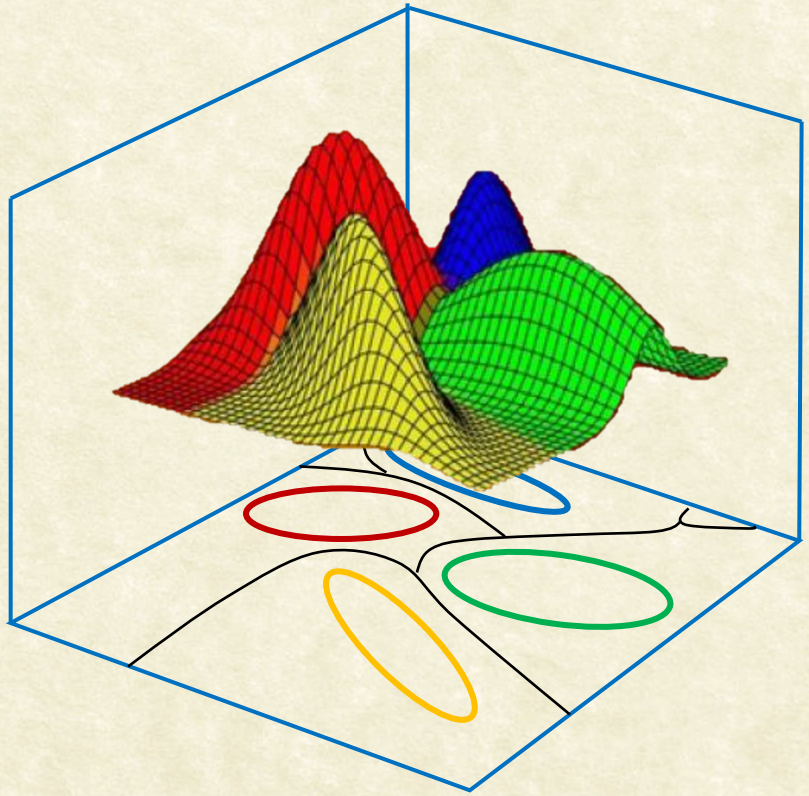
CS7.404: Digital Image Processing

Monsoon 2023: Sampling and Quantization



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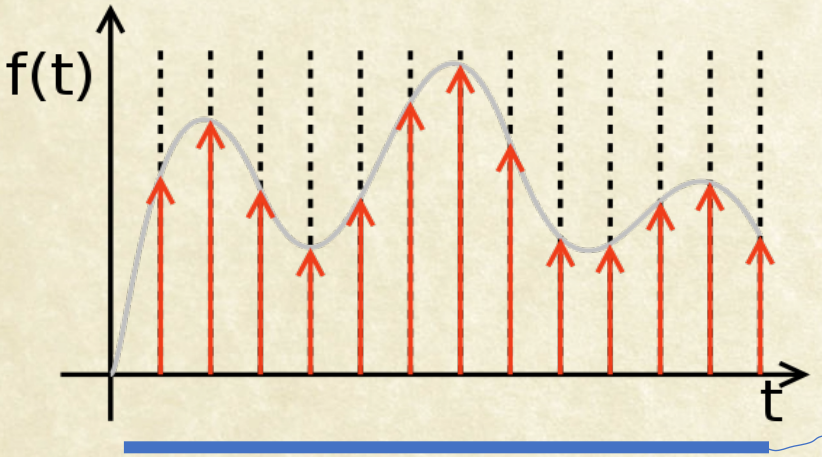
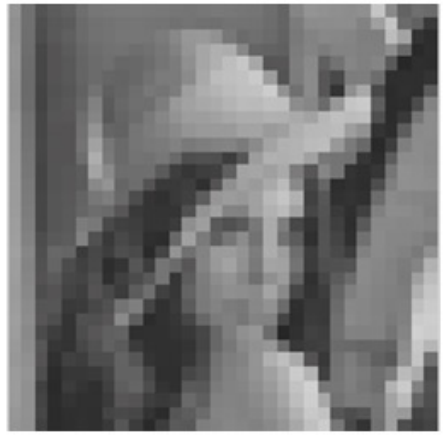
Summary



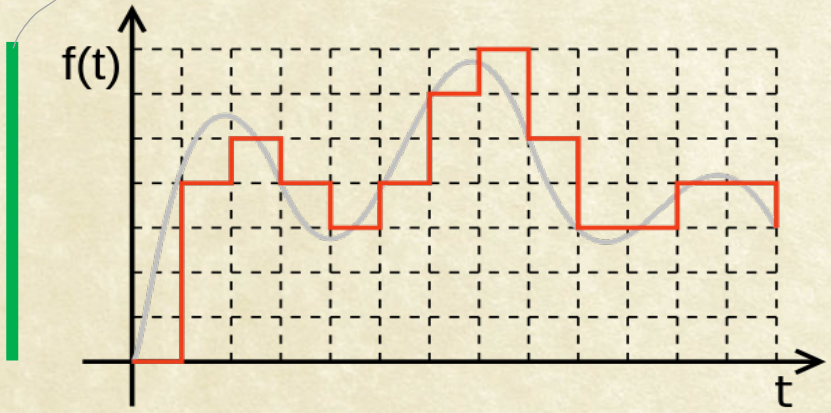
Sampling

256 × 256



32 × 32

16 × 16



Quantization

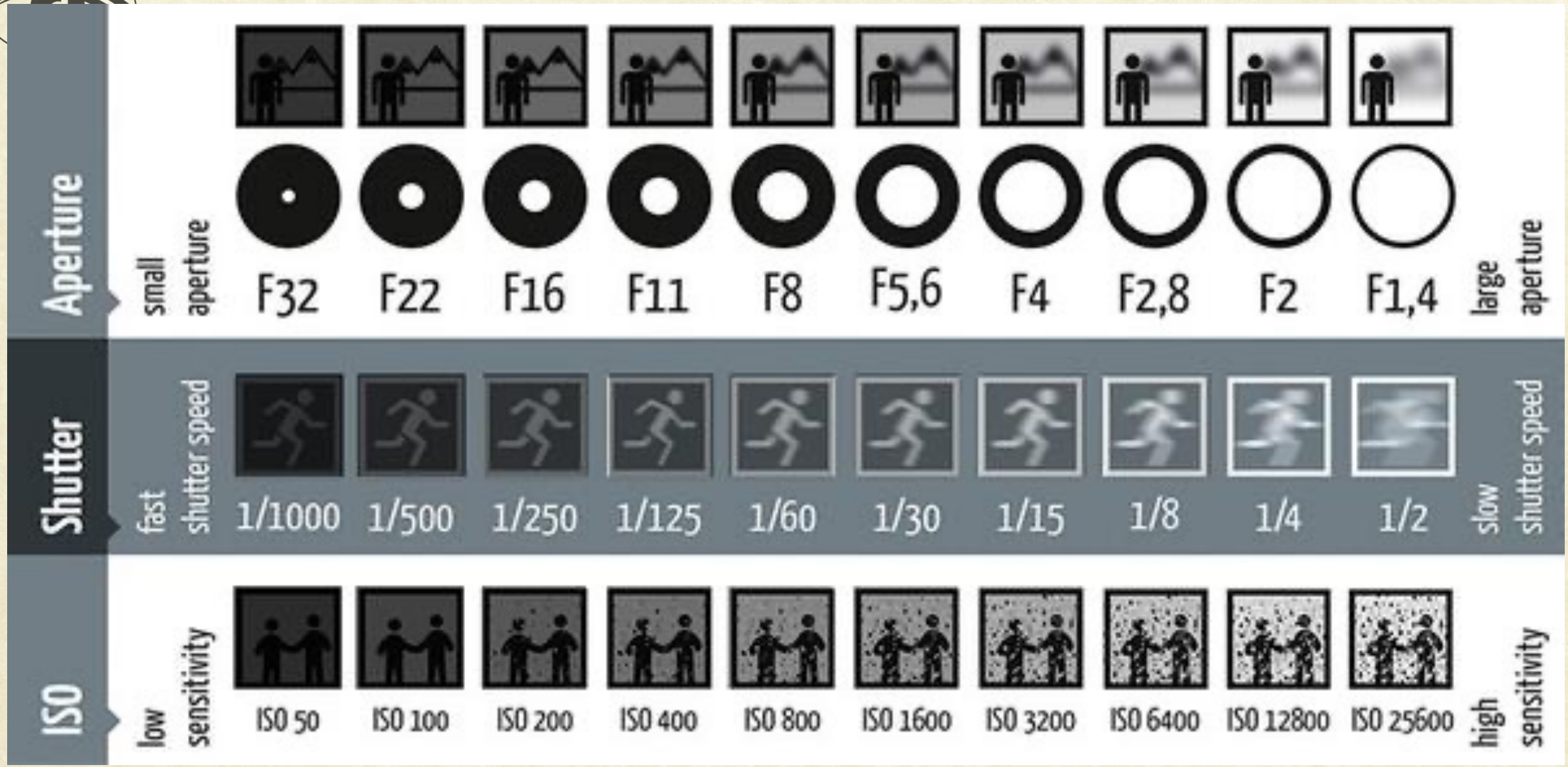
8 bits per pixel

4 bits per pixel

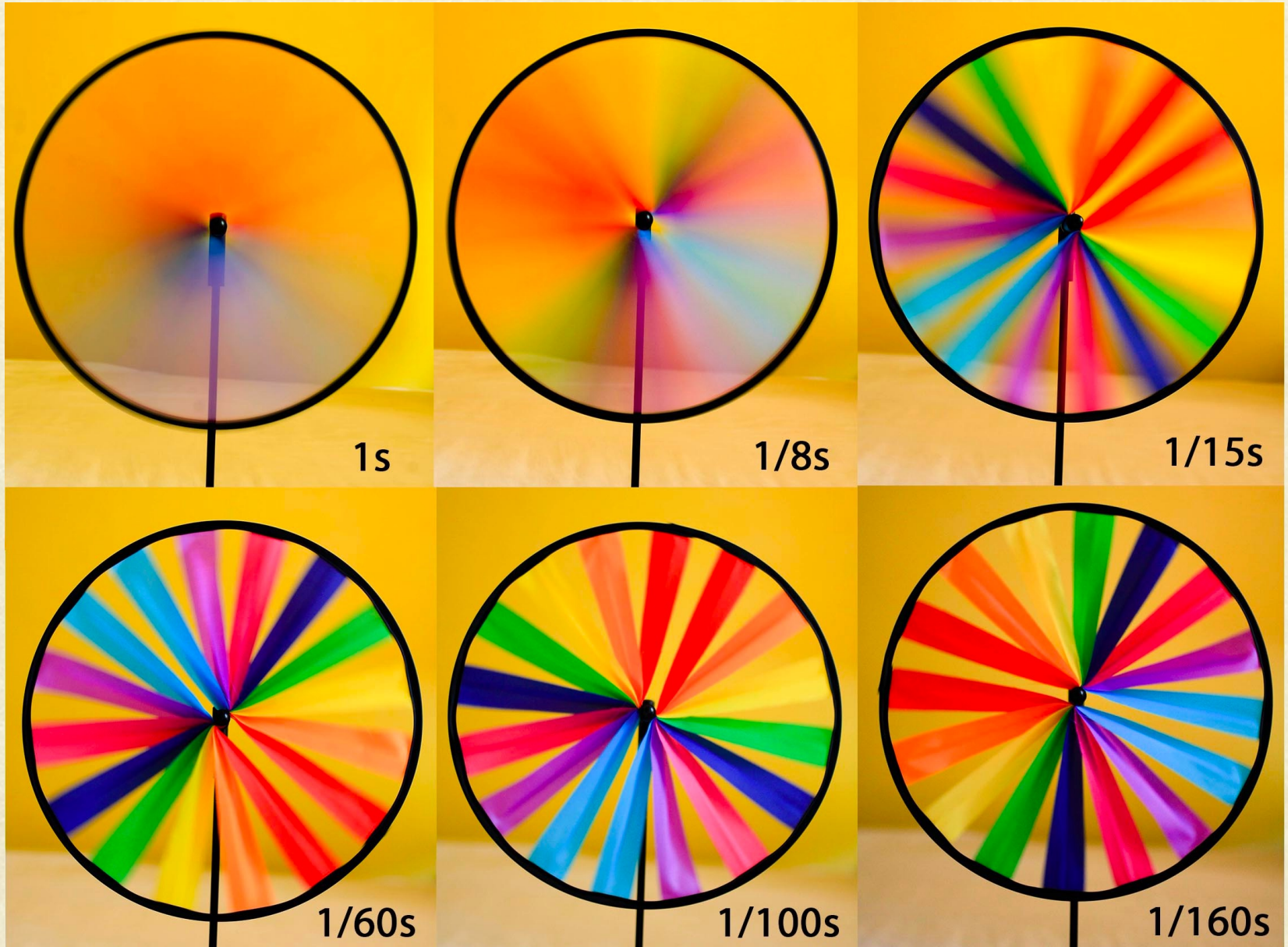
2 bits per pixel

1 bit per pixel

Temporal Sampling


Aperture
small aperture
F32
F22
F16
F11
F8
F5,6
F4
F2,8
F2
F1,4
large aperture
Shutter
fast shutter speed
1/1000
1/500
1/250
1/125
1/60
1/30
1/15
1/8
1/4
1/2
slow shutter speed
ISO
low sensitivity
ISO 50
ISO 100
ISO 200
ISO 400
ISO 800
ISO 1600
ISO 3200
ISO 6400
ISO 12800
ISO 25600
high sensitivity

Temporal Sampling



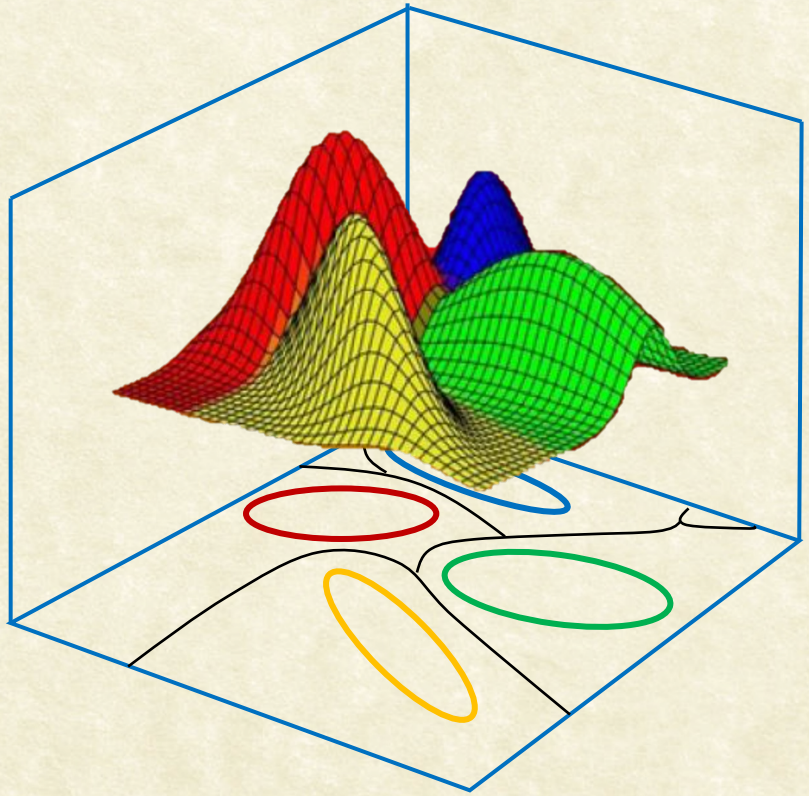
Temporal Sampling

References

- Gonzalez and Woods (2.1,2.3-2.4)
  - Problems : 2.1 – 2.10
- Optional Reading
  - https://www.edmundoptics.com/resources/application-notes/imaging/camera-resolution-for-improved-imaging-system-performance/
  - http://www.andor.com/learning-academy/ccd-spatial-resolution-understanding-spatial-resolution
  - http://av.jpn.support.panasonic.com/support/global/cs/dsc/knowhow/knowhow26.html
  - http://www.vision-doctor.com/en/camera-technology-basics/sensor-and-pixel-sizes.html
  - https://nostalgicmedia.com/pages/resolution-scanning-dpi-ppi
  - http://www.ubergizmo.com/what-is/ppi-pixels-per-inch/

CS7.404: Digital Image Processing

Monsoon 2023: Pixel Processing



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Two Paradigms of Image Processing

Directly in Spatial Domain

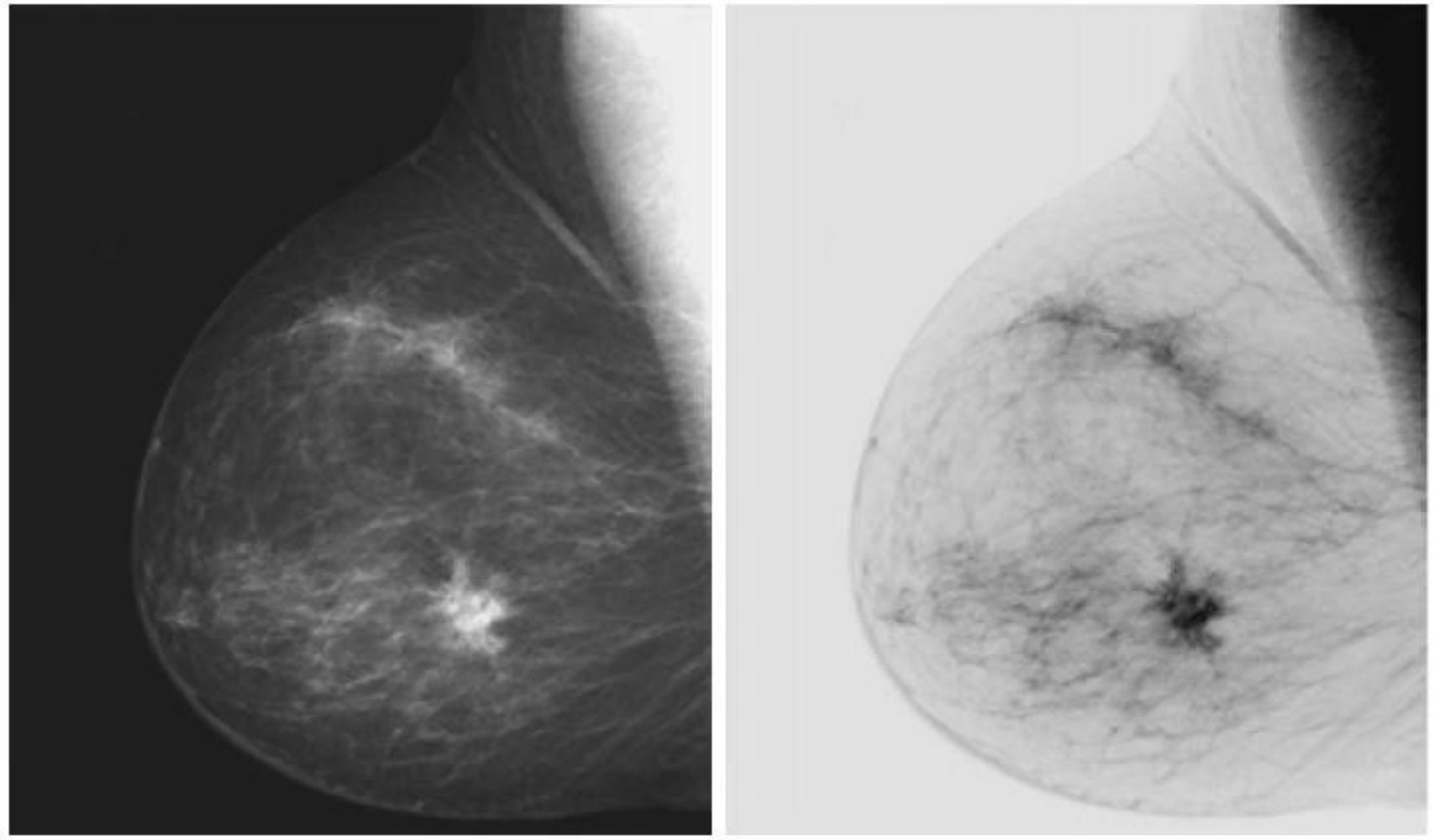
- Manipulating Pixels
  - Easier to Understand
  - Easier to Implement
  - Local Changes
  - Not so efficient

Processing in Transform Domain

- Manipulating JPG coefficients
  - Complex to visualize
  - Tricky to implement
  - Changes can be global
  - Can be very efficient, effective, …

Intensity Transformations: Point-to-Point

- b(x,y) = T(*a*(x,y)); T(z) = K- z

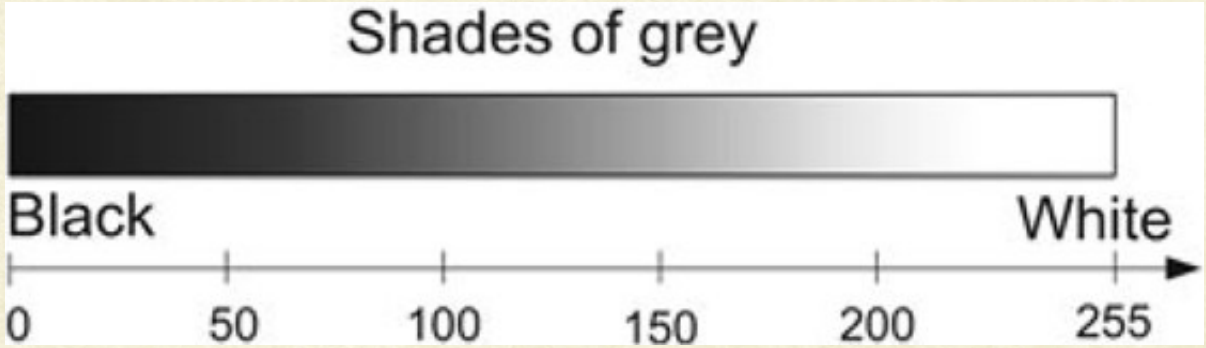


a b

FIGURE 3.4
(a) Original digital mammogram. (b) Negative image obtained using the negative transformation in Eq. (3.2-1). (Courtesy of G.E. Medical Systems.)

Linear Intensity Transforms

- $T(z) = z + K$
- $T(z) = z - K$
- $T(z) = Kz$
- $T(z) = K_1 z + K_2$

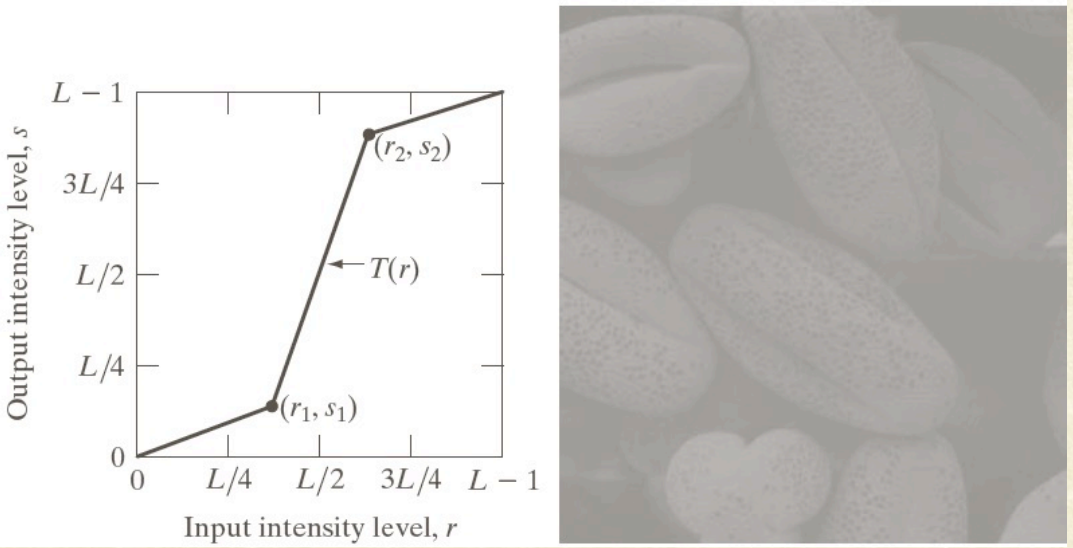


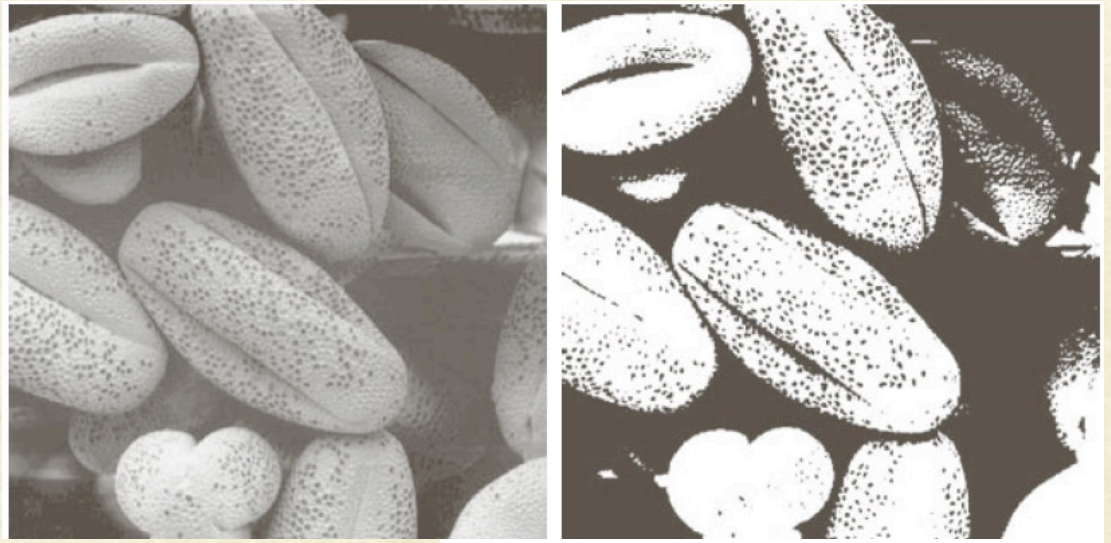
e.g.,

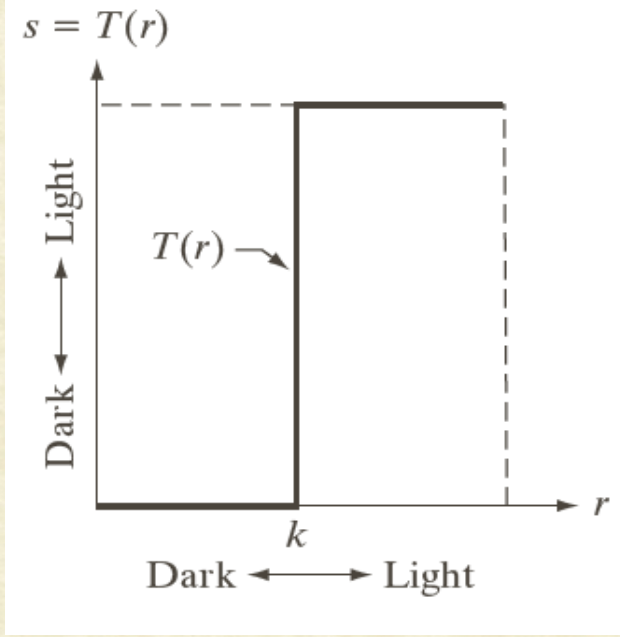
- Image Negative
- Data Visualization:
  - Map to display range

$$J = \texttt{round}\left(255 * \frac{I - min(I)}{max(I) - min(I)}\right)$$

Piece-wise Linear Transformations





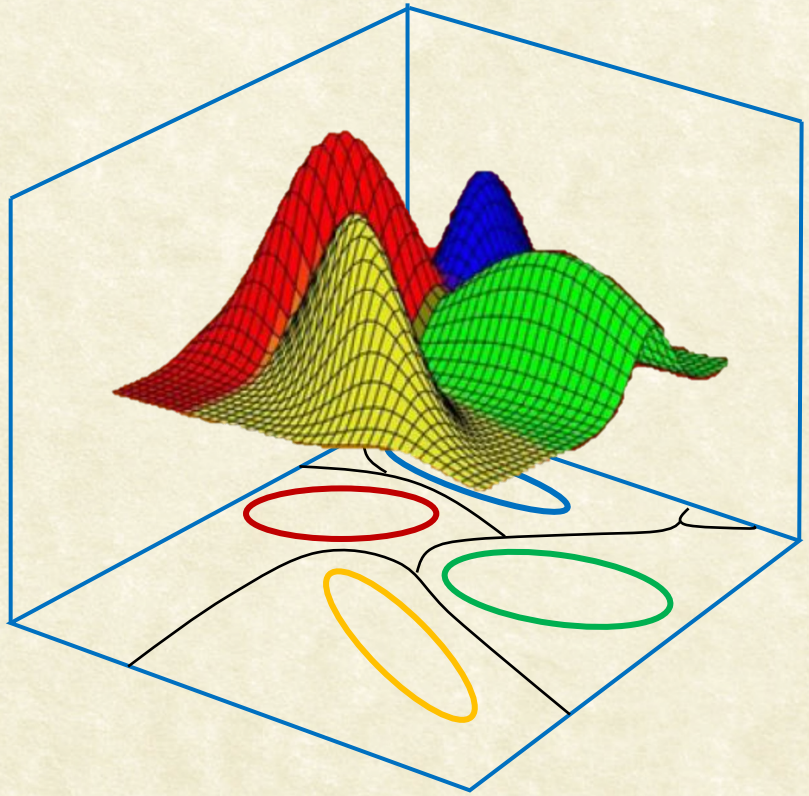


- Can be arbitrarily complex
- Finer control over transformation
- Thresholding
- Contrast Stretching
  - Expand intensity range to full intensity range
  - What are the constraints on (r1,s1) and (r2,s2) ?

Questions?

CS7.404: Digital Image Processing

Monsoon 2023: Non-Linear Transformations



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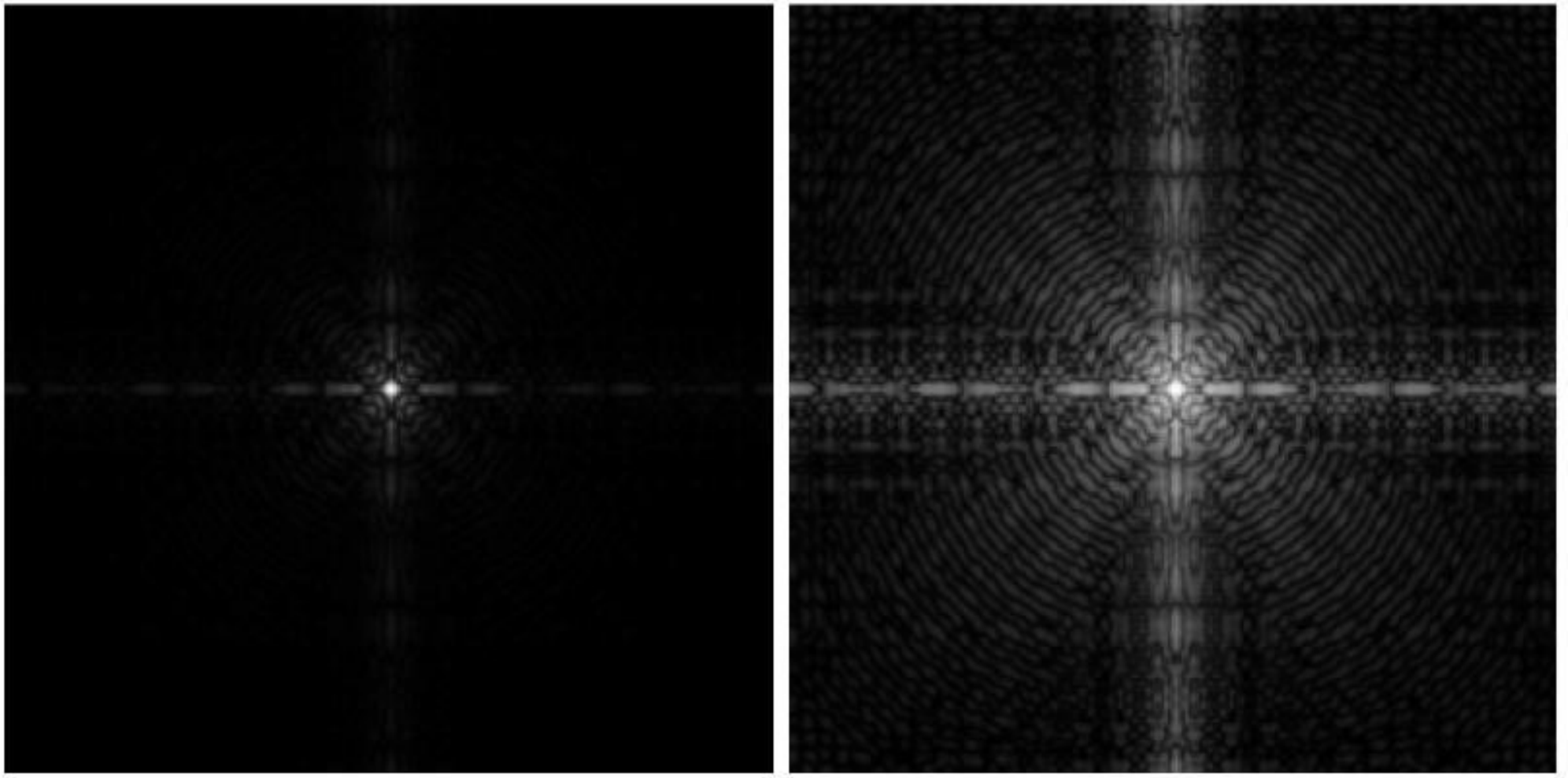
Log Transformations

a b

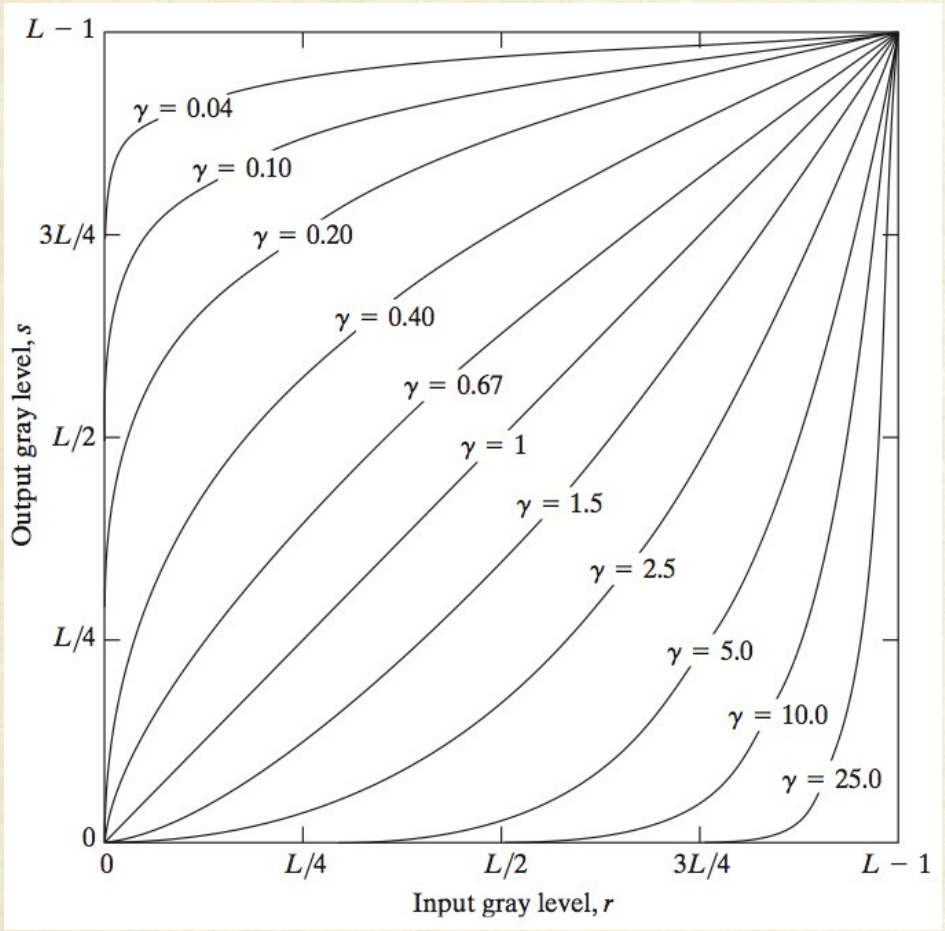
FIGURE 3.5
(a) Fourier spectrum.
(b) Result of applying the log transformation given in Eq. (3.2-2) with $c = 1$.

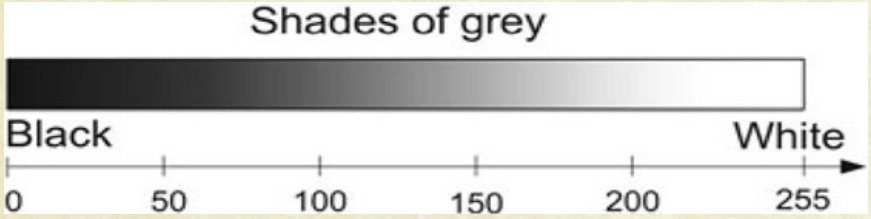


$$s = T(r) = c\ log(1 + r)$$

Power-Law Transformations

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





a b
c d

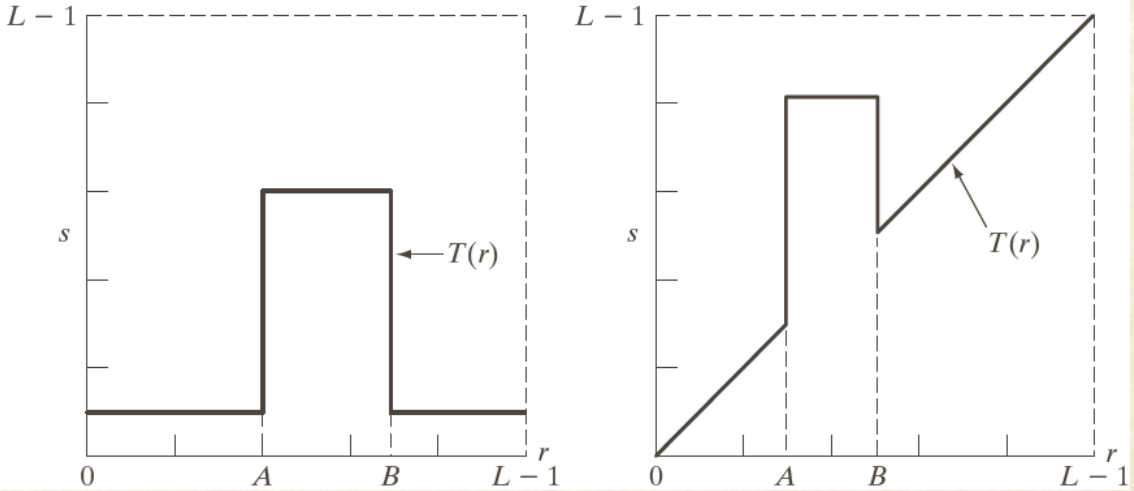
FIGURE 3.9
(a) Aerial image. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 3.0, 4.0$, and 5.0, respectively. (Original image for this example courtesy of NASA.)

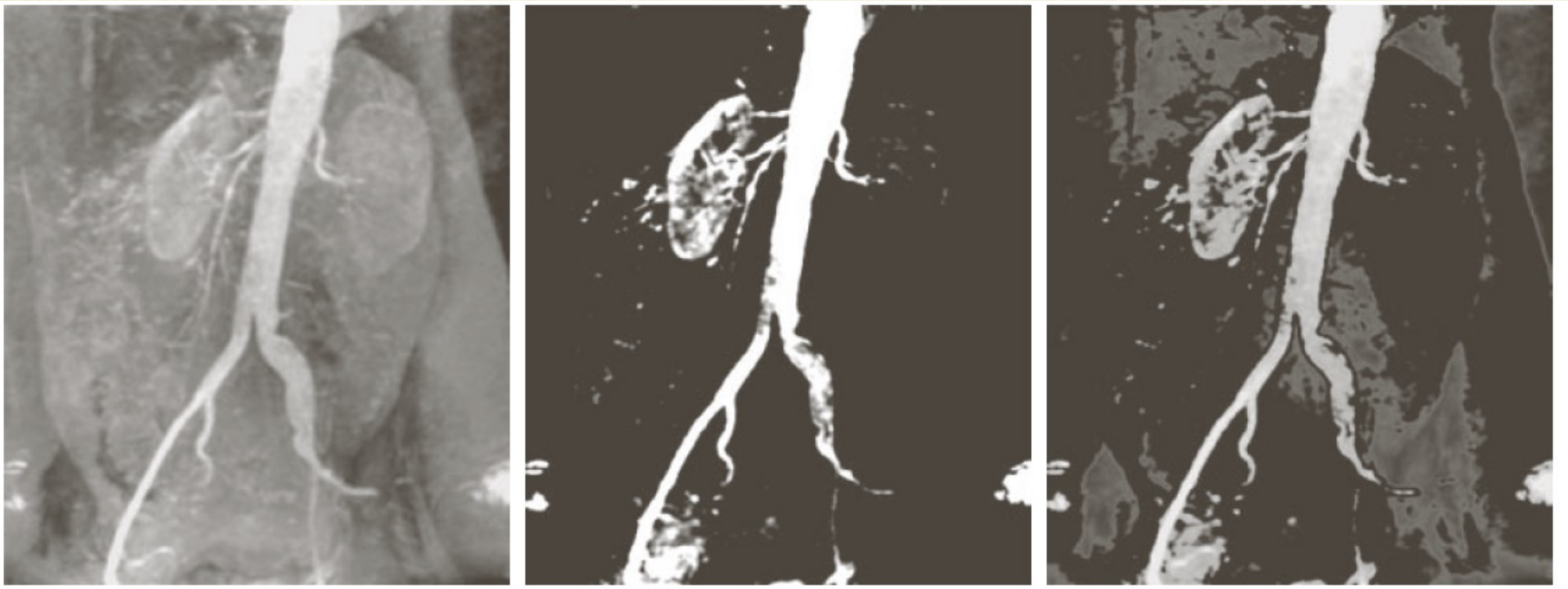
Demo:
https://colab.research.google.com/drive/11qIL0VKleZnONtPuxAryAf9WkUC7kEMI#scrollTo=aU5WQaqOpSCr&line=12&uniqifier=1

Intensity Slicing

a b

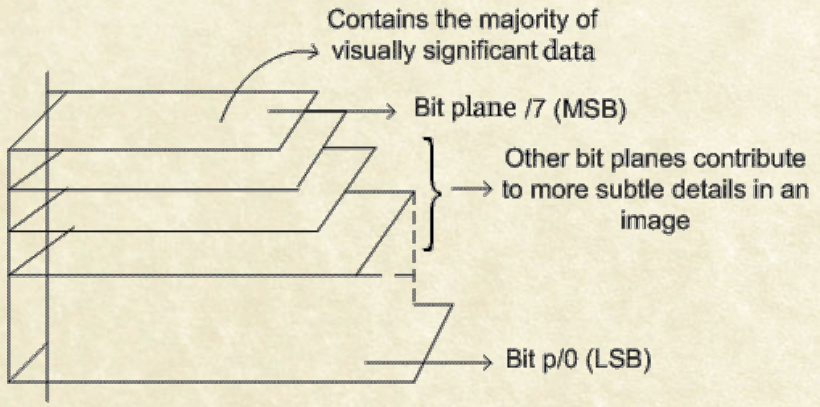
FIGURE 3.11 (a) This transformation highlights intensity range $[A, B]$ and reduces all other intensities to a lower level. (b) This transformation highlights range $[A, B]$ and preserves all other intensity levels.





a b c

Bit plane slicing



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.

https://archive.nptel.ac.in/content/storage2/courses/117104069/chapter_8/page%2015.gif

Bit plane slicing

a b c

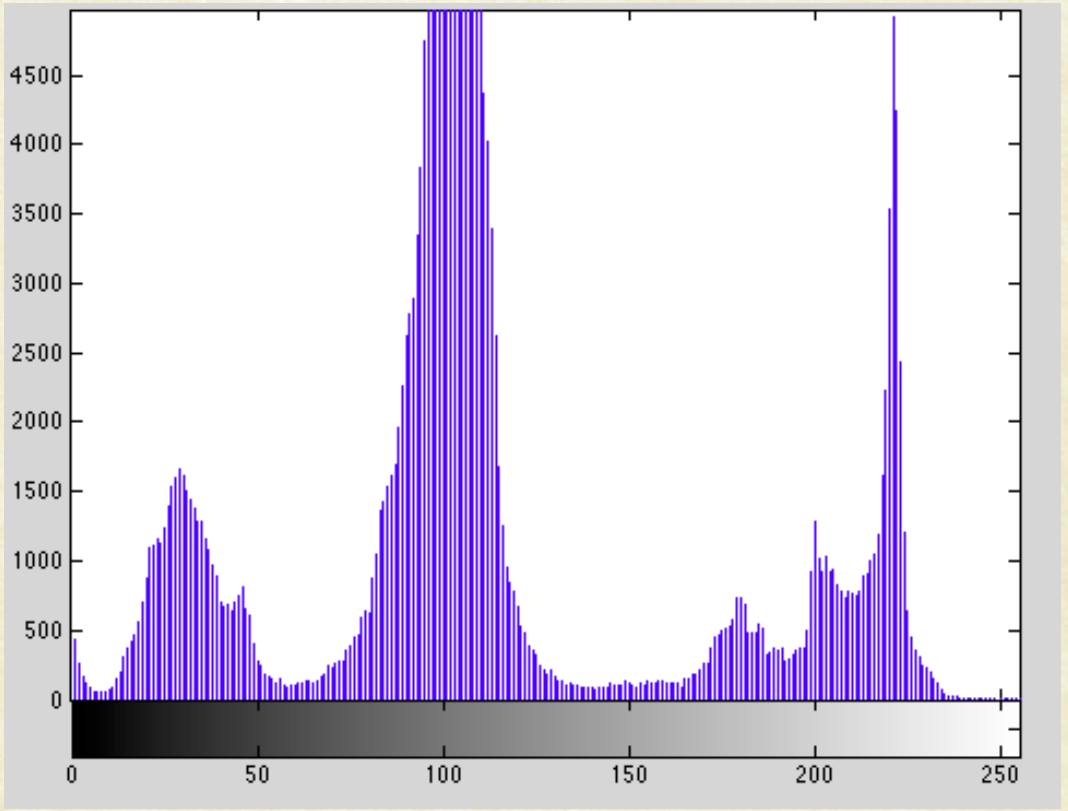
FIGURE 3.15 Images reconstructed using (a) bit planes 8 and 7; (b) bit planes 8, 7, and 6; and (c) bit planes 8 7, 6, and 5. Compare (c) with Fig. 3.14(a).

Histogram

$$h_r(i) = n_i$$

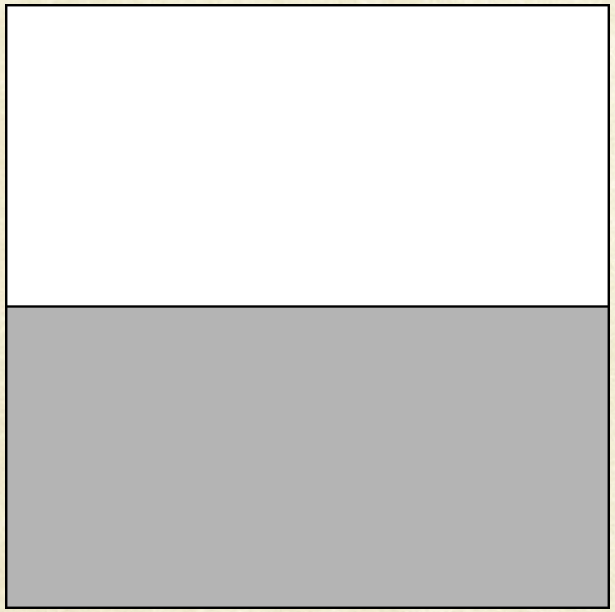
i → intensity value, range [0,L-1]

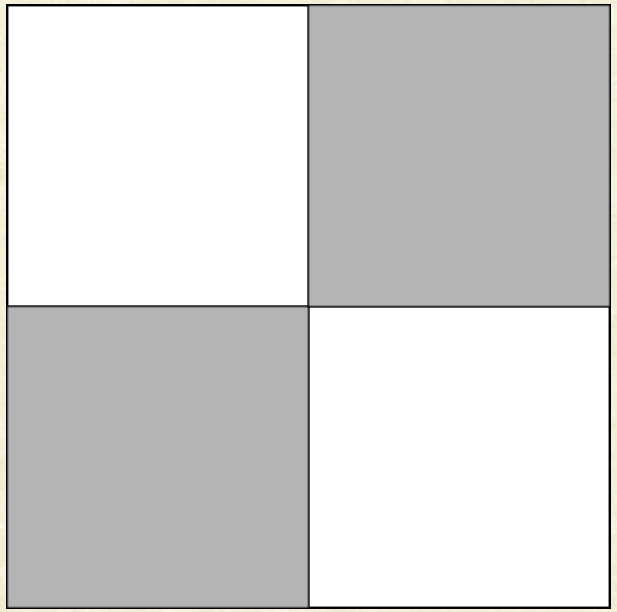
n_i → number of pixels with intensity i

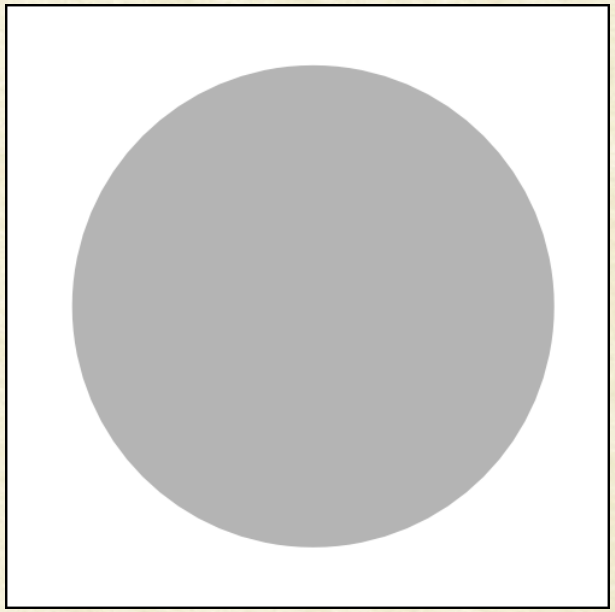


Histograms

- Different images can have same histogram







- No information about spatial distribution of intensity values

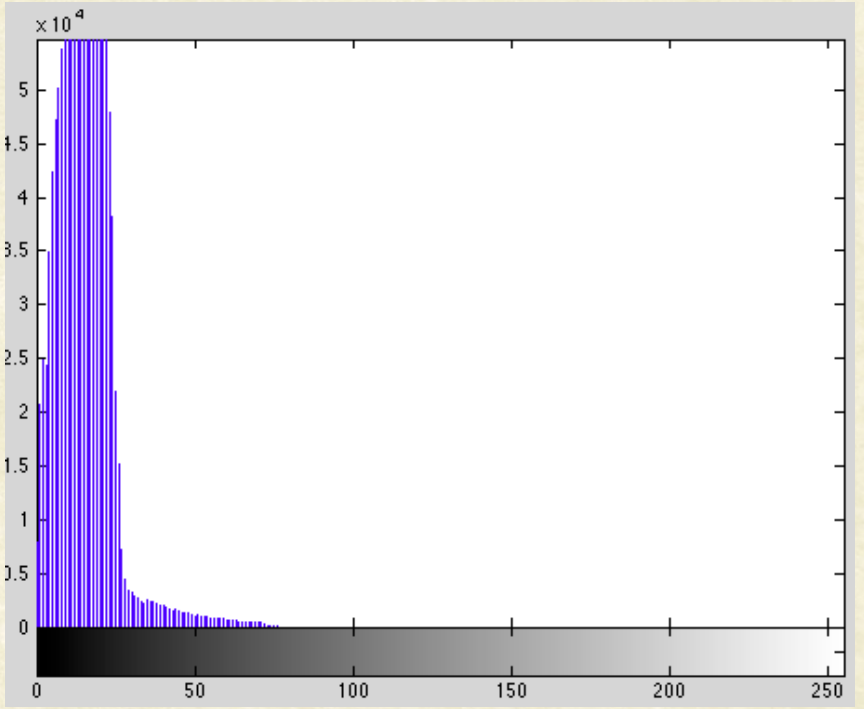
Histograms

- What can we infer from histograms?

Histogram viewing standard in most DSLR cameras

Histograms

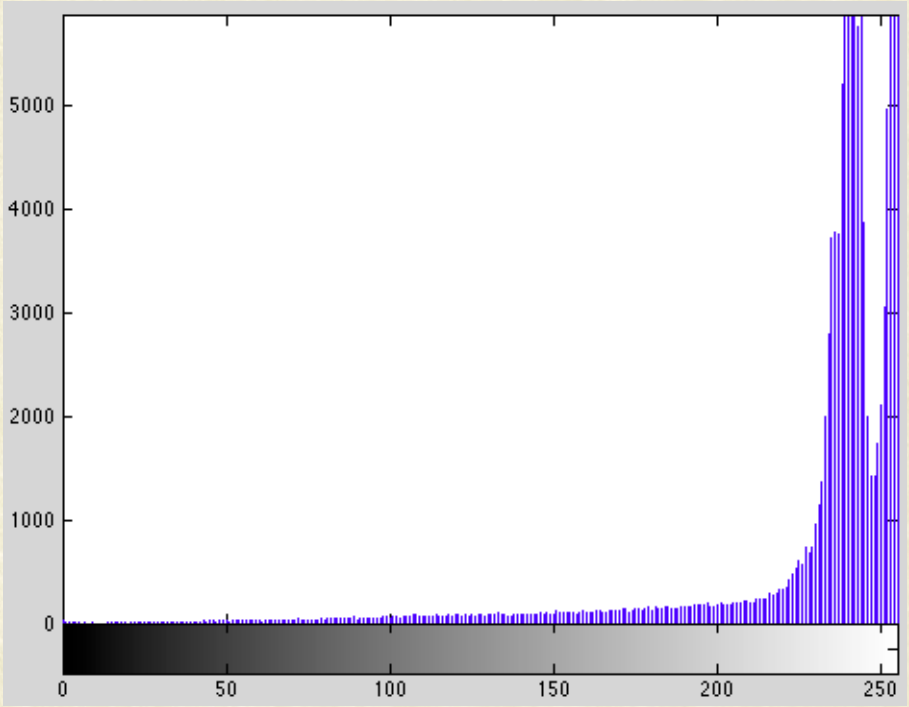
- Histograms and brightness



Under exposure

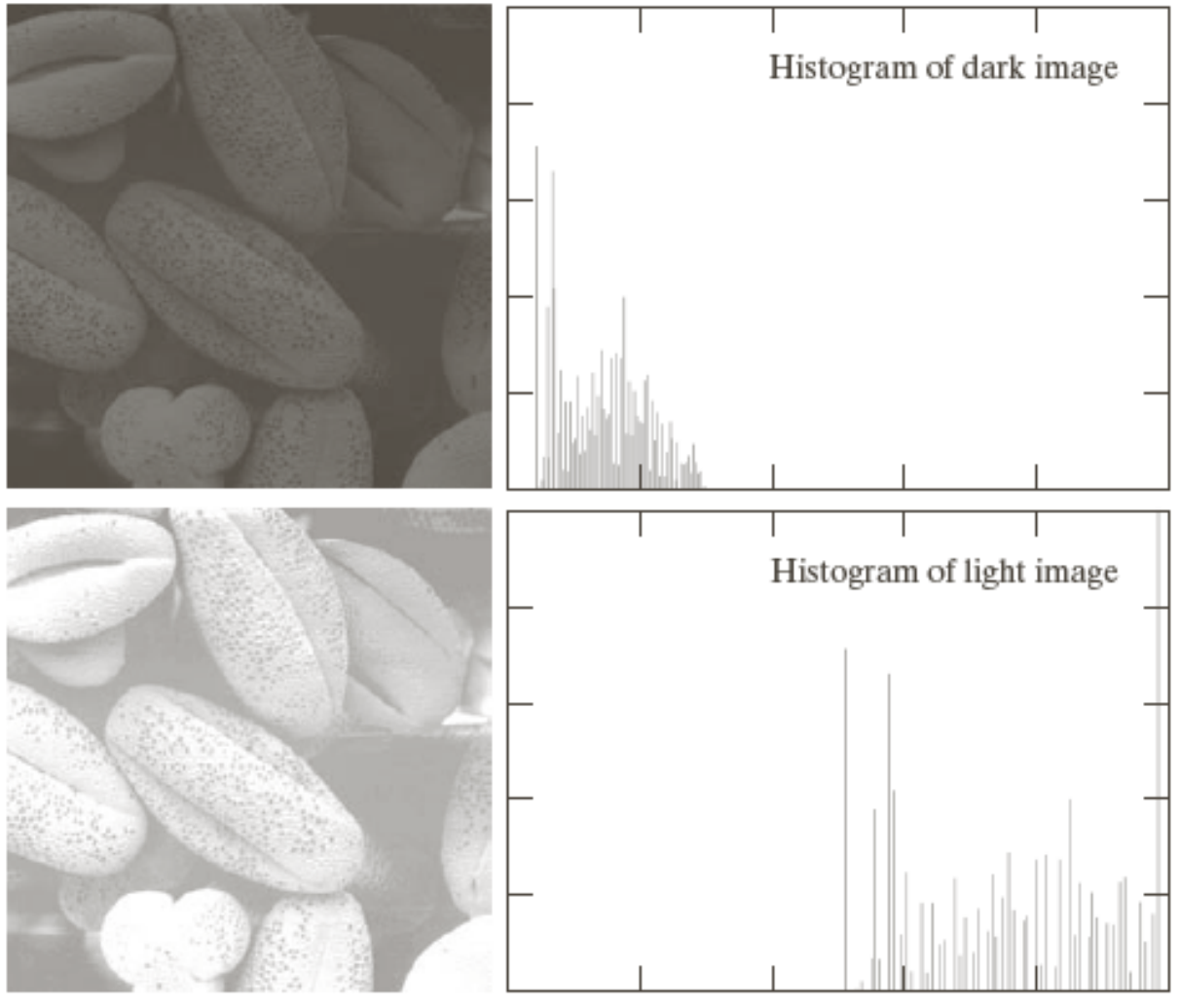
Histograms

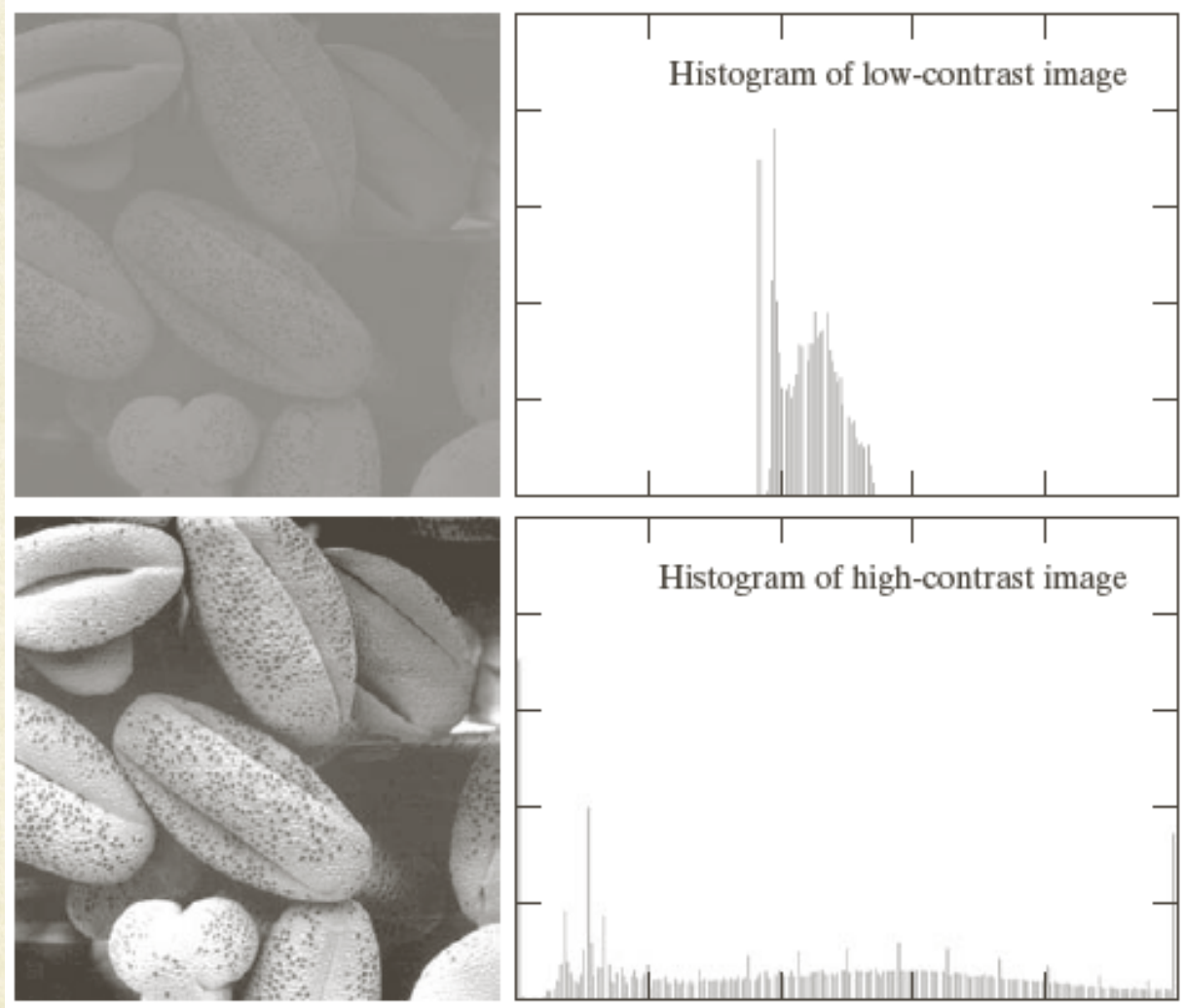
- Histograms and brightness

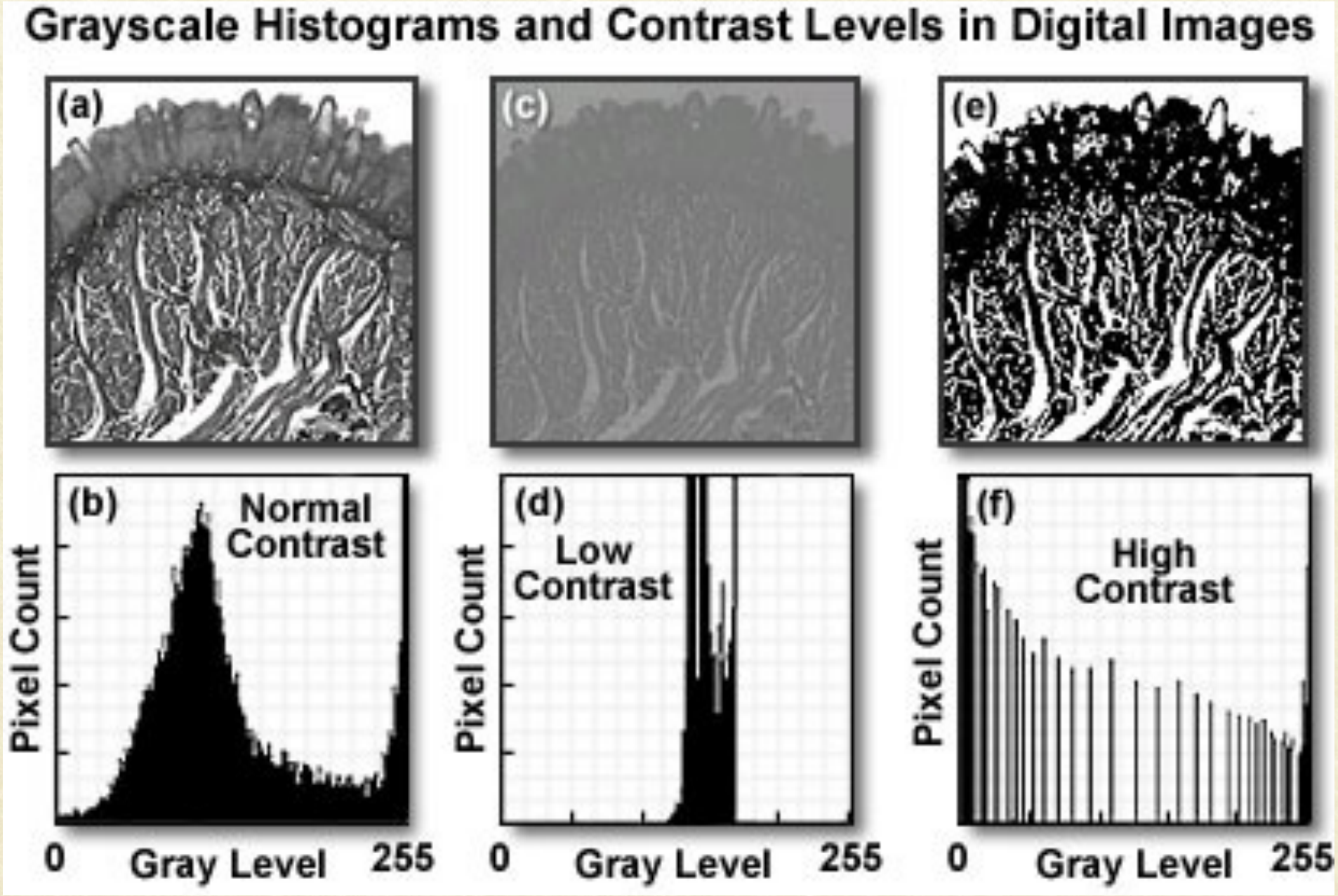


Over exposure

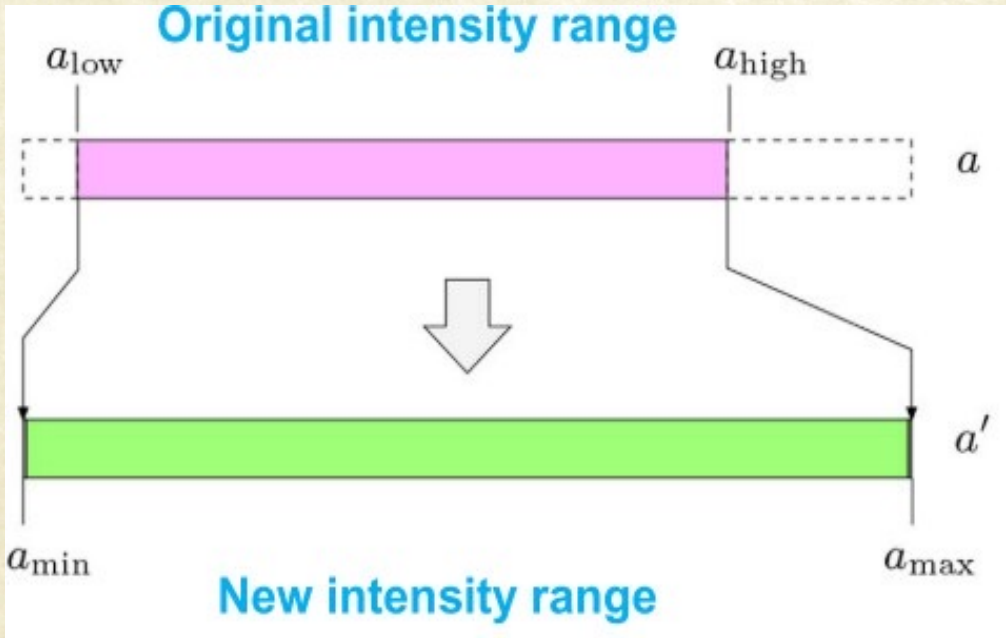
Histogram and Contrast



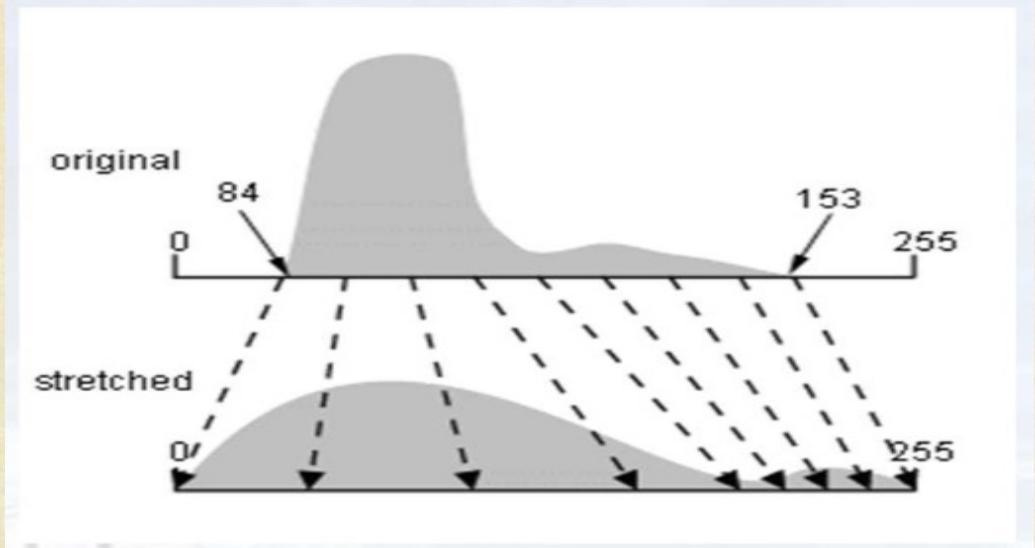


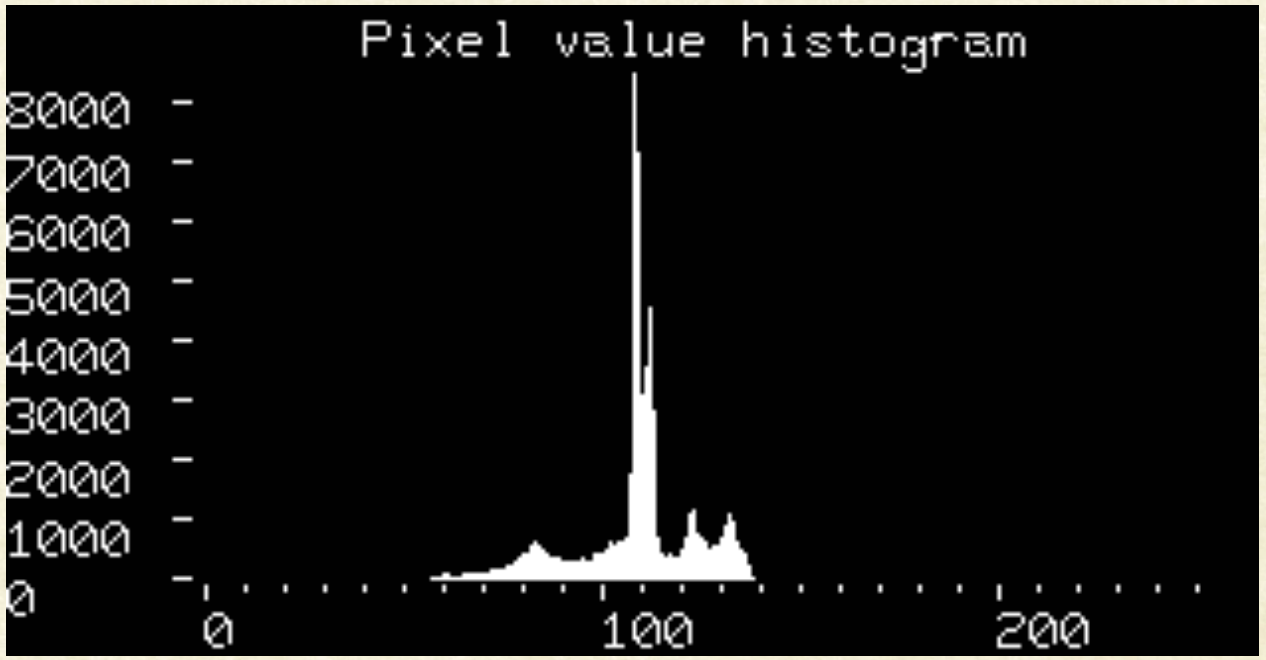

Grayscale Histograms and Contrast Levels in Digital Images
(a)
(c)
(e)
(b)
Normal Contrast
Pixel Count
0
Gray Level
255
(d)
Low Contrast
Pixel Count
0
Gray Level
255
(f)
High Contrast
Pixel Count
0
Gray Level
255

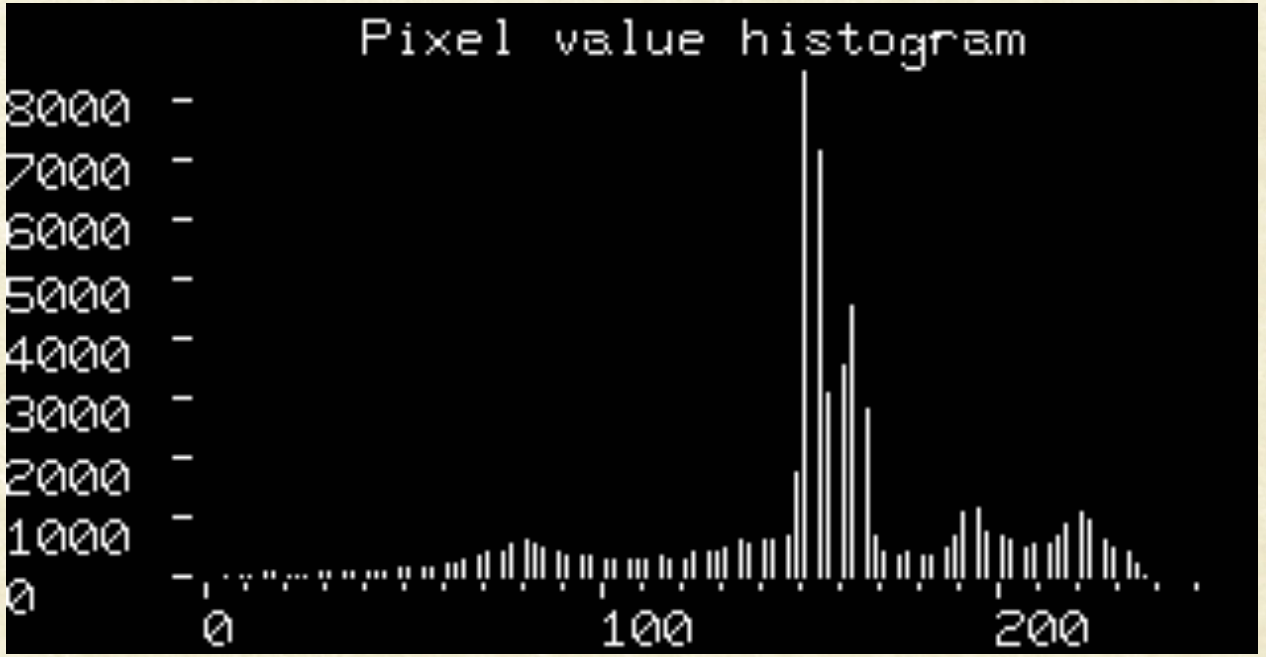
Contrast Stretching



$$f_{ac}(a) = a_{min} + (a - a_{low}) \cdot \frac{a_{max} - a_{min}}{a_{high} - a_{low}}$$




Pixel value histogram
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200

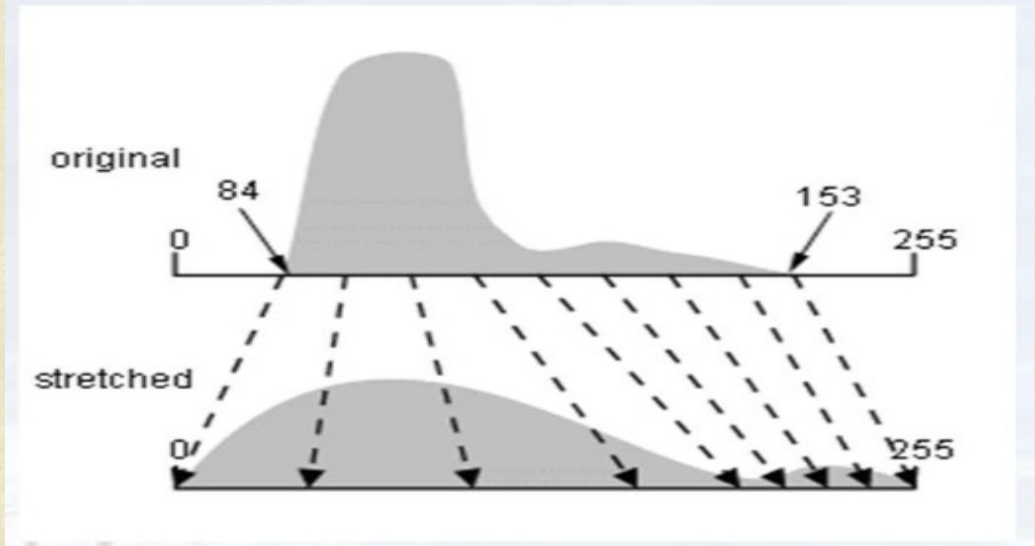

Pixel value histogram
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200

Contrast Stretching

$$f_{ac}(a) = a_{min} + (a - a_{low}) \cdot \frac{a_{max} - a_{min}}{a_{high} - a_{low}}$$

If $a_{min} = 0$ and $a_{max} = 255$

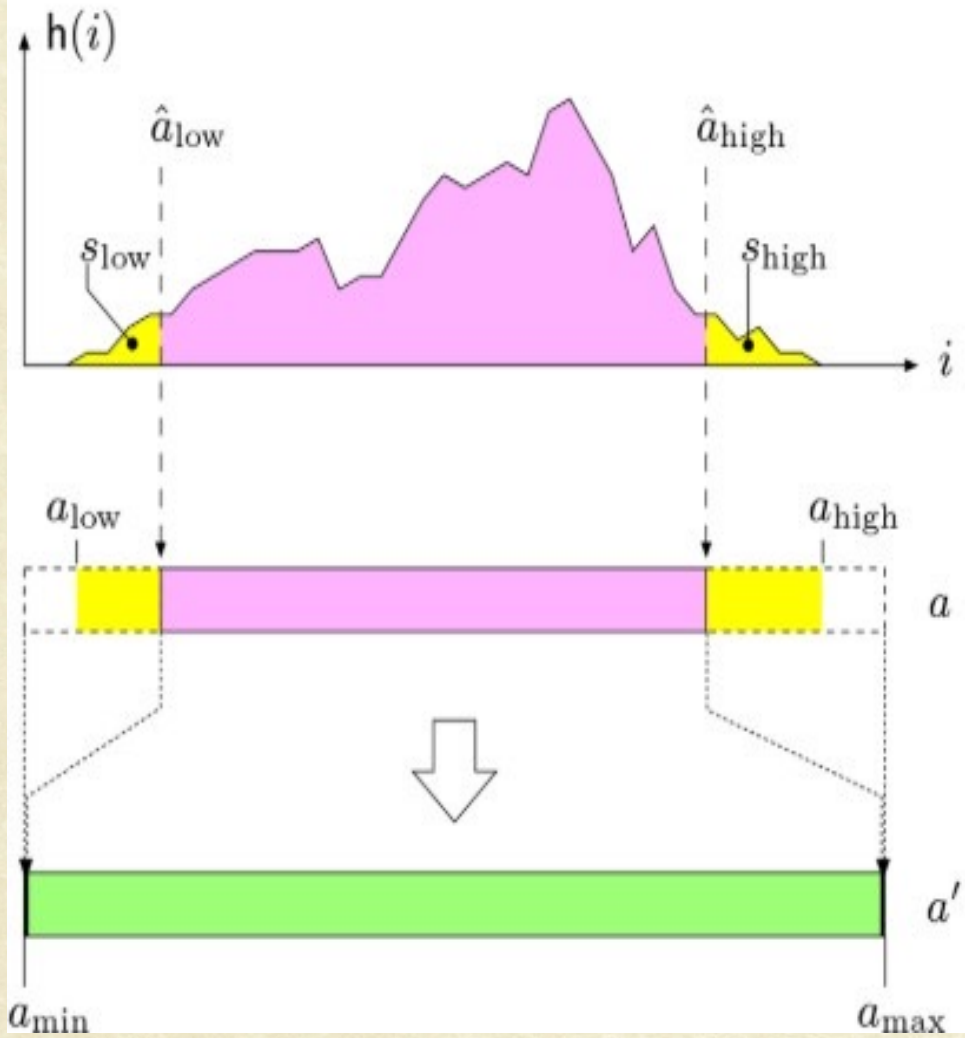
$$f_{ac}(a) = (a - a_{low}) \cdot \frac{255}{a_{high} - a_{low}}$$



What happens if we have a single pixel with intensity 255 in the original intensity range?

What happens if we have a single pixel with intensity 0 in the original intensity range?

Contrast Stretching ver. 2

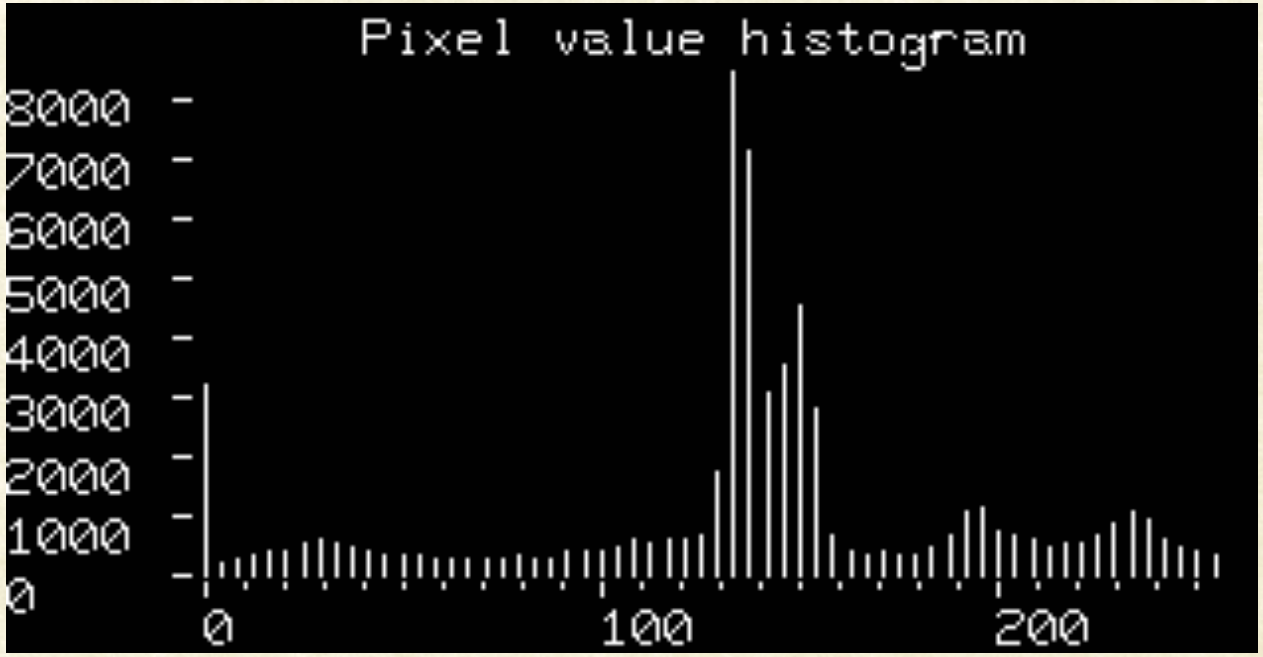


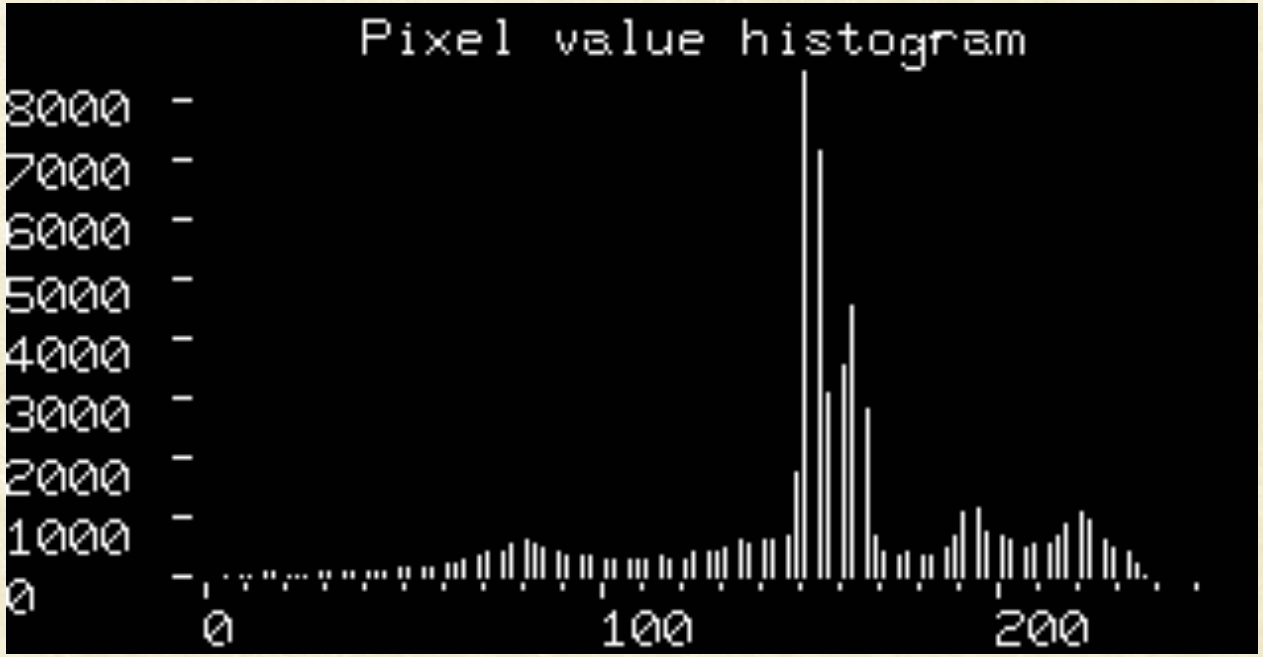
$$\hat{a}_{\text{low}} = \min\{\, i \mid \mathsf{H}(i) \geq M \cdot N \cdot s_{\text{low}} \}$$

$$\hat{a}_{\text{high}} = \max\{\, i \mid \mathsf{H}(i) \leq M \cdot N \cdot (1 - s_{\text{high}}) \}$$

$$f_{\text{mac}}(a) = \begin{cases} a_{\text{min}} & \text{for } a \leq \hat{a}_{\text{low}} \\ a_{\text{min}} + (a - \hat{a}_{\text{low}}) \cdot \dfrac{a_{\text{max}} - a_{\text{min}}}{\hat{a}_{\text{high}} - \hat{a}_{\text{low}}} & \text{for } \hat{a}_{\text{low}} < a < \hat{a}_{\text{high}} \\ a_{\text{max}} & \text{for } a \geq \hat{a}_{\text{high}} \end{cases}$$

Ver. 2

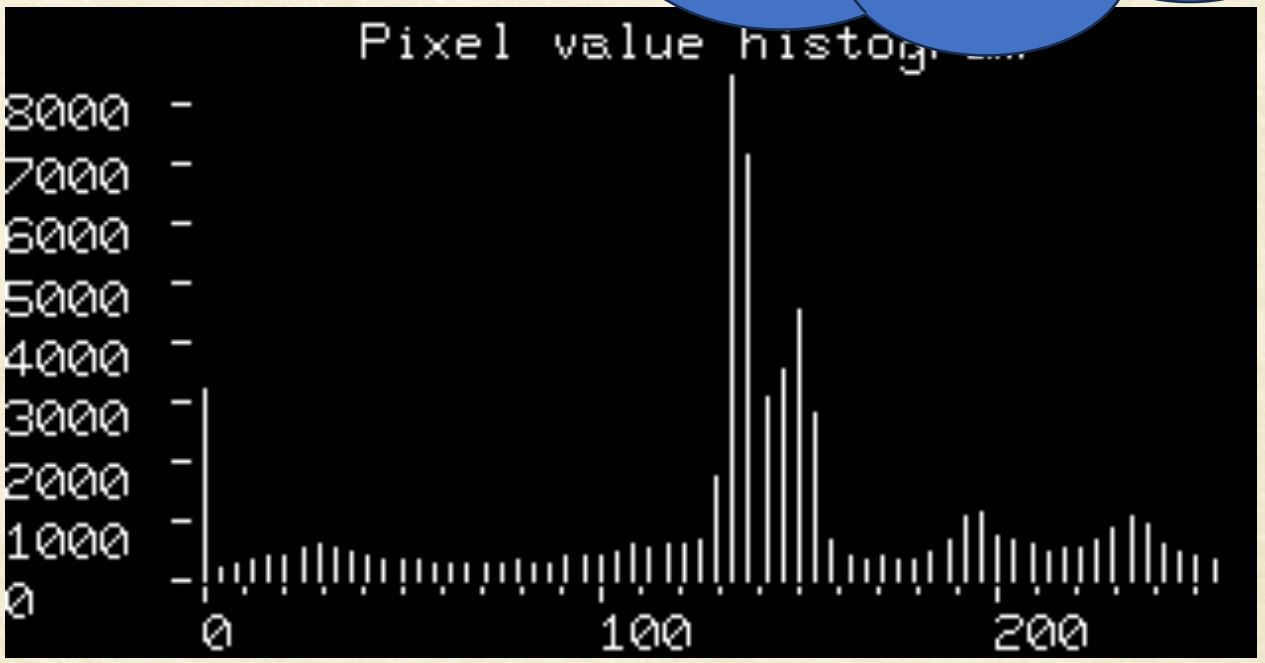

Pixel value histogram
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200


Pixel value histogram
8000
7000
6000
5000
4000
3000
2000
1000
0
0
100
200

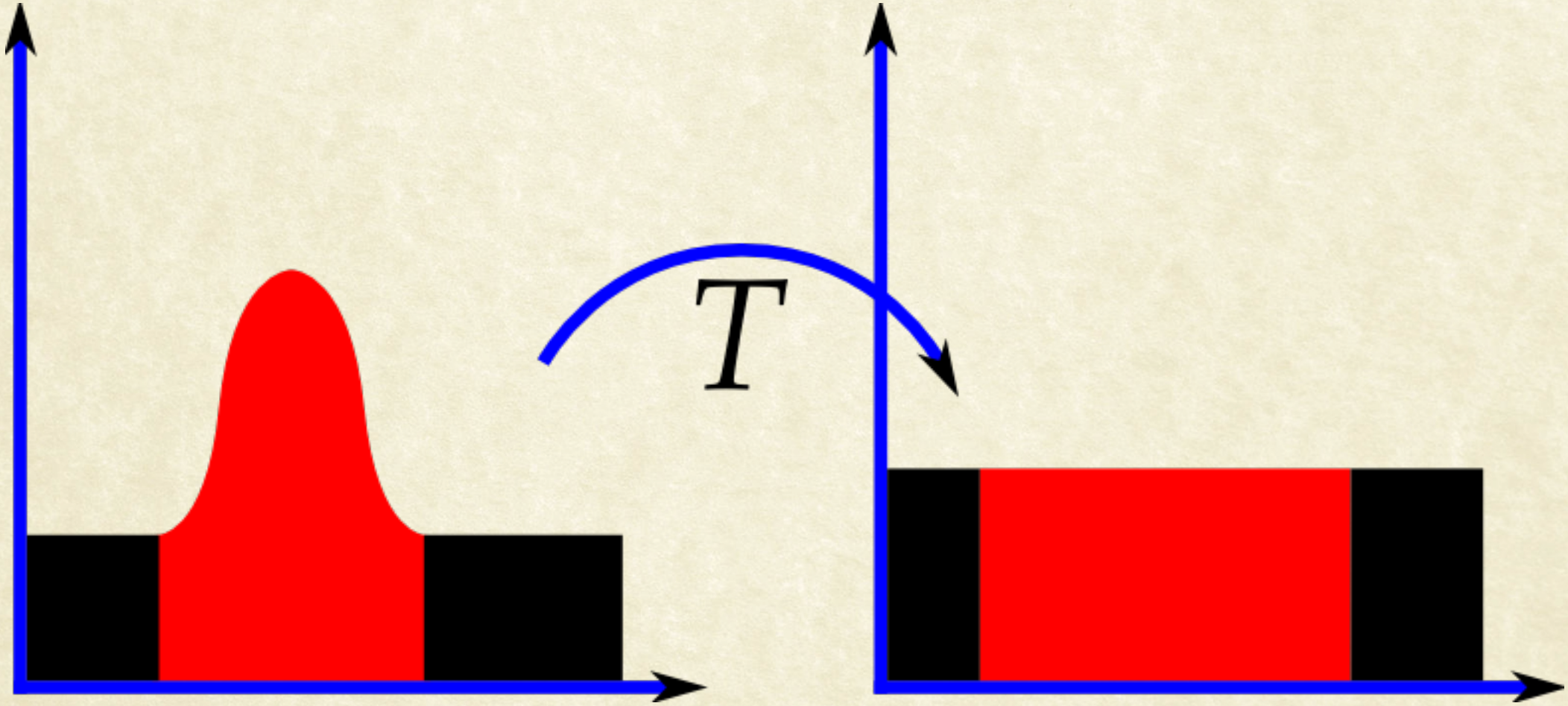
Are all intensities well represented ?

All Intensities Matter

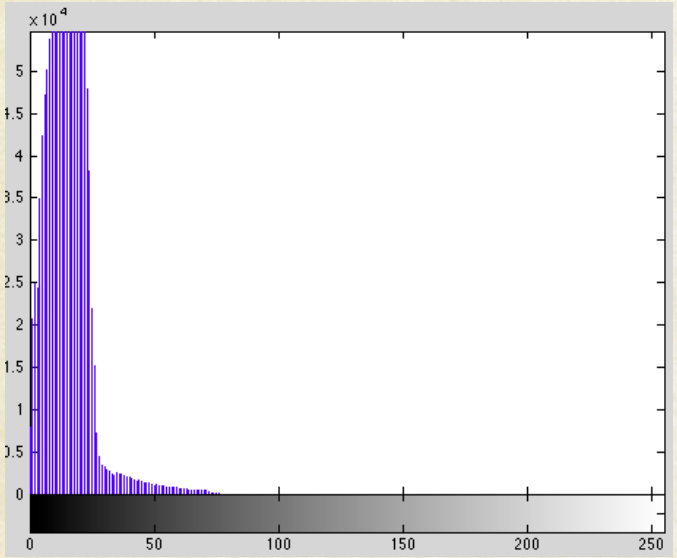
Ver. 2

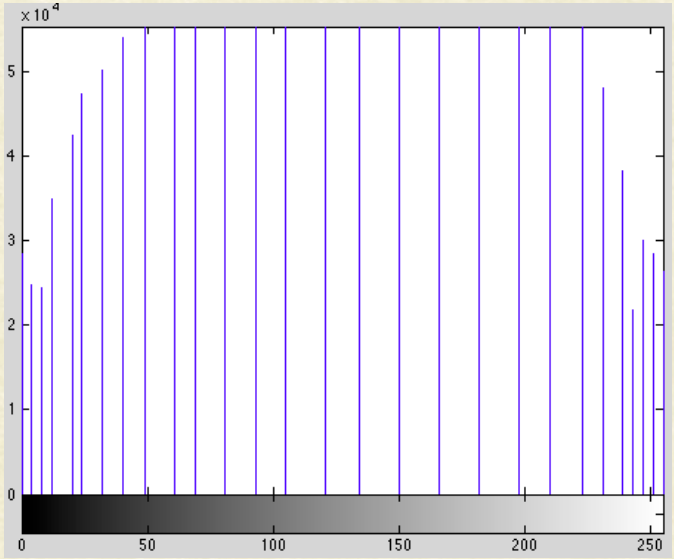


Histogram Equalization



Histogram Equalization



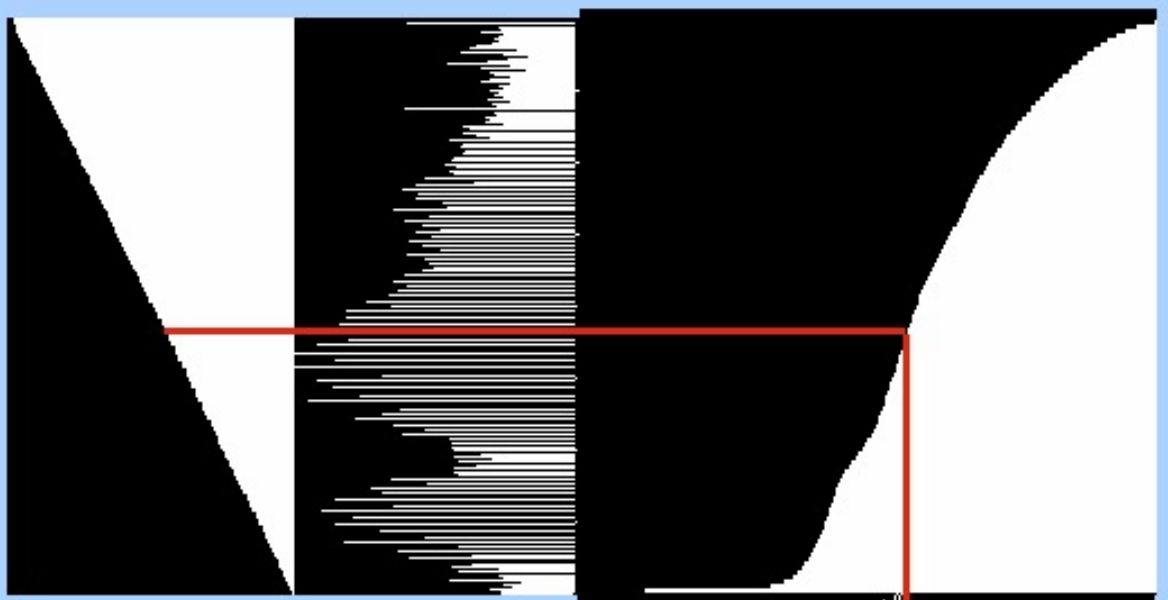


Histogram Equalization

Contrast Stretching

Histogram Equalization

Equalized histogram



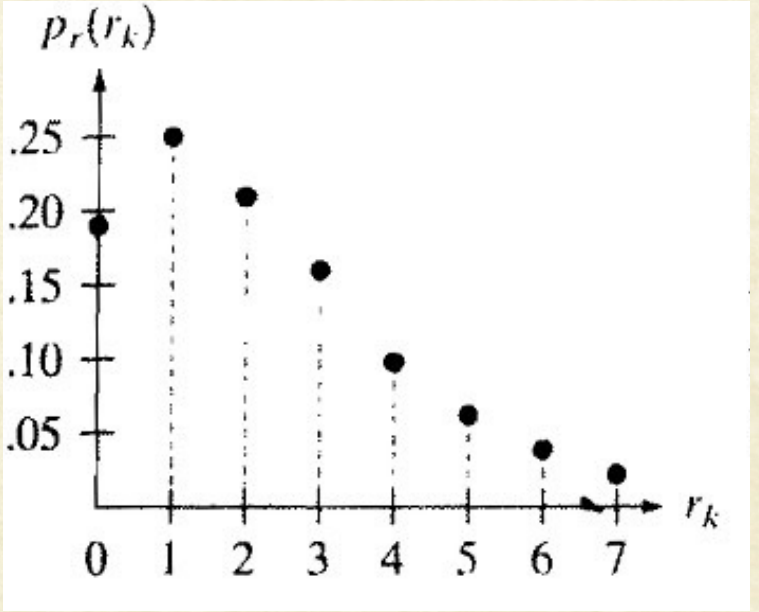
Histogram of riginal image

Histogram Equalization - Example

64 x 64 image

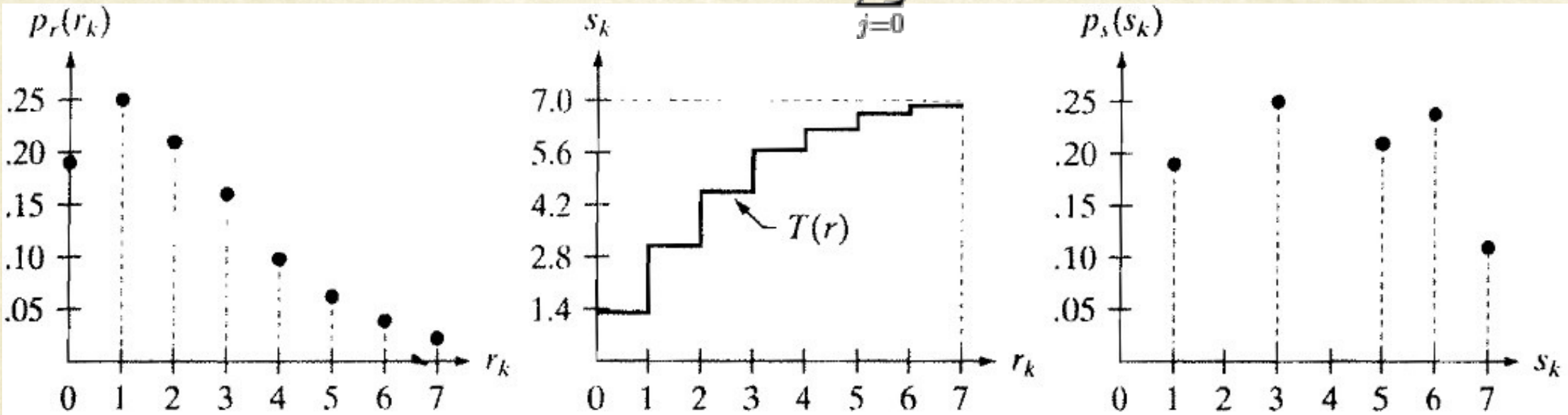
3-bits / pixel

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



Histogram Equalization - Example

$$s_k = \text{round}\left[(L-1)\sum_{j=0}^{k} p_r(r_k)\right]$$



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.

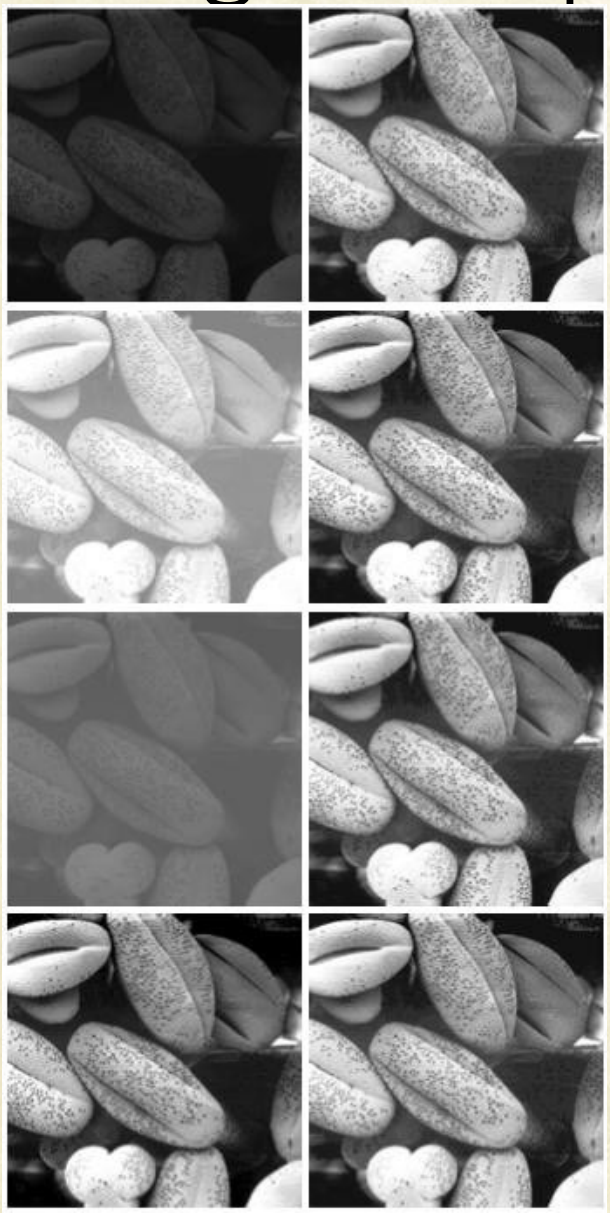
Histogram Equalization

1

2

3

4



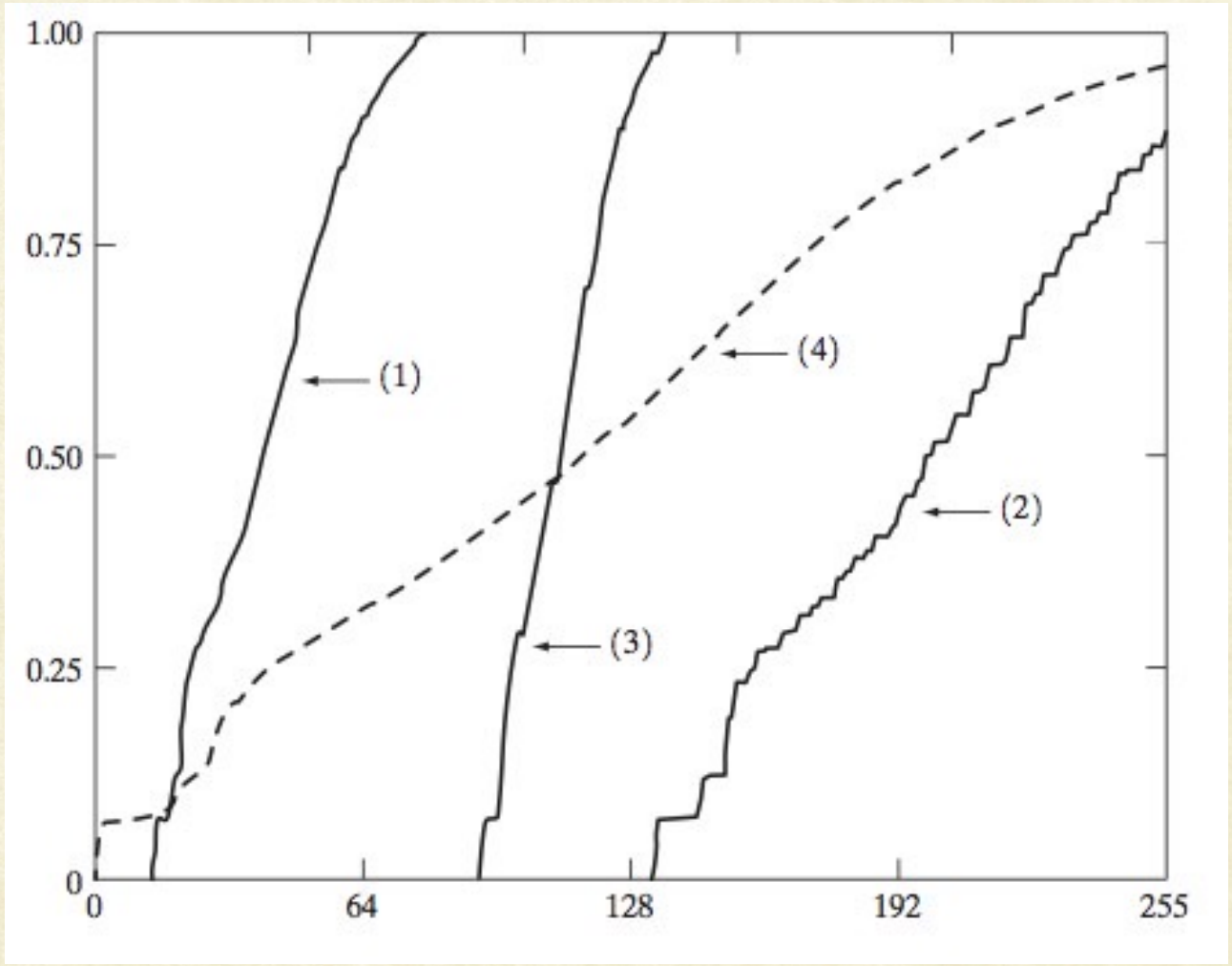


Image Courtesy: Gonzalez and Woods

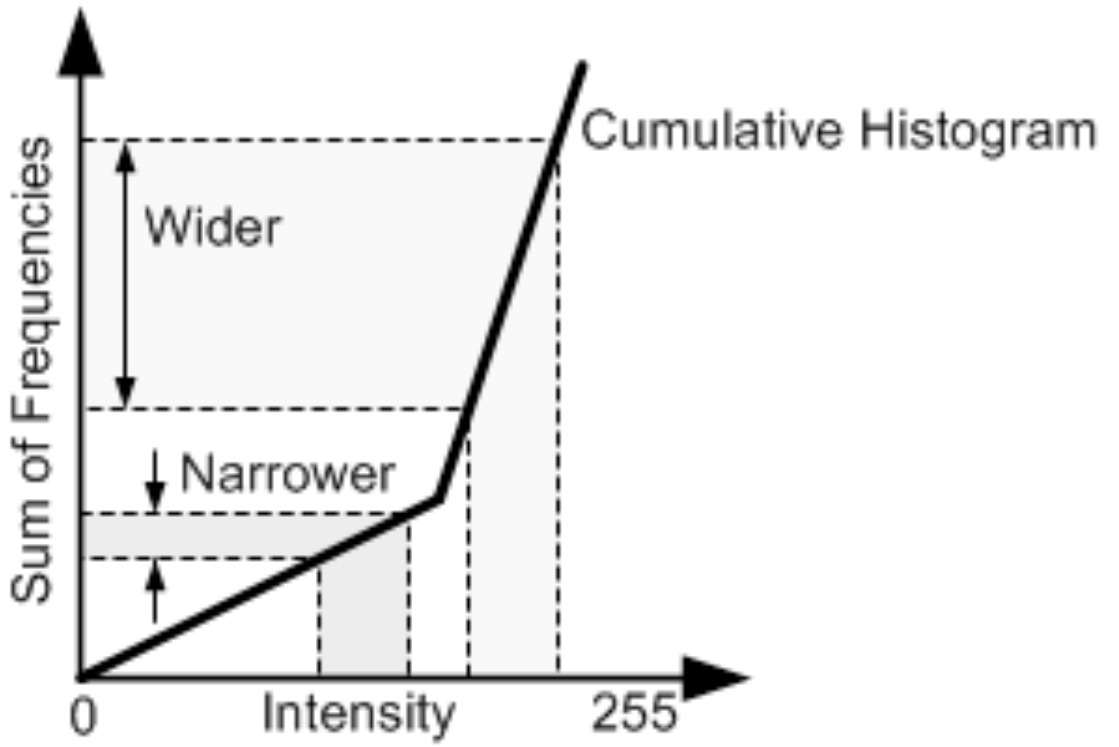
Histogram Equalization v/s Contrast Enhancement

Contrast Enhancement

Histogram equalization

Histogram Equalization: A Visual Explanation

$$h[i] = \text{constant}, \qquad 0 \leq i \leq L-1$$



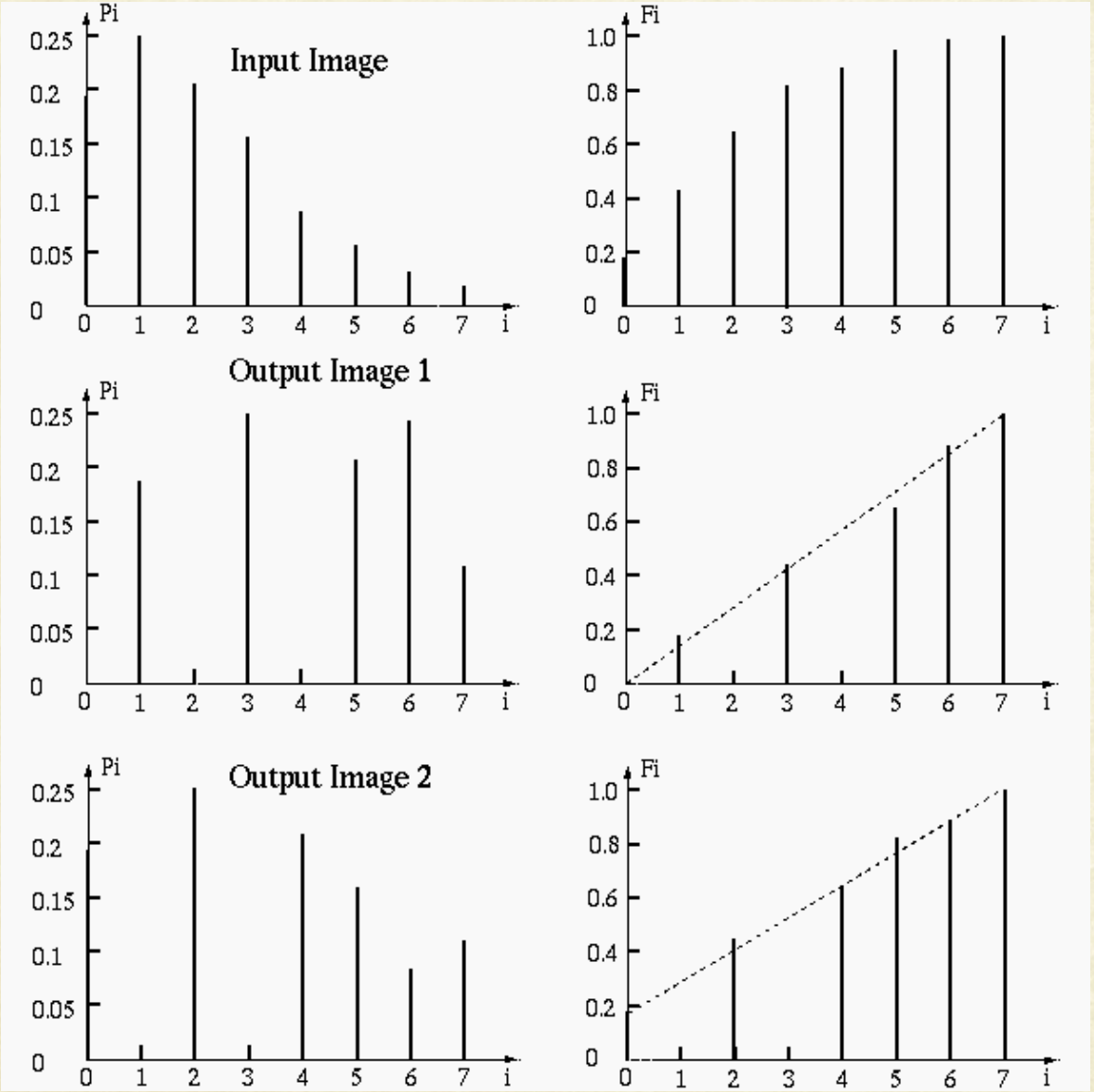
$$s = T(r) = (L-1)\int_0^r p_r(w)dw$$

$$s_k = T(r_k) = round\left((L-1)\sum_{j=0}^{k} p_r(r_j)\right)$$

$$s_k = T(r_k) = round\left((L-1)\frac{cdf(r_k) - cdf_{min}}{1 - cdf_{min}}\right)$$

$$cdf_{min} = p_r(r_a) \text{ where } r_a = \min\{r_t | p_r(r_t) > 0\}; 0 \leqslant r_t \leqslant (L-1)$$

Histogram Equalization (Default v/s Ver. 2)

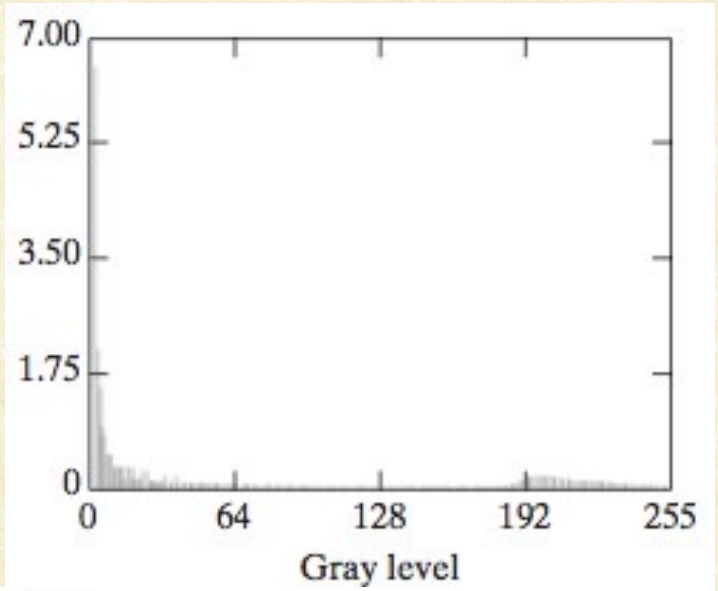


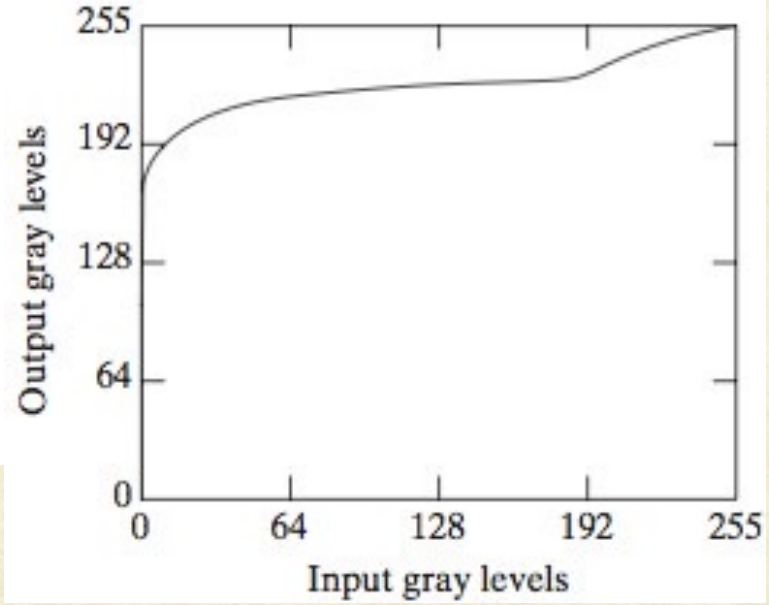
$$s_k = T(r_k) = round\left((L-1) \sum_{j=0}^{k} p_r(r_j) \right)$$

Ver. 2

$$s_k = T(r_k) = round\left((L-1) \frac{cdf(r_k) - cdf_{min}}{1 - cdf_{min}} \right)$$

Histogram Equalization





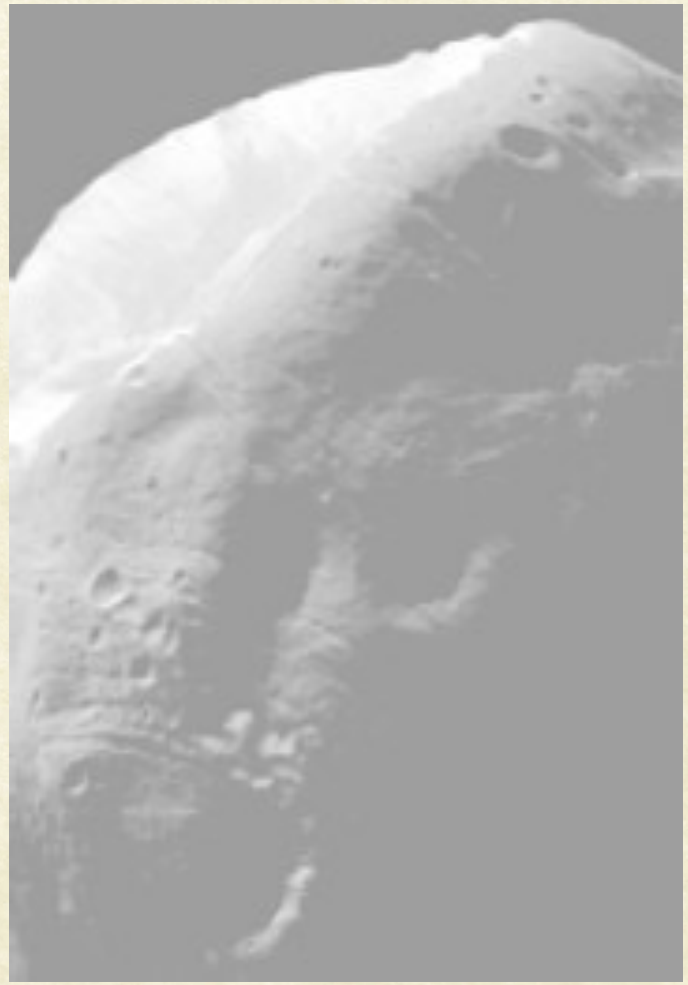
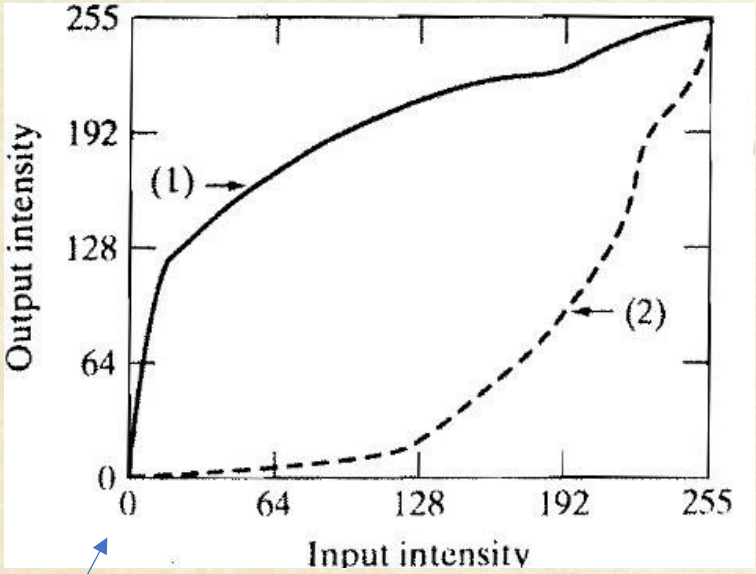
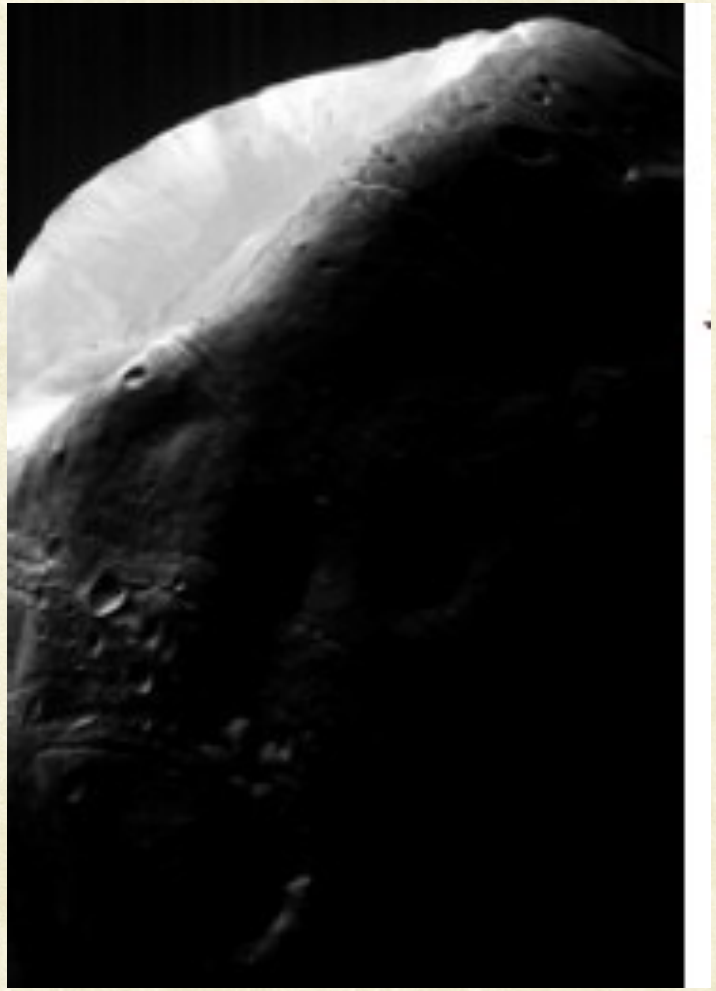


Image Courtesy: Gonzalez and Woods

Histogram Specification / Matching [Section 3.3.2]

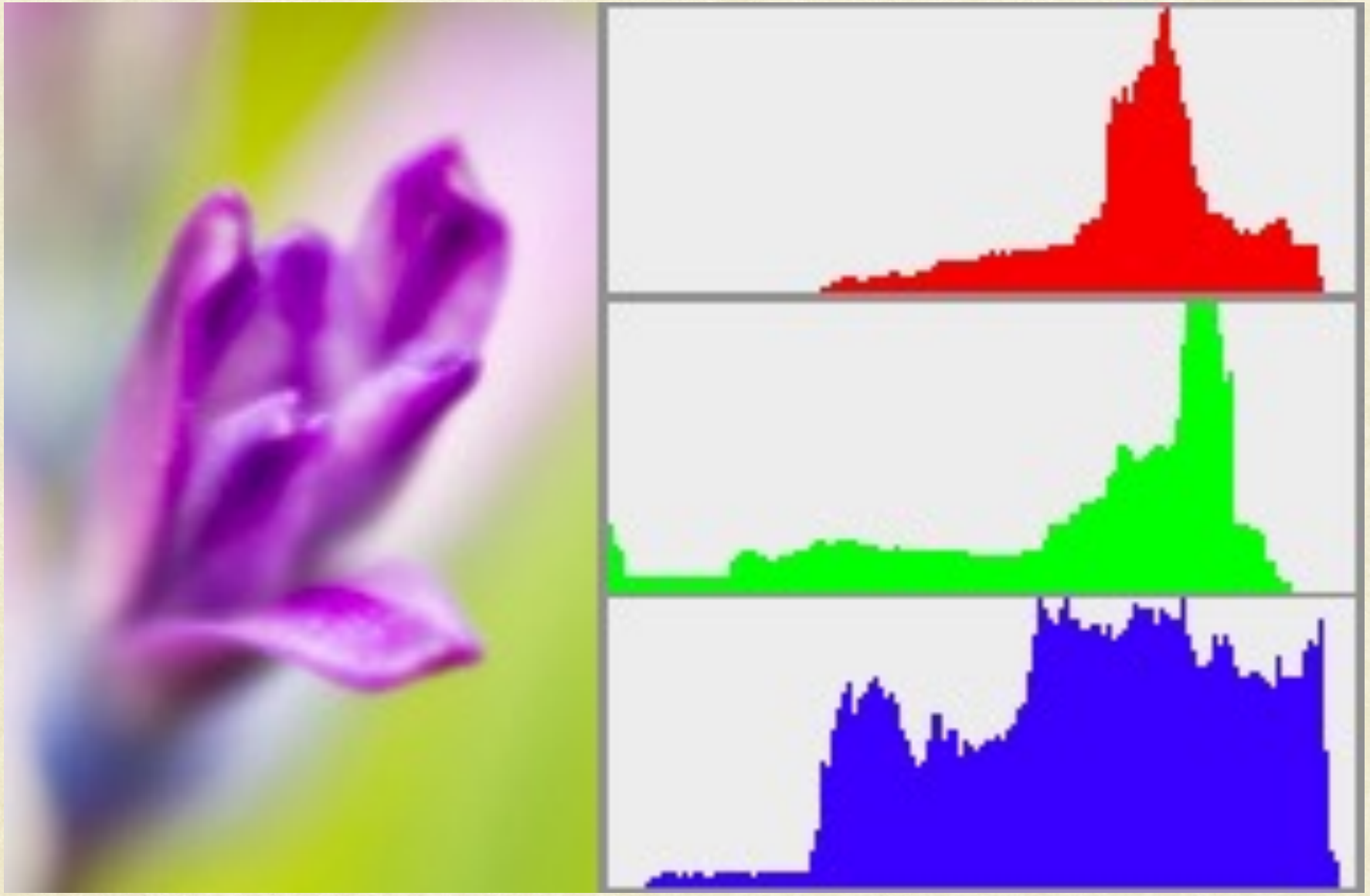


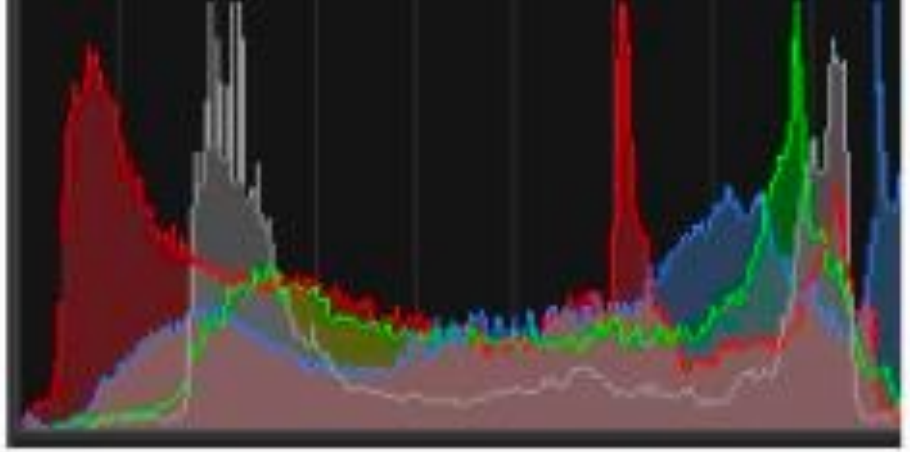


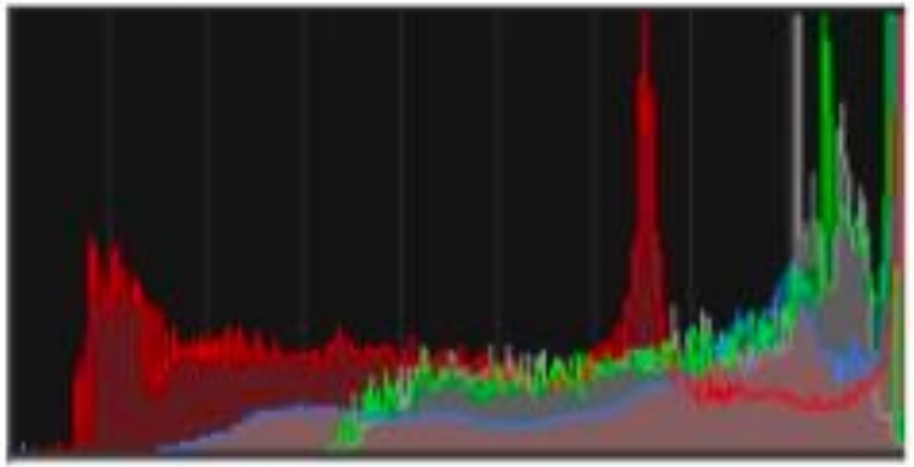
Compare with the curves we saw for contrast enhancement. What's the difference ?

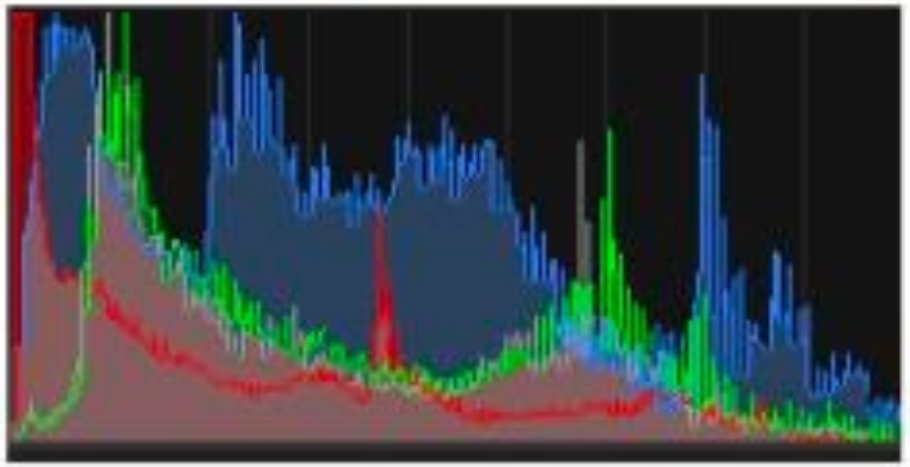
Image Courtesy: Gonzalez and Woods

Histograms for RGB images



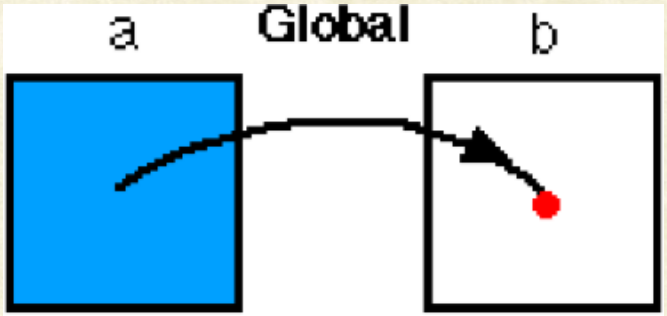






Histogram Processing

- Global to Point



Histogram : Discussion

- A visualization
- A useful statistical representation of image intensities
  - Not dependent on image size
- Drawbacks
  - No spatial information
  - Intensity-centric
  - Raw (unnormalized form): Image-size dependent
- Equalization:
  - An image ‘normalization’ approach
  - Improves global contrast, but can also boost noise

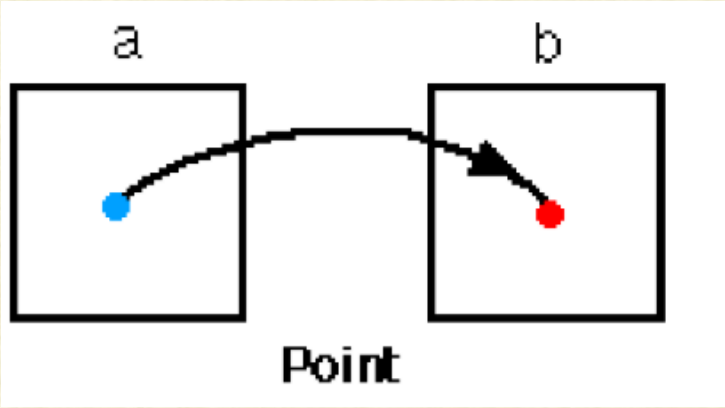
References

- GW Chapter – 3.3.1 to 3.3.3

- Transformations of Random Variables
  - http://www.randomservices.org/random/dist/Transformations.html
  - Section 1 of http://www.cs.cmu.edu/~minx/transform.pdf
  - Leibnitz Integration Rule : https://en.wikipedia.org/wiki/Leibniz_integral_rule#Alternative_derivation
  - Univariate transformation of a random variable

Summary

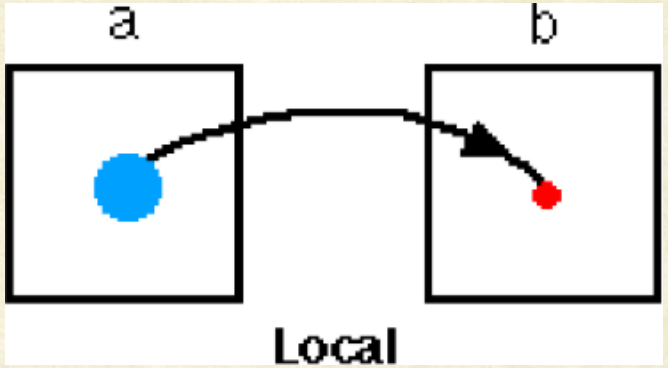
- Manipulating Pixels Directly in Spatial Domain
- 3 approaches
- 1. Point to Point



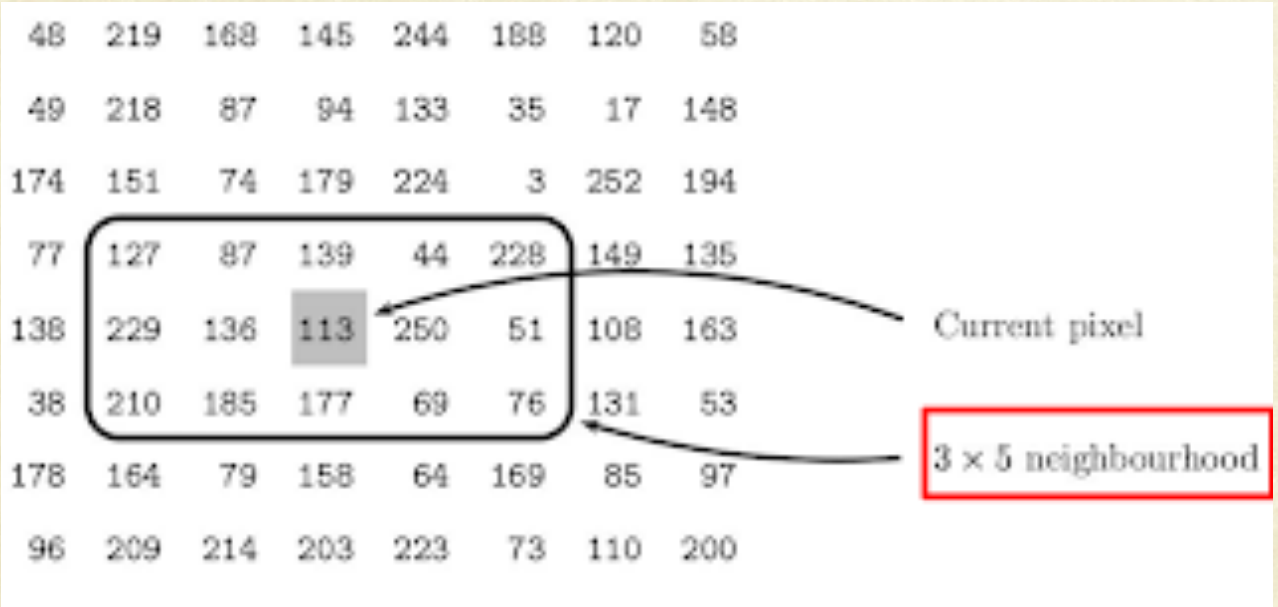
- Linear Intensity Transforms
  - e.g., Negative
- Non-linear Transforms
  - e.g., Logarithm
- Histogram

Spatial Domain Processing

- Manipulating Pixels Directly in Spatial Domain
- 3 approaches



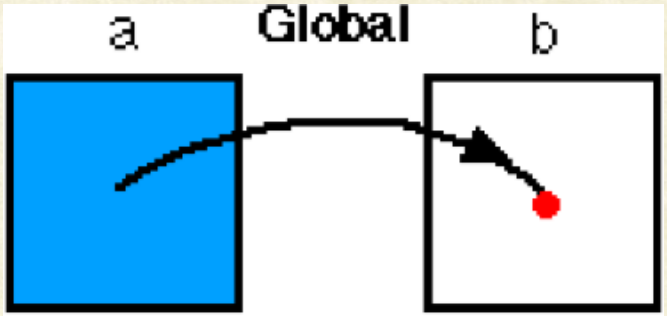
- 2. Neighborhood to Point



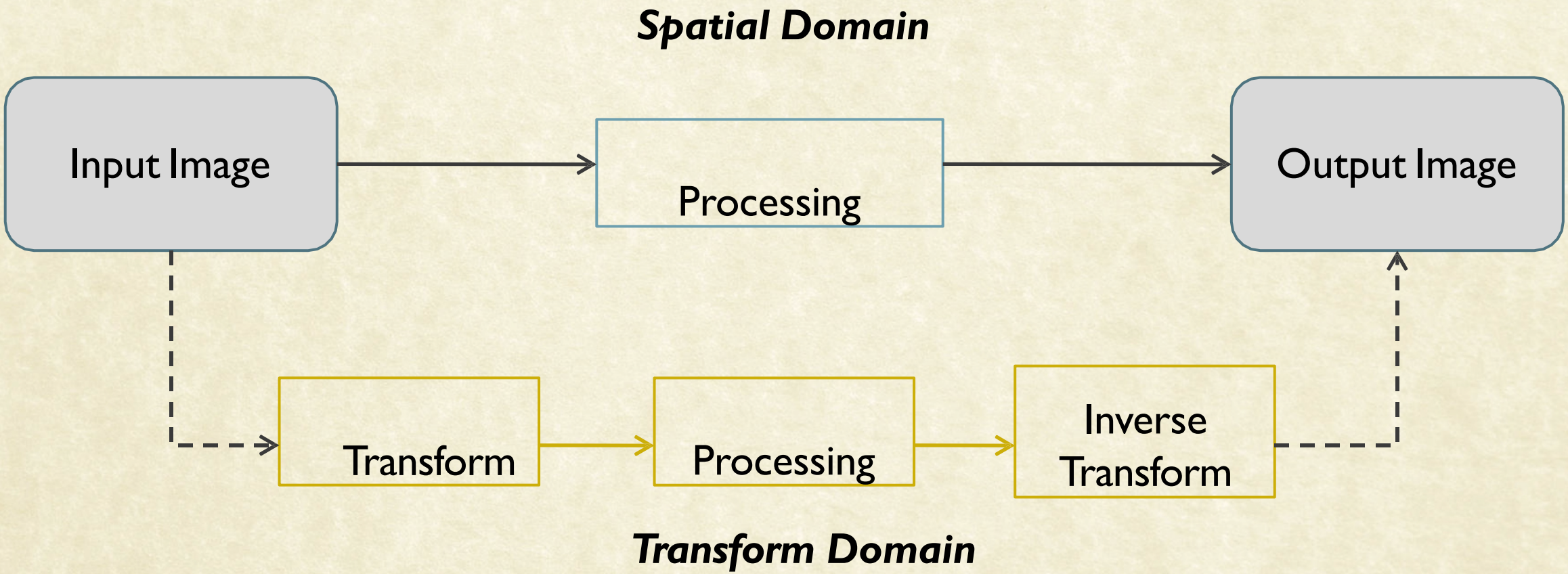
Spatial Domain Processing

- Manipulating Pixels Directly in Spatial Domain
- 3 approaches

- 3. Global to Point



Spatial vs. Transform Domain Processing



Spatial vs. Transform Domain Processing

Bandhani / Bandhej

Tie & Dye

Spatial vs. Transform Domain Processing

Transform (Tie)

Process (Dye)

Inverse Transform (Untie)