the PDF of the r's.

Histogram Equalisation

- Spreading out the frequencies in an image (or equalising the image) is a simple way to improve dark or washed out images



a b

FIGURE 3.17 (a) Monotonically increasing function, showing how multiple values can map to a single value. (b) Strictly monotonically increasing function. This is a one-to-one mapping, both ways.

Histogram Equalisation

- The formula for histogram equalisation is given where
  - r_k: input intensity
  - s_k: processed intensity
  - k: the intensity range (0 ... L-1) (e.g 0 – 255)
  - n_j: the frequency of intensity j
  - n: the sum of all frequencies

$$
\begin{aligned}
s_k &= T(r_k) \\
&= (L-1)\sum_{j=0}^{k} p_r(r_j) \\
&= (L-1)\sum_{j=0}^{k} \frac{n_j}{n}
\end{aligned}
$$

Example (3.5 G&W)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

r_k	n_k	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02

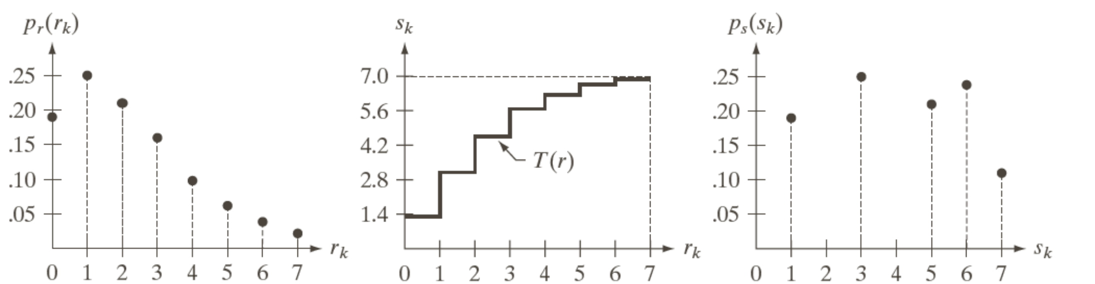
TABLE 3.1 Intensity distribution and histogram values for a 3-bit, 64×64 digital image.

$$s_k = T(r_k) = (L-1)\sum_{j=0}^{k} p_r(r_j) \qquad k = 0,1,2,\ldots,L-1$$

$$s_0 = T(r_0) = 7\sum_{j=0}^{0} p_r(r_j) = 7p_r(r_0) = 1.33$$

$$s_0 = 1.33 \rightarrow 1 \quad s_2 = 4.55 \rightarrow 5 \quad s_4 = 6.23 \rightarrow 6 \quad s_6 = 6.86 \rightarrow 7$$

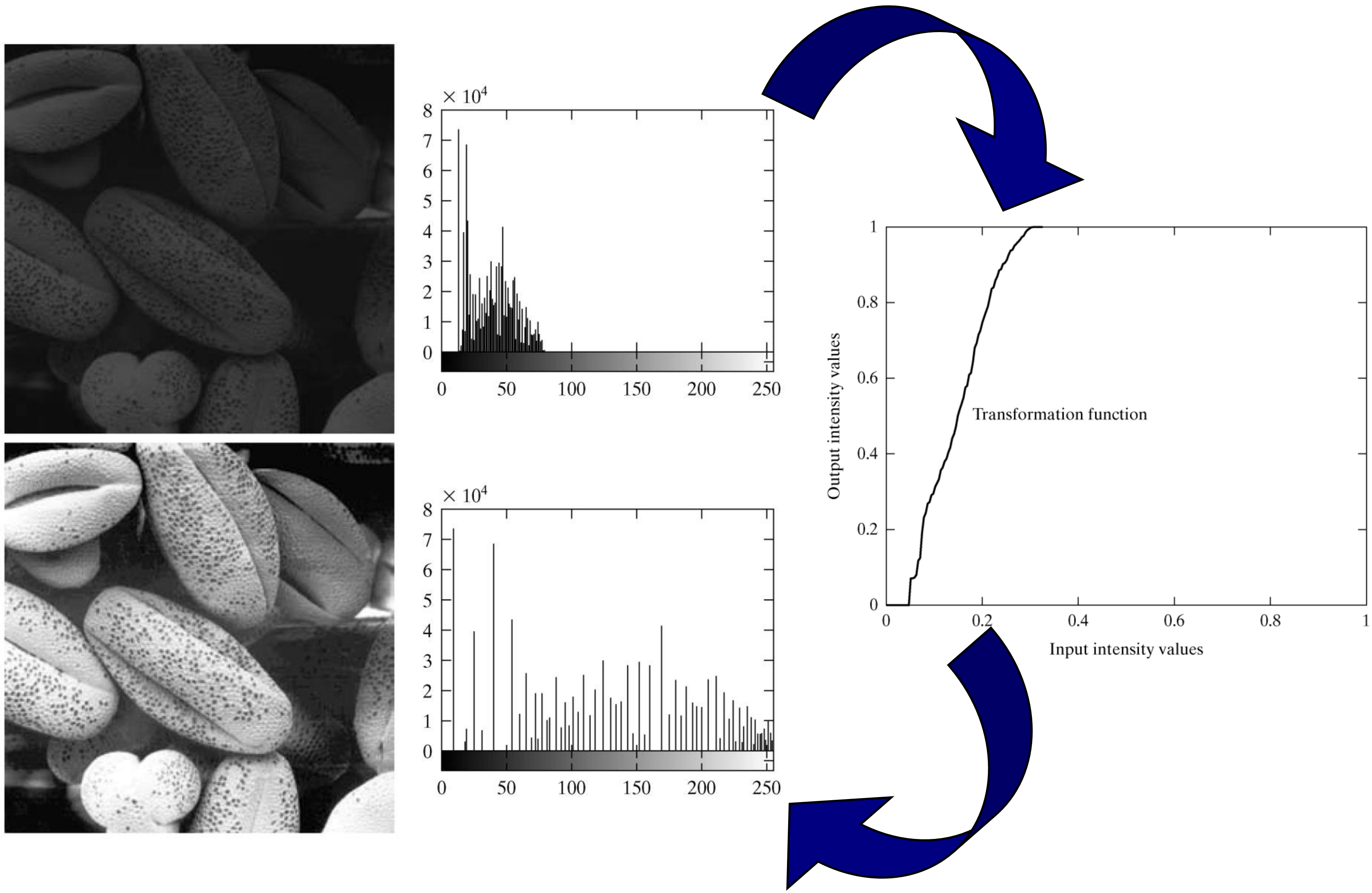
$$s_1 = 3.08 \rightarrow 3 \quad s_3 = 5.67 \rightarrow 6 \quad s_5 = 6.65 \rightarrow 7 \quad s_7 = 7.00 \rightarrow 7$$



a b c

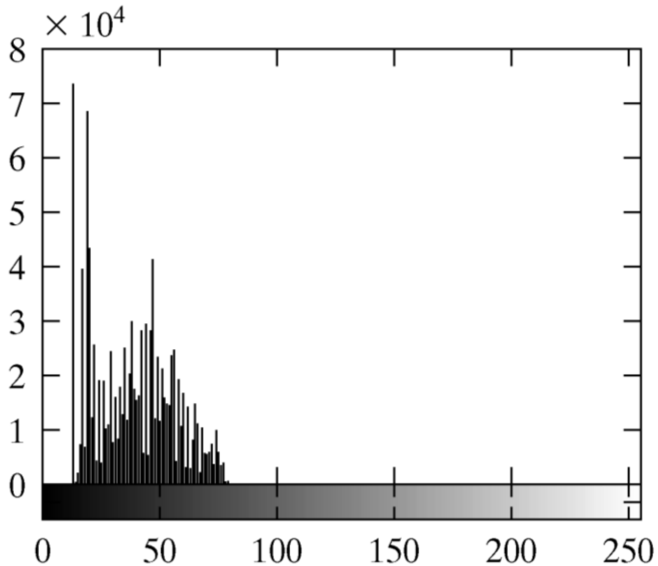
FIGURE 3.19 Illustration of histogram equalization of a 3-bit (8 intensity levels) image. (a) Original histogram. (b) Transformation function. (c) Equalized histogram.

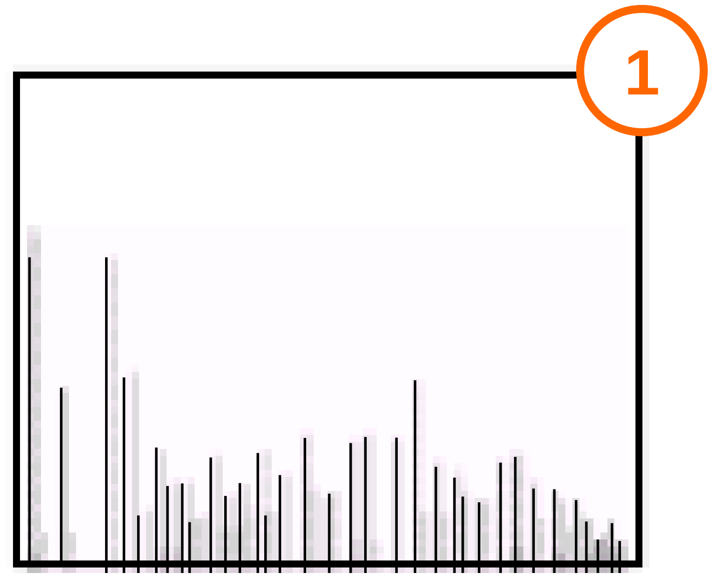
Equalisation Transformation Function

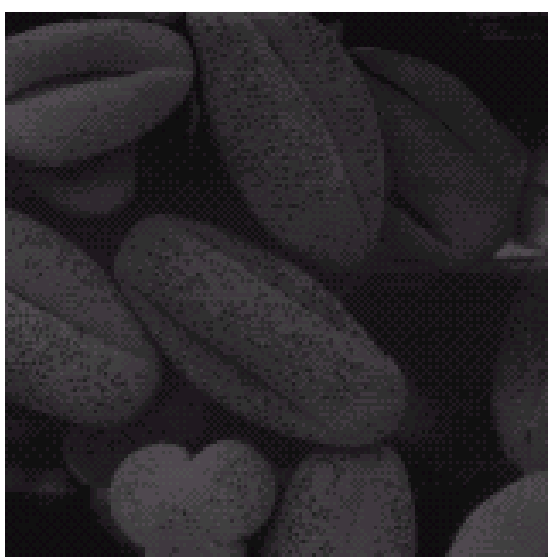


Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Equalisation Examples



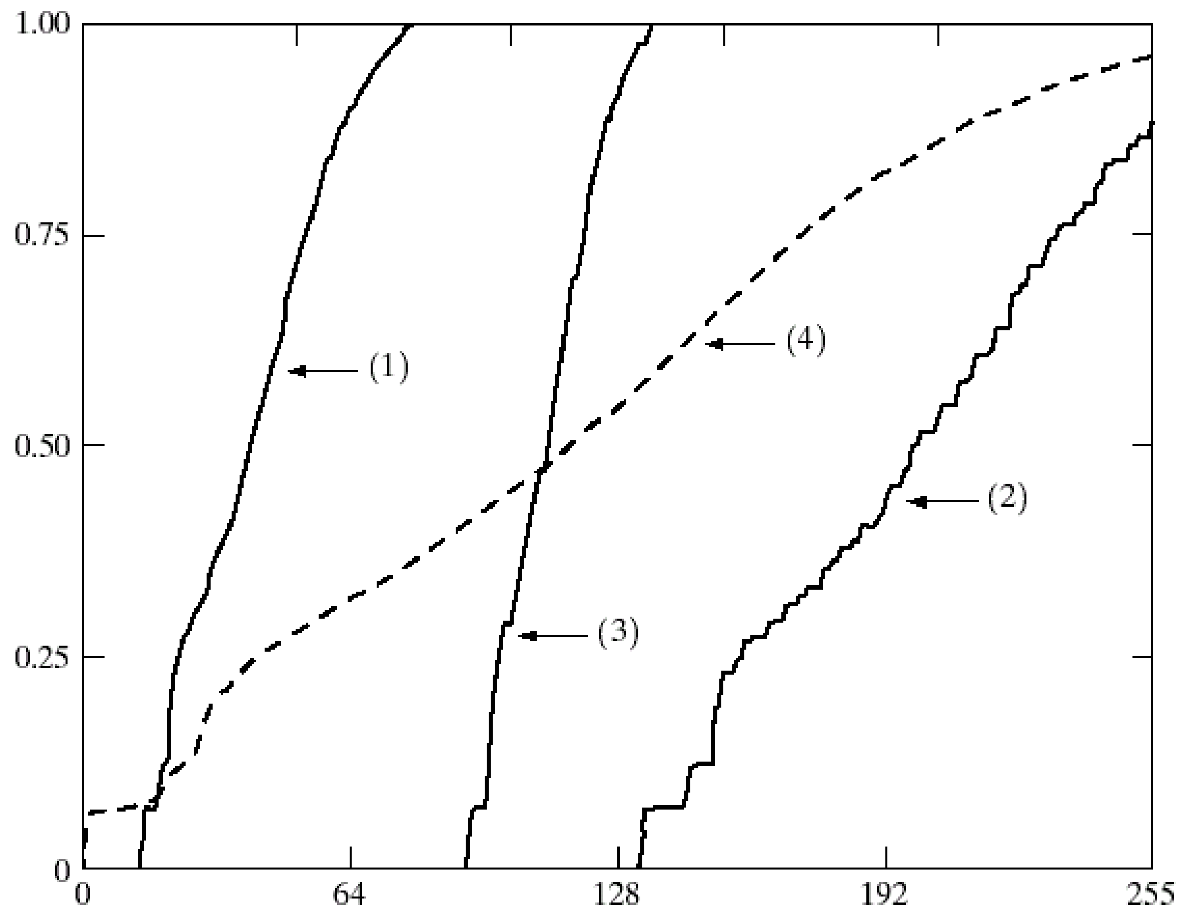




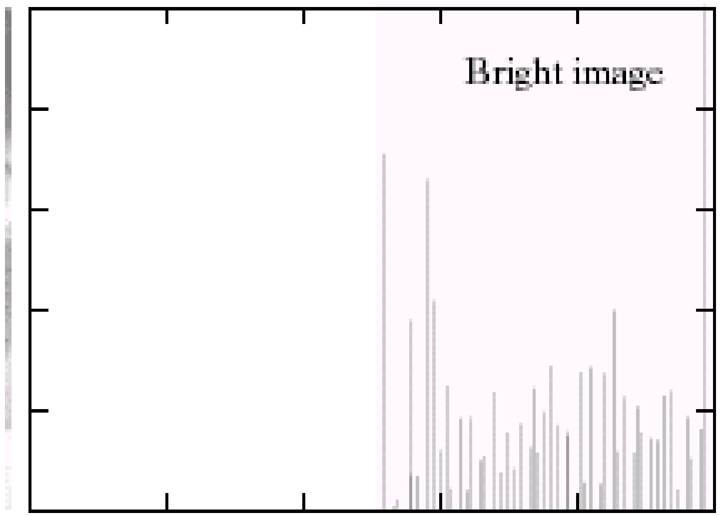
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

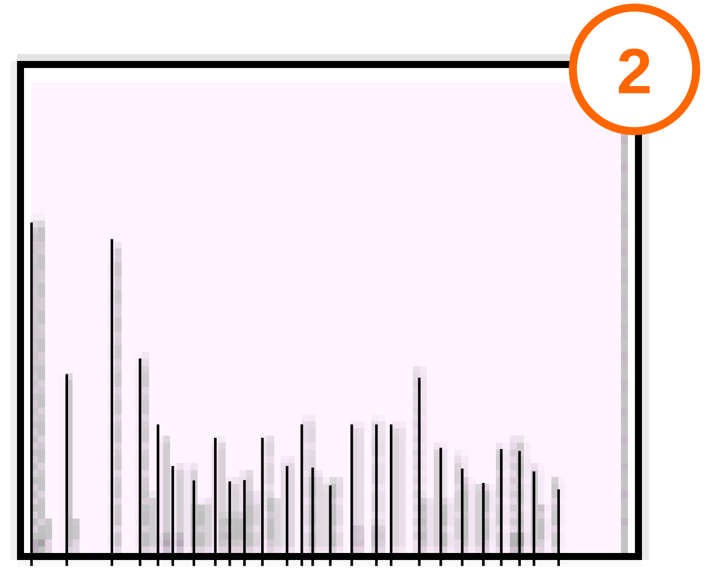
Equalisation Transformation Functions

The functions used to equalise the images in the previous example



Equalisation Examples

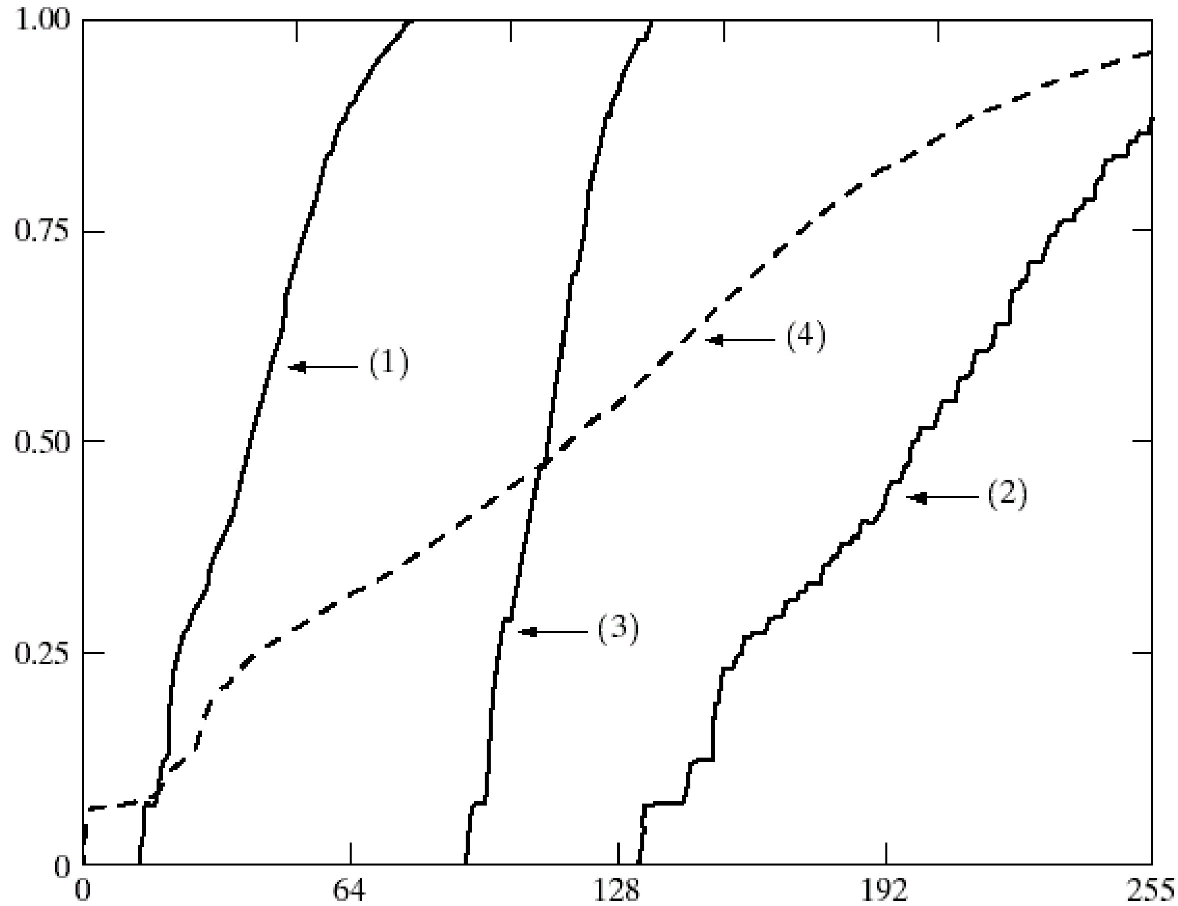




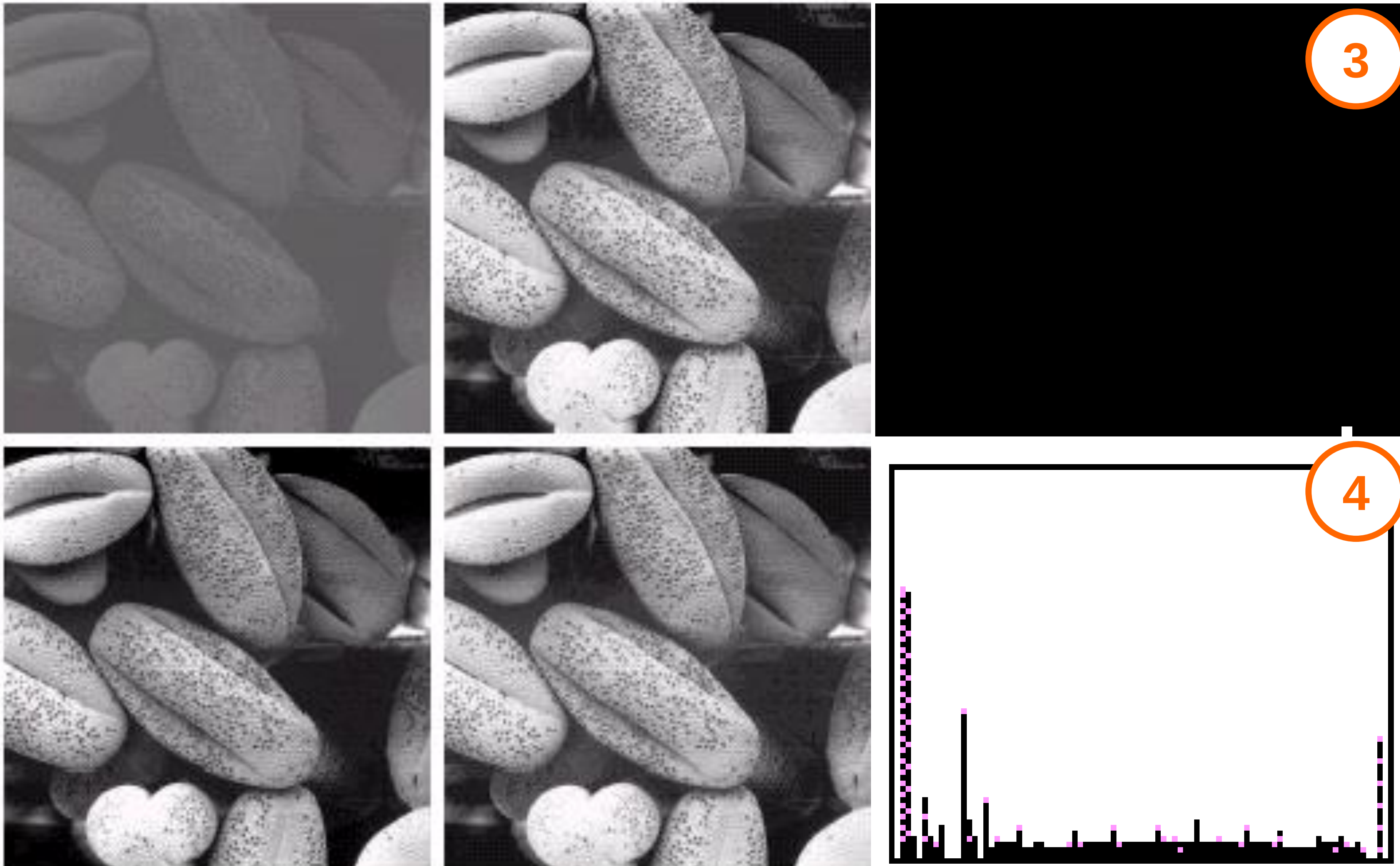
Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Equalisation Transformation Functions

The functions used to equalise the images in the previous example



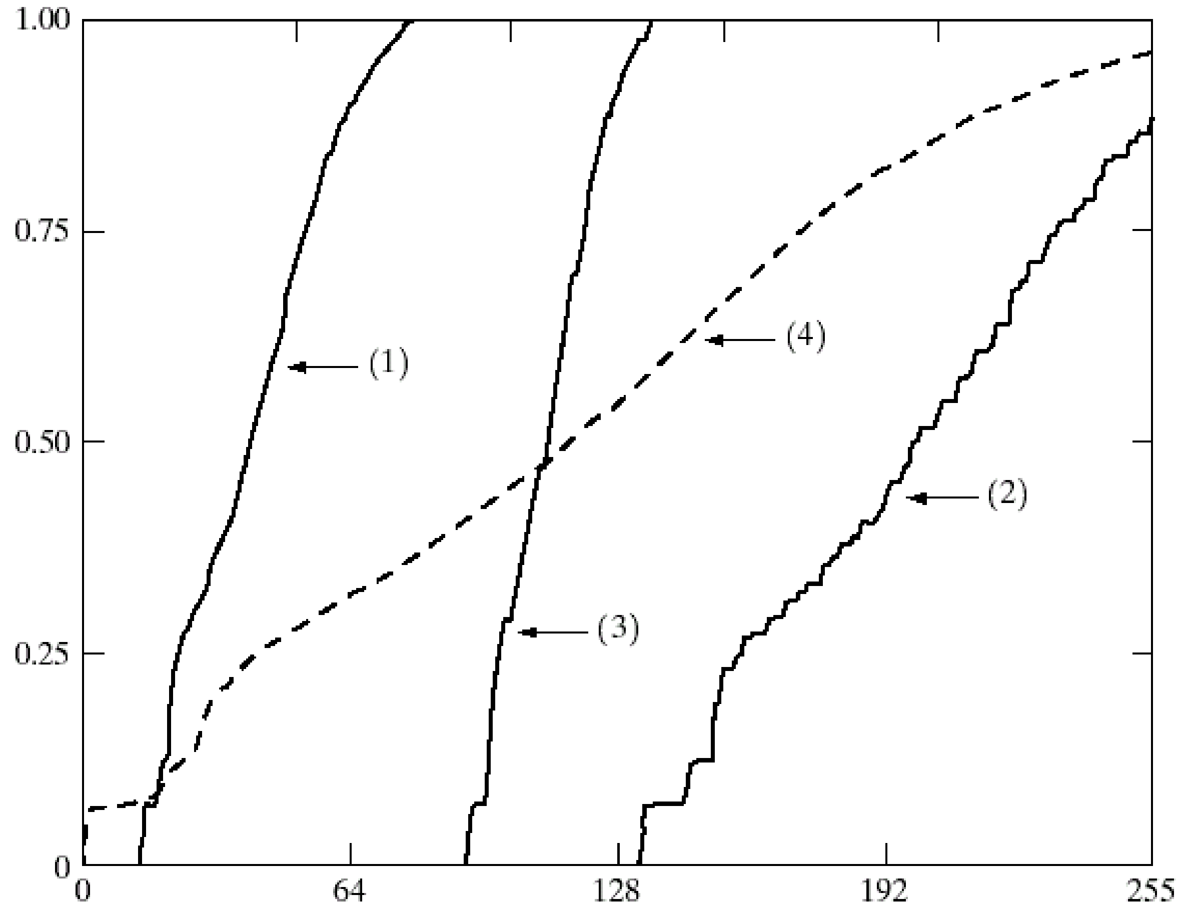
Equalisation Examples (cont...)



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Equalisation Transformation Functions

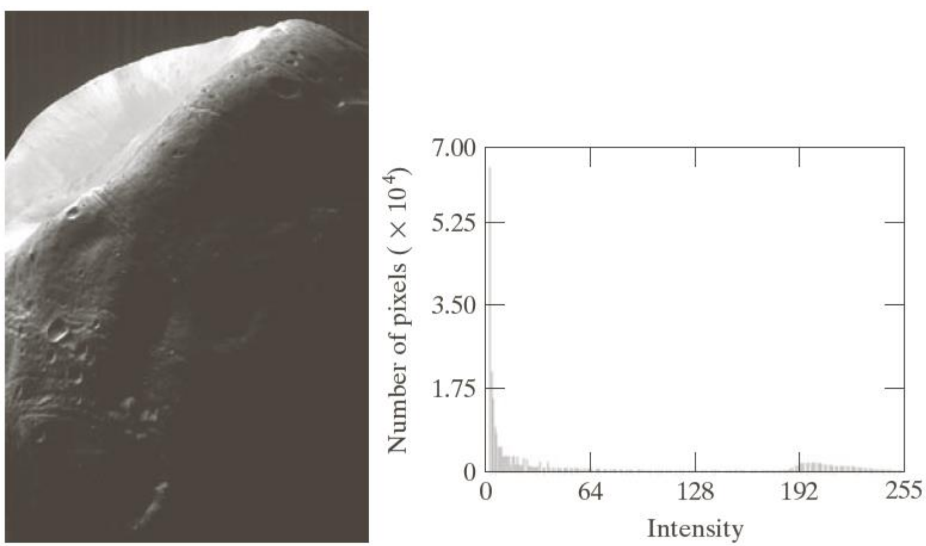
The functions used to equalise the images in the previous examples



Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Matching

- There are applications in which histogram equalization is not suitable.
- It is useful sometimes to be able to specify the shape of the histogram that we wish the processed image to have.



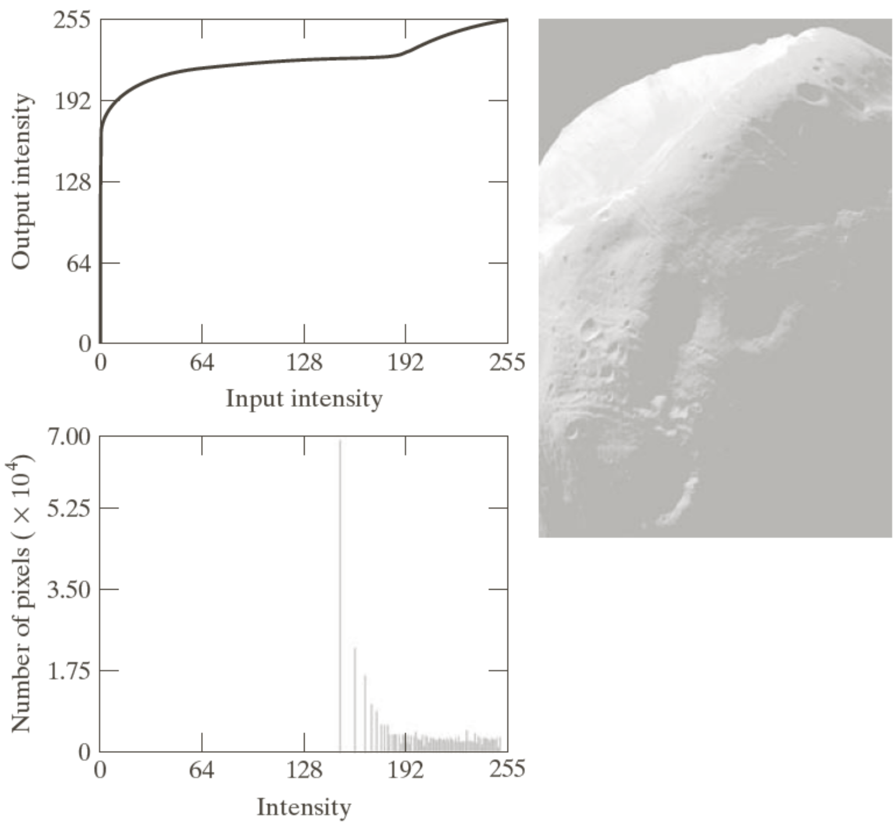
a b

FIGURE 3.23 (a) Image of the Mars moon Phobos taken by NASA's *Mars Global Surveyor.* (b) Histogram. (Original image courtesy of NASA.)

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Histogram Matching

☹

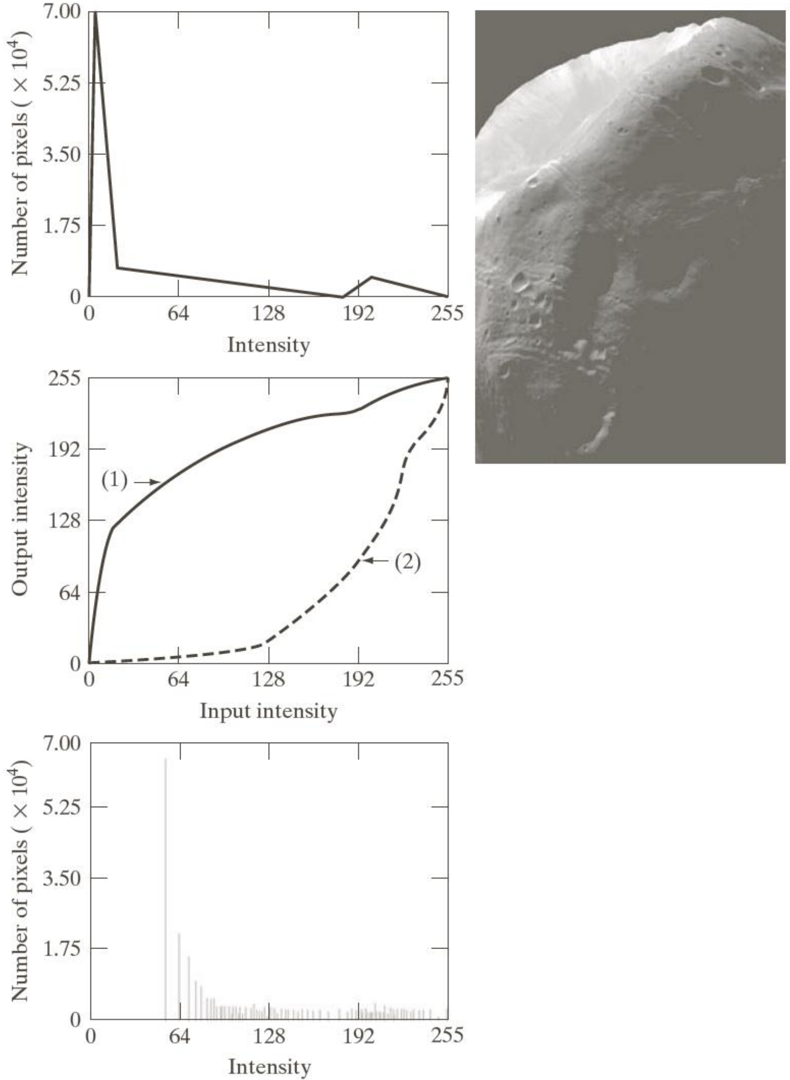


a b
c

FIGURE 3.24
(a) Transformation function for histogram equalization.
(b) Histogram-equalized image (note the washed-out appearance).
(c) Histogram of (b).

Histogram Matching

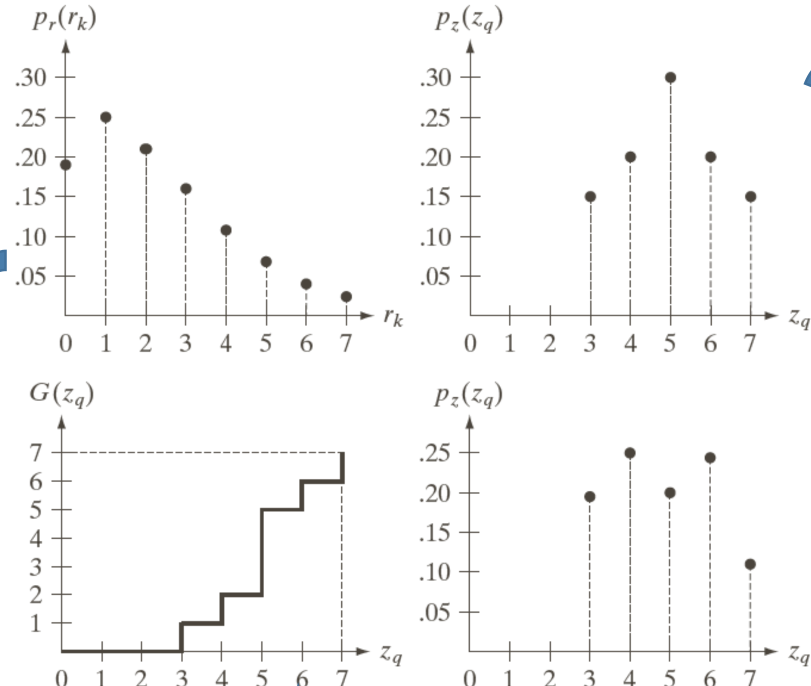
☺



a c
b
d

FIGURE 3.25
(a) Specified histogram.
(b) Transformations.
(c) Enhanced image using mappings from curve (2).
(d) Histogram of (c).

Example (3.7 G&W)



a b
c d

FIGURE 3.22 (a) Histogram of a 3-bit image. (b) Specified histogram. (c) Transformation function obtained from the specified histogram. (d) Result of performing histogram specification. Compare (b) and (d).

$G(z_0) = 0.00 \to 0$ $G(z_4) = 2.45 \to 2$

$G(z_1) = 0.00 \to 0$ $G(z_5) = 4.55 \to 5$

$G(z_2) = 0.00 \to 0$ $G(z_6) = 5.95 \to 6$

$G(z_3) = 1.05 \to 1$ $G(z_7) = 7.00 \to 7$

z_q	$G(z_q)$
$z_0 = 0$	0
$z_1 = 1$	0
$z_2 = 2$	0
$z_3 = 3$	1
$z_4 = 4$	2
$z_5 = 5$	5
$z_6 = 6$	6
$z_7 = 7$	7

$s_0 = 1.33 \to 1$ $s_2 = 4.55 \to 5$ $s_4 = 6.23 \to 6$ $s_6 = 6.86 \to 7$

$s_1 = 3.08 \to 3$ $s_3 = 5.67 \to 6$ $s_5 = 6.65 \to 7$ $s_7 = 7.00 \to 7$

Example (3.7 G&W)

r_k	n_k	$p_r(r_k) = n_k/MN$
$r_0 = 0$	790	0.19
$r_1 = 1$	1023	0.25
$r_2 = 2$	850	0.21
$r_3 = 3$	656	0.16
$r_4 = 4$	329	0.08
$r_5 = 5$	245	0.06
$r_6 = 6$	122	0.03
$r_7 = 7$	81	0.02

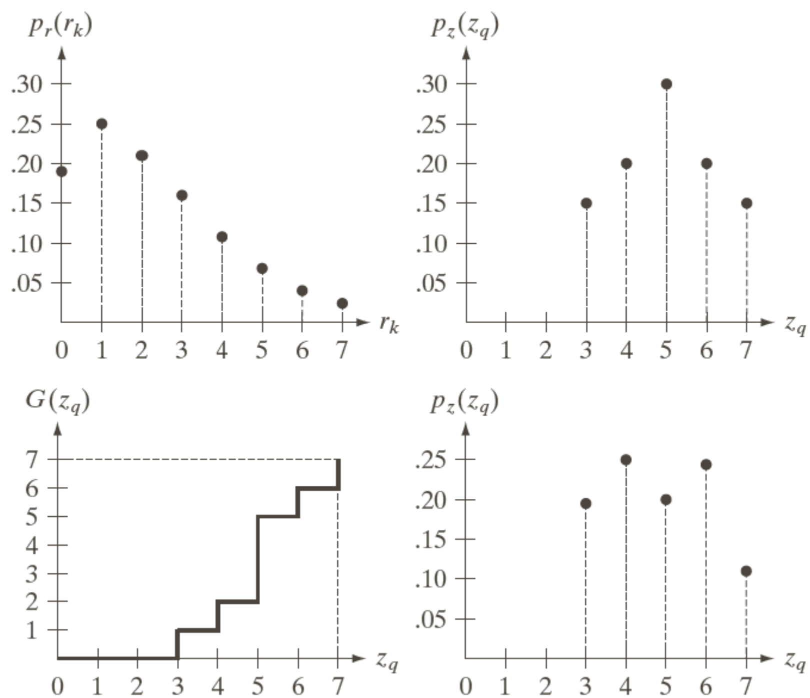
z_q	$G(z_q)$
$z_0 = 0$	0
$z_1 = 1$	0
$z_2 = 2$	0
$z_3 = 3$	1
$z_4 = 4$	2
$z_5 = 5$	5
$z_6 = 6$	6
$z_7 = 7$	7

$$s_0 = 1.33 \rightarrow 1 \quad s_2 = 4.55 \rightarrow 5 \quad s_4 = 6.23 \rightarrow 6 \quad s_6 = 6.86 \rightarrow 7$$

$$s_1 = 3.08 \rightarrow 3 \quad s_3 = 5.67 \rightarrow 6 \quad s_5 = 6.65 \rightarrow 7 \quad s_7 = 7.00 \rightarrow 7$$

Mapping

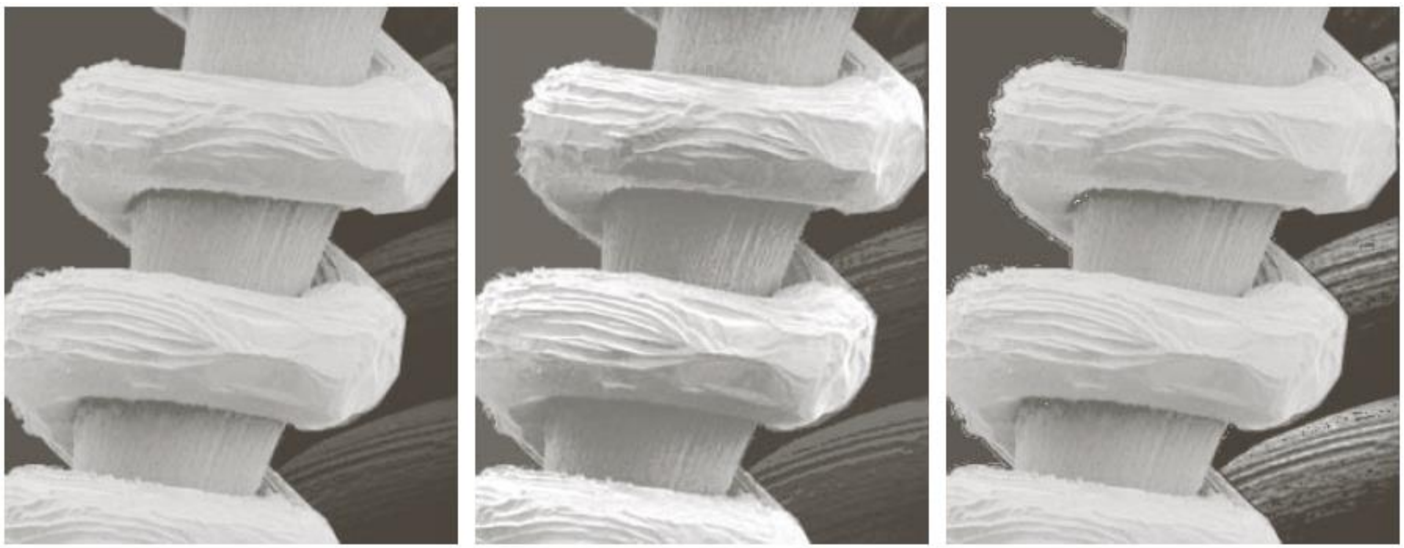
Example (3.7 G&W)



z_q	Specified $p_z(z_q)$	Actual $p_z(z_k)$
$z_0 = 0$	0.00	0.00
$z_1 = 1$	0.00	0.00
$z_2 = 2$	0.00	0.00
$z_3 = 3$	0.15	0.19
$z_4 = 4$	0.20	0.25
$z_5 = 5$	0.30	0.21
$z_6 = 6$	0.20	0.24
$z_7 = 7$	0.15	0.11

Images taken from Gonzalez & Woods, Digital Image Processing (2002)

Partial Transformations



a b c

FIGURE 3.27 (a) SEM image of a tungsten filament magnified approximately 130×. (b) Result of global histogram equalization. (c) Image enhanced using local histogram statistics. (Original image courtesy of Mr. Michael Shaffer, Department of Geological Sciences, University of Oregon, Eugene.)

Summary

- We have looked at:
  - Different kinds of image enhancement
  - Histograms
  - Histogram equalisation, matching.
- We have looked at different kinds of point processing image enhancement
- Next time we will start to look at neighbourhood operations – in particular *filtering* and *convolution*