CPSC 4040/6040 Computer Graphics Images

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Lecture 10
Point Processing

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Agenda

- Updates on PA01/PA02 Grading
- PA03 questions?

Point Processing

Taxonomy

- Images can be represented in two domains
  - **Spatial Domain**: Represents light intensity at locations in space
  - **Frequency Domain**: Represents frequency amplitudes across a spectrum
- Operations can be classified as either per
  - **Point**: a single input sample is processed to produce an output
  - **Regional**: the output is dependent upon a region of samples

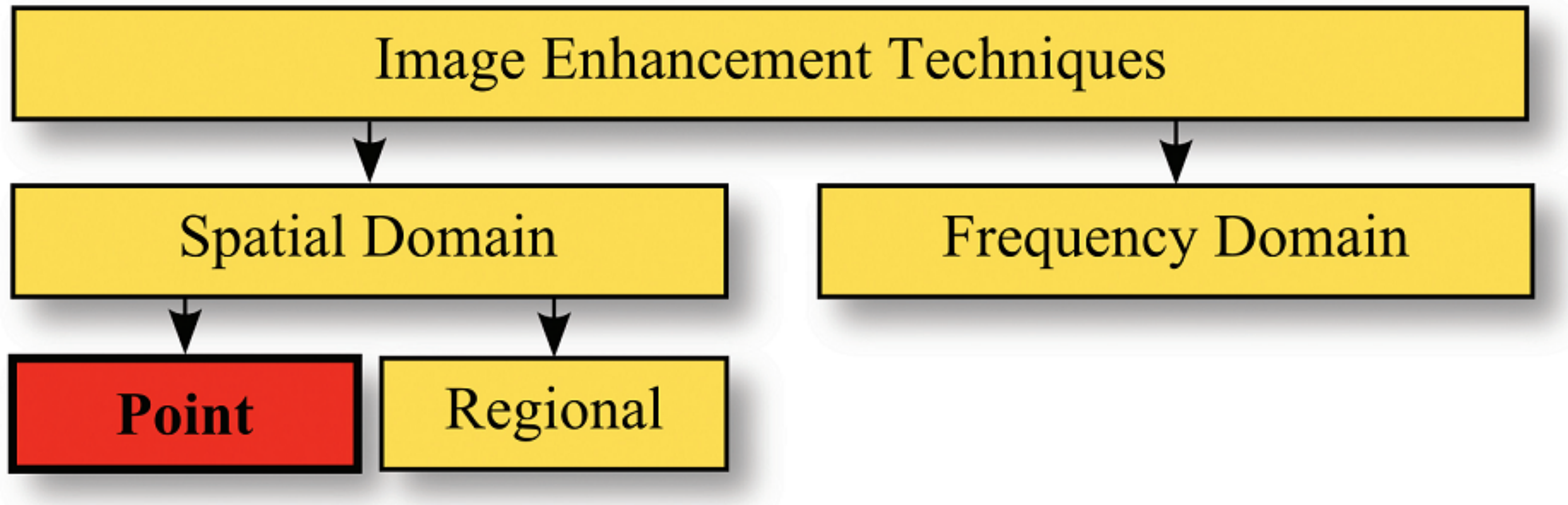
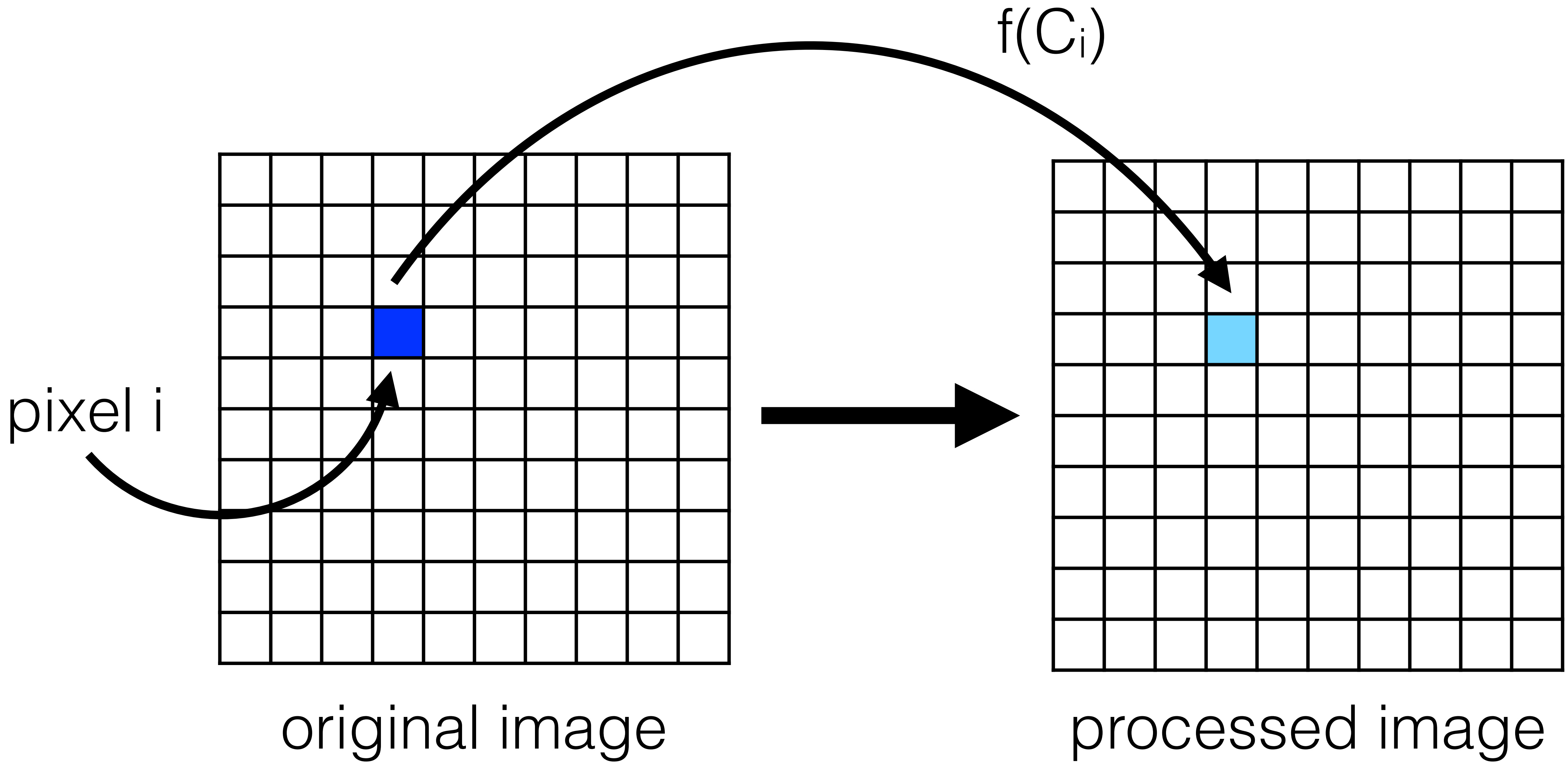


Figure 5.1. Taxonomy of image processing techniques.

Point Processing (Schematic)

$$C_{out} = f(C_{in})$$



Point Processing (Algorithm)

```
//given input: greyscale image
//produces output image: output

for (row = 0, row < H; row++) {
   for (col = 0; col < W; col++) {
      new_color = some_function(image[row][col]);

      output[row][col] = new_color;
   }
}
```

- This basic, but simple algorithm can be extended in lots of ways, depending on the function that we apply to each pixel and each color channel

First Example: Linear Rescaling

- **Rescaling** is a point processing technique that alters the **contrast** and/or **brightness** of an image.
- In photography, **exposure** is a measure of how much light is projected onto the imaging sensor.
    - **Overexposure** causes detail loss in images because more light is projected onto the sensor than what the sensor can measure.
    - **Underexposure** causes detail loss because the sensor is unable to detect the amount of projected light.
- Images which are underexposed or overexposed can frequently be improved by brightening or darkening them.
- In addition, the overall contrast of an image can be altered to improve the aesthetic appeal or to bring out the internal structure of the image.

Rescaling Math

- Given a sample C_{in} of the source image, rescaling computes the output sample, C_{out}, using the scaling function

$$C_{out} = \boldsymbol{\alpha} C_{in} + \boldsymbol{\beta}$$

- $\boldsymbol{\alpha}$ is a real-valued scaling factor known as **gain**
- $\boldsymbol{\beta}$ is a real-valued scaling factor known as **bias**

Rescaling Effects

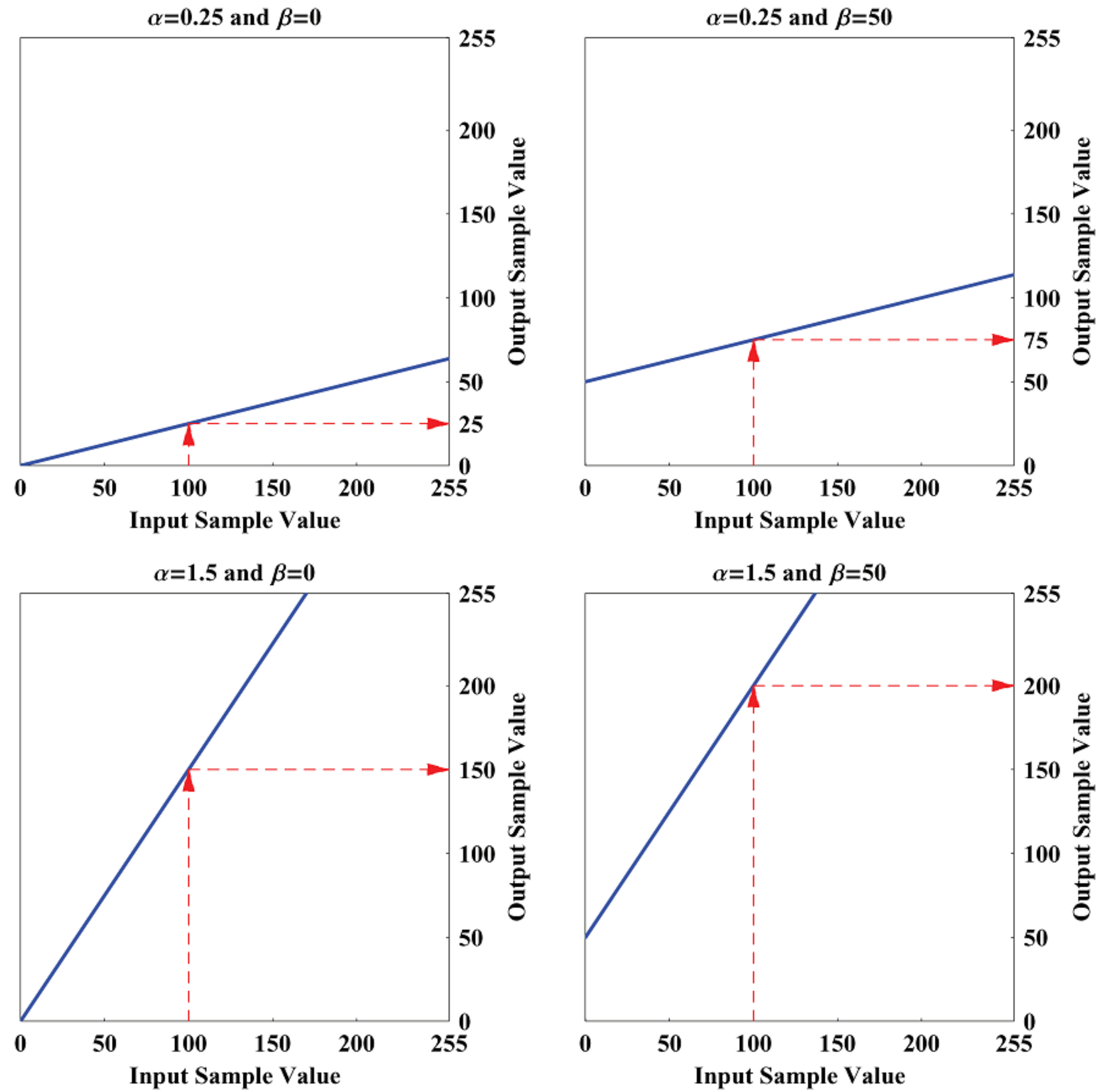


Figure 5.2. Graph of the linear scaling function with various gain and bias settings.

Why Use Both **α**, **β**?

- Take two rescaled source samples S rescaled to S'.

$$\begin{aligned} S'_1 &= \alpha S_1 + \beta, \\ S'_2 &= \alpha S_2 + \beta. \end{aligned}$$

- Calculate the contrast (the absolute difference) between the source and destination, called **Δ**S and **Δ**S'.

$$\begin{aligned} \triangle S' &= |S'_1 - S'_2|, \\ \triangle S &= |S_1 - S_2|. \end{aligned}$$

- Now consider the relative change in contrast between the source and destination.

$$\frac{\triangle S'}{\triangle S} = \frac{|S'_1 - S'_2|}{|S_1 - S_2|}.$$

Why Use Both **α**, **β**?

- The relative change in contrast can be simplified as

$$
\begin{aligned}
\frac{\triangle S'}{\triangle S} &= \frac{|(\alpha S_1 + \beta) - (\alpha S_2 + \beta)|}{|S_1 - S_2|} \\
&= \frac{|\alpha| \cdot |S_1 - S_2|}{|S_1 - S_2|} \\
&= |\alpha|.
\end{aligned}
$$

- Thus, gain (**α**) controls the change in contrast.
- Whereas bias (**β**) does not affect the contrast
- Bias, however, controls the final brightness of the rescaled image. Negative bias darkens and positive bias brightens the image

Clamping

- Rescaling may produce samples that lie outside of the output images 8-bit dynamic range.
  - May be less than zero or more than 255
- **Clamping** the output values ensures that the output samples are truncated to the 8-bit dynamic range limit
  - Any output greater than 255 is set to 255
  - Any output less than zero is set to be zero
  - Note that clamping does 'lose' information as a result of truncation

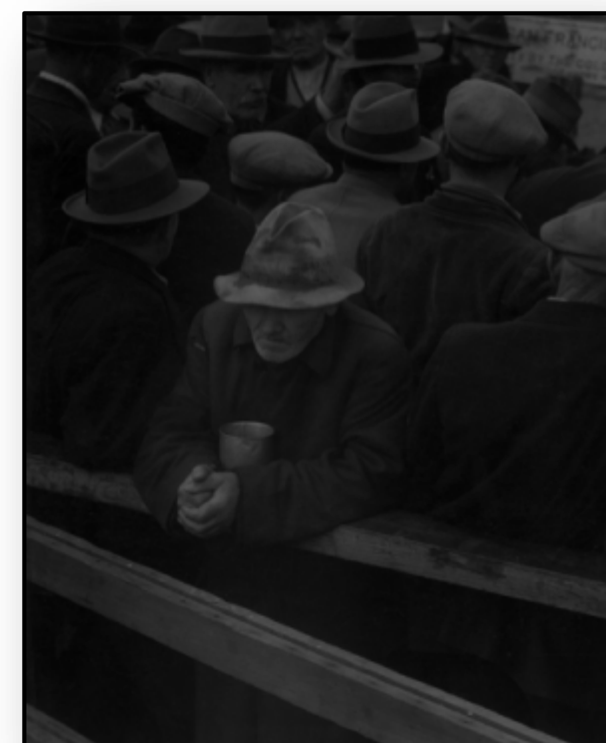
$$\boxed{clamp(x, min, max) = \begin{cases} \min & \text{if } \lfloor x \rfloor \leq \min, \\ \max & \text{if } \lfloor x \rfloor \geq \max, \\ \lfloor x \rfloor & \text{otherwise.} \end{cases}}$$

Examples

gain = 1, bias = 55

gain = 1, bias = -55

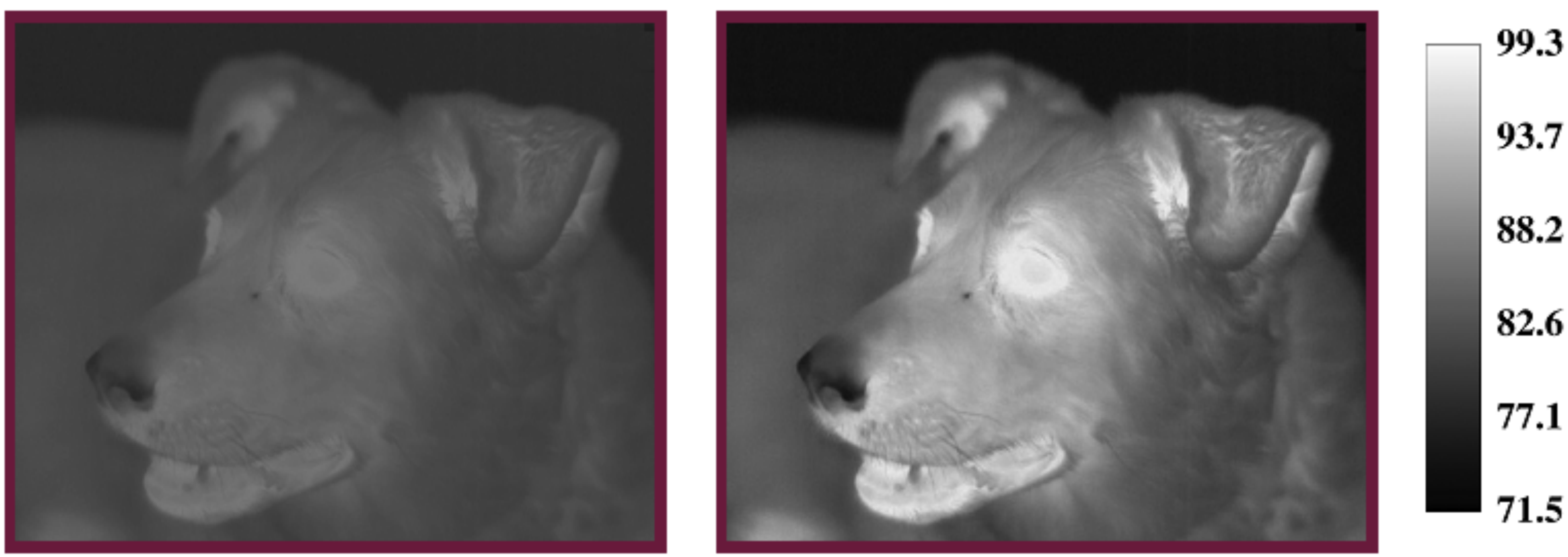
gain = 2, bias=0



gain = .5, bias=0

“Scientific” Example

- The thermal image of a dog below is from a hot summer evening.
- The range of temperatures might extend from 71.5 to 99.3, but these values don’t correspond well to visual data (it’s a mostly dark-gray image with little contrast).
- The data can be rescaled to increase contrast enhance the visual interpretation of the data.



(a) Original thermal image.

(b) Rescaled image and legend.

Figure 5.3. A thermal imaging system captures temperature readings. (Images courtesy of Jason McAdoo.)

Rescaling Color Images

- Rescaling can be naturally extended to color images by rescaling every channel of the source using the same gain and bias settings.

- Often it is desirable to apply different gain and bias values to each channel of a color image separately, examples:

    1. A color image that utilizes the HSB color model. Since all color information is contained in the H and S channels, it may be useful to adjust the brightness, encoded in channel B, without altering the color of the image in any way.

    2. An RGB image that has, in the process of acquisition, become unbalanced in the color domain. It may be desirable to adjust the relative RGB colors by scaling each channel independently of the others.

- Rescaling the channels of a color image in a non-uniform manner is also possible by treating each channel as a single grayscale image

(a) Original.

(b) Gain = .7, bias = 0.

(c) Gain = 1.2, bias = 40.

(d) Gain = -1, bias = 255.

Rescaling Channels Separately

(e) Gain = (1,0,0), bias = (0,0,0).

(f) Gain = (-1,1,1), bias = (255,0,0).

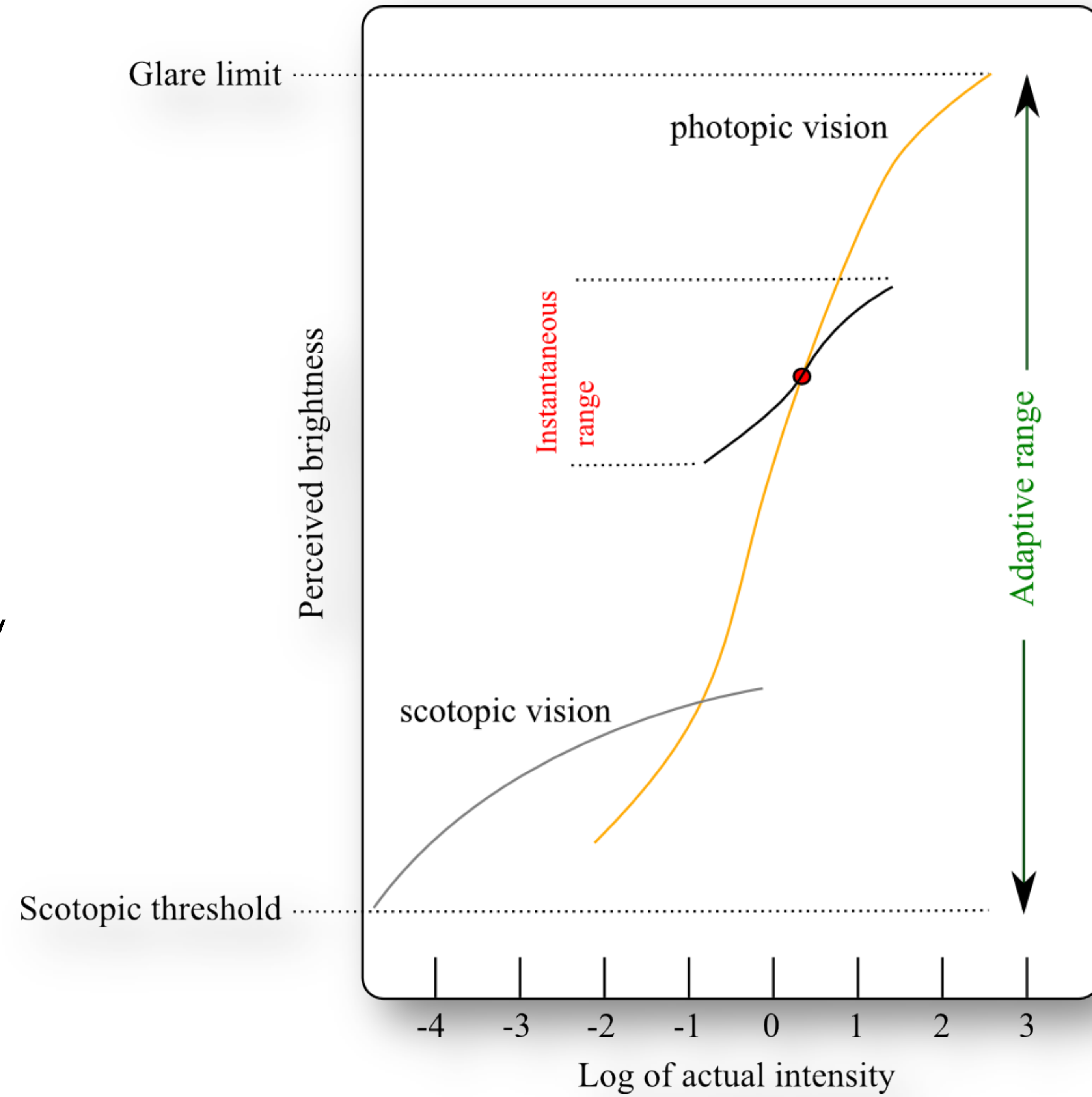
Gamma Correction

Gamma Correction

- **Gamma correction** is an image enhancement operation that seeks to maintain perceptually uniform sample values throughout an entire imaging pipeline.
- Since each phase of the process described above may introduce distortions of the image it can be difficult to achieve precise uniformity.
- Gamma correction seeks to eliminate the nonlinear distortions introduced by the first (acquisition) and the final (display) phases of the image processing pipeline.

Recall: Brightness Adaptation

- Actual light intensity is (basically) log-compressed for perception.
- Human vision can see light between the glare limit and scotopic threshold but not all levels at the same time.
- The eye adjusts to an average value (the red dot) and can simultaneously see all light in a smaller range surrounding the adaptation level.
- Light appears black at the bottom of the instantaneous range and white at the top of that range.



Human Perception

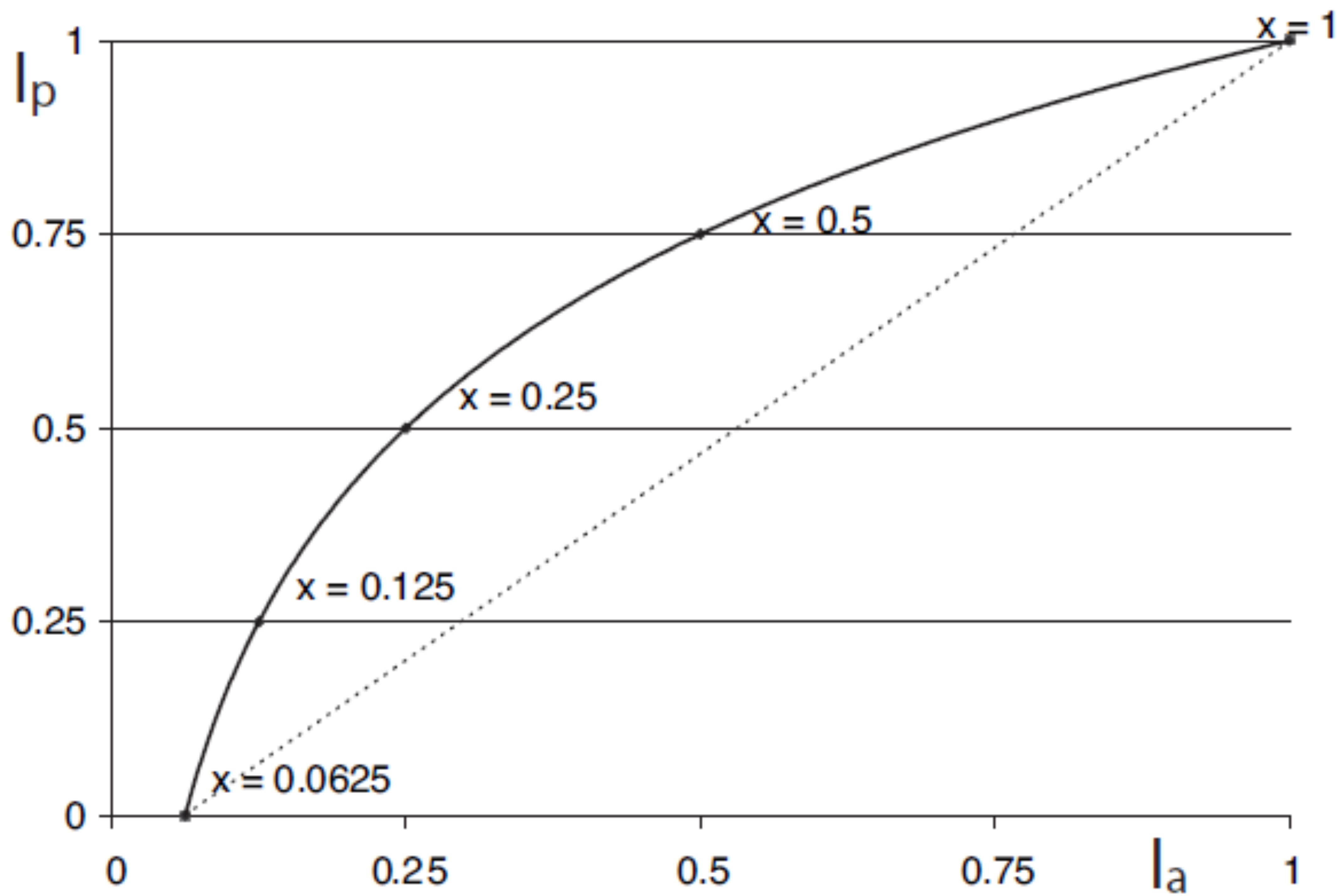
- Eye distinguishes color intensities as a function of the *ratio* between intensities.

- Consider $I_1 < I_2 < I_3$, for the step between I_1 and I_2 to look like the step from I_2 to I_3, it must be that:

$$I_2 / I_1 = I_3 / I_2$$

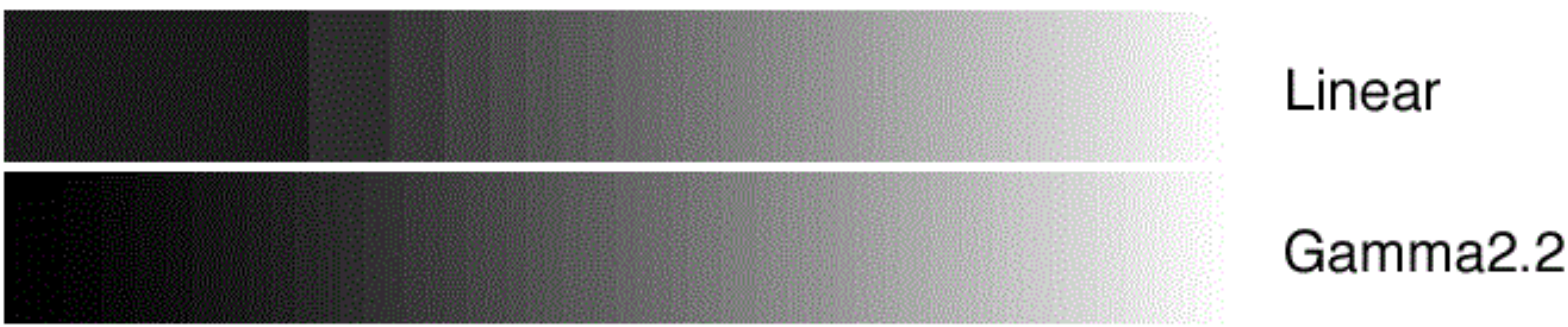
- As opposed to the differences! $I_2 - I_1 \neq I_3 - I_2$

Perceived (I_p) vs. Actual (I_a)



Perceived (I_p) vs. Actual (I_a) Intensity

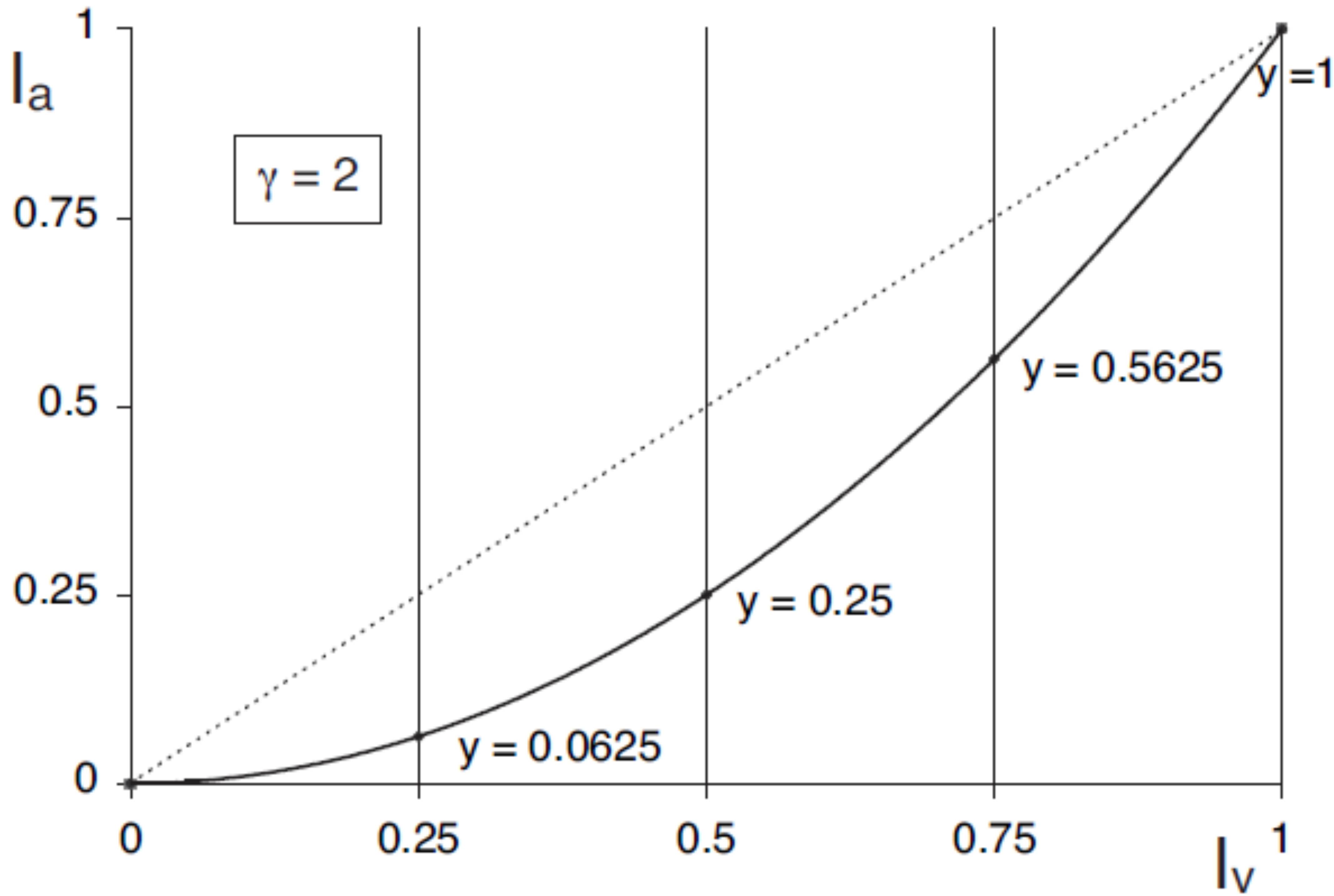
- Perceived light actually behaves like $I_p = (I_a)^{\gamma}$

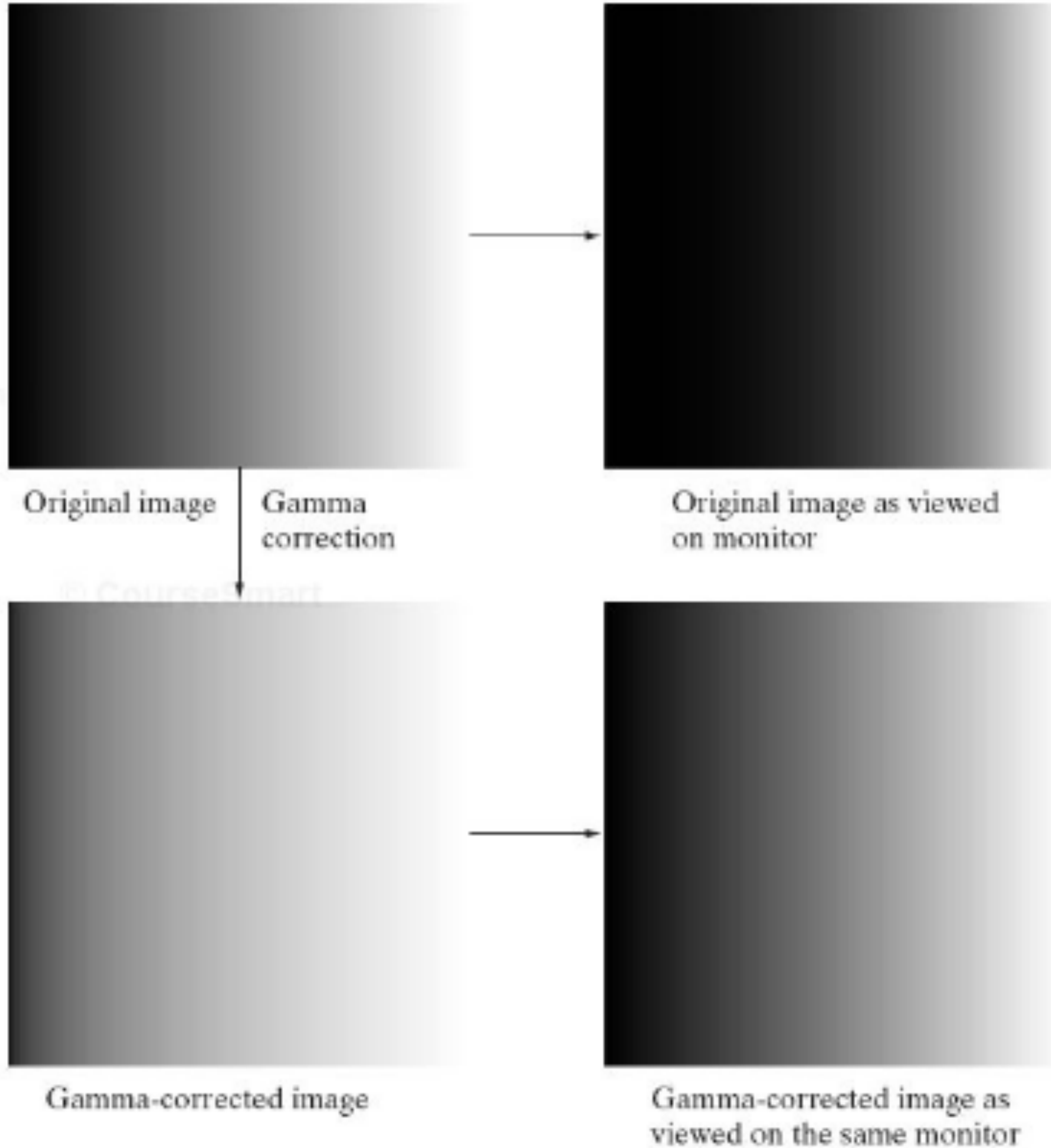


$$I_p = I_a^{(1.0/2.2)}$$

http://www.anyhere.com/gward/hdrenc/

Displays exhibit a different relationship between Actual (I_a) and voltage (I_v) intensities



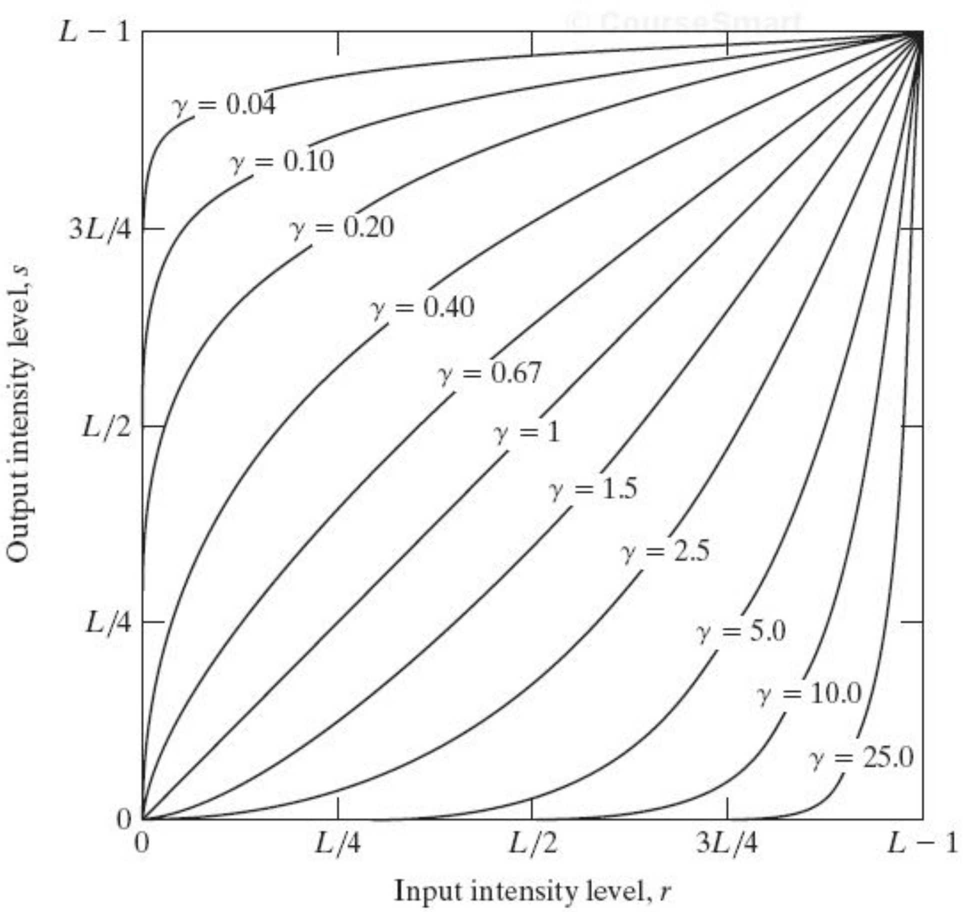


a b
c d

FIGURE 3.7 (a) Intensity ramp image. (b) Image as viewed on a simulated monitor with a gamma of 2.5. (c) Gamma-corrected image. (d) Corrected image as viewed on the same monitor. Compare (d) and (a).

Example: Gamma Correction

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



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.)

Example: Gamma Correction

a b c d

FIGURE 3.8 (a) Magnetic resonance image (MRI) of a fractured human spine. (b)–(d) Results of applying the transformation in Eq. (3.2-3) with $c = 1$ and $\gamma = 0.6, 0.4,$ and 0.3, respectively. (Original image courtesy of Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Gamma Correction vs. Scaling with Gain/Bias Adjustments

- Gamma changes curve instead of sliding it (bias) or changing just slope (gain)

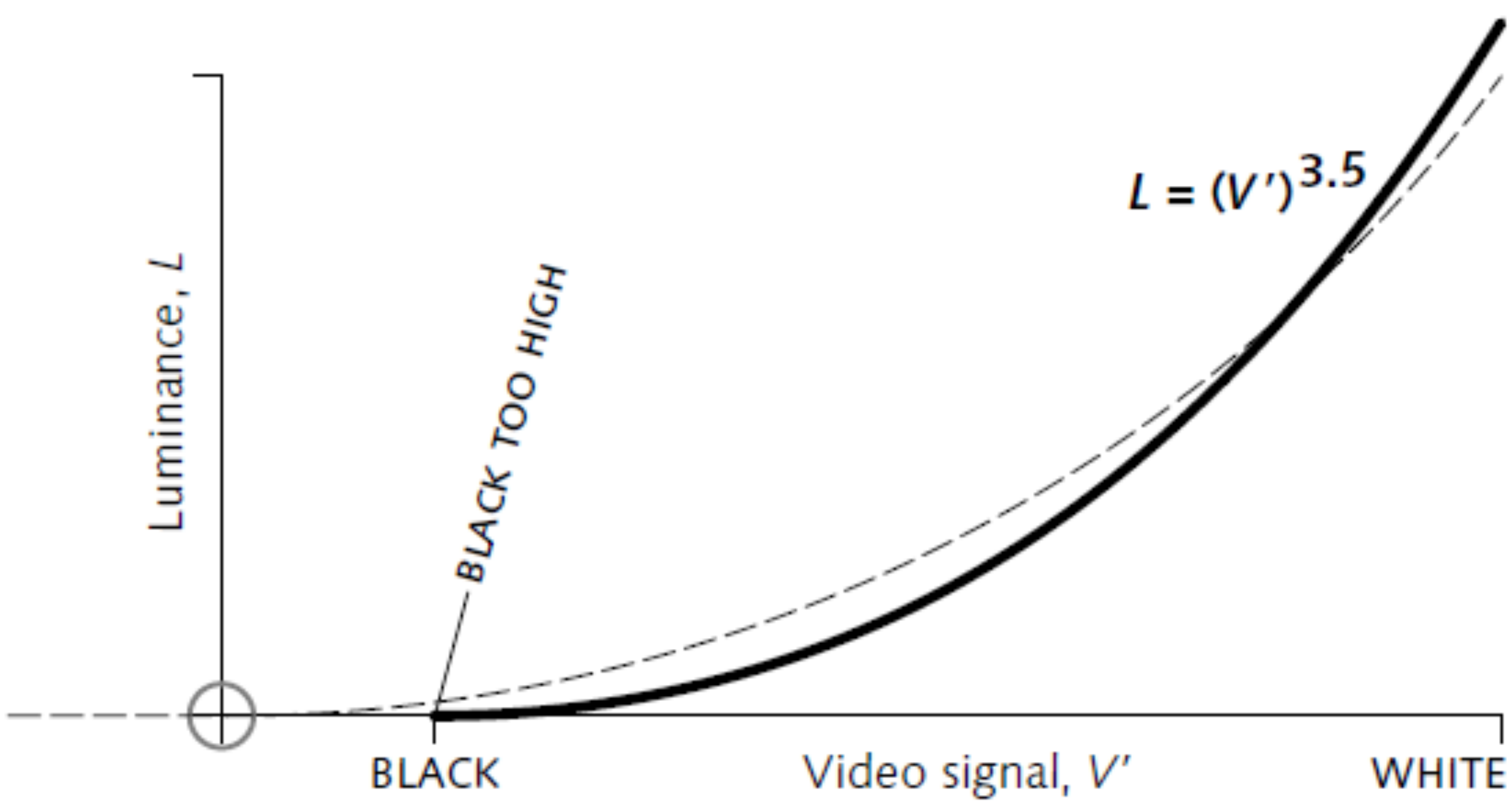


Figure 4 **Gamma 3.5** A naive approach to the measurement of CRT nonlinearity is to model the response as $L = (V')^{\gamma}$, and to find the exponent of the power function that is the best fit to the voltage-to-intensity transfer function of a particular CRT. However, if this measurement is undertaken with BRIGHTNESS set too high, an unrealistically large value of gamma results from the modelled curve being “pegged” at the origin.

http://www.poynton.com/PDFs/Rehabilitation_of_gamma.pdf

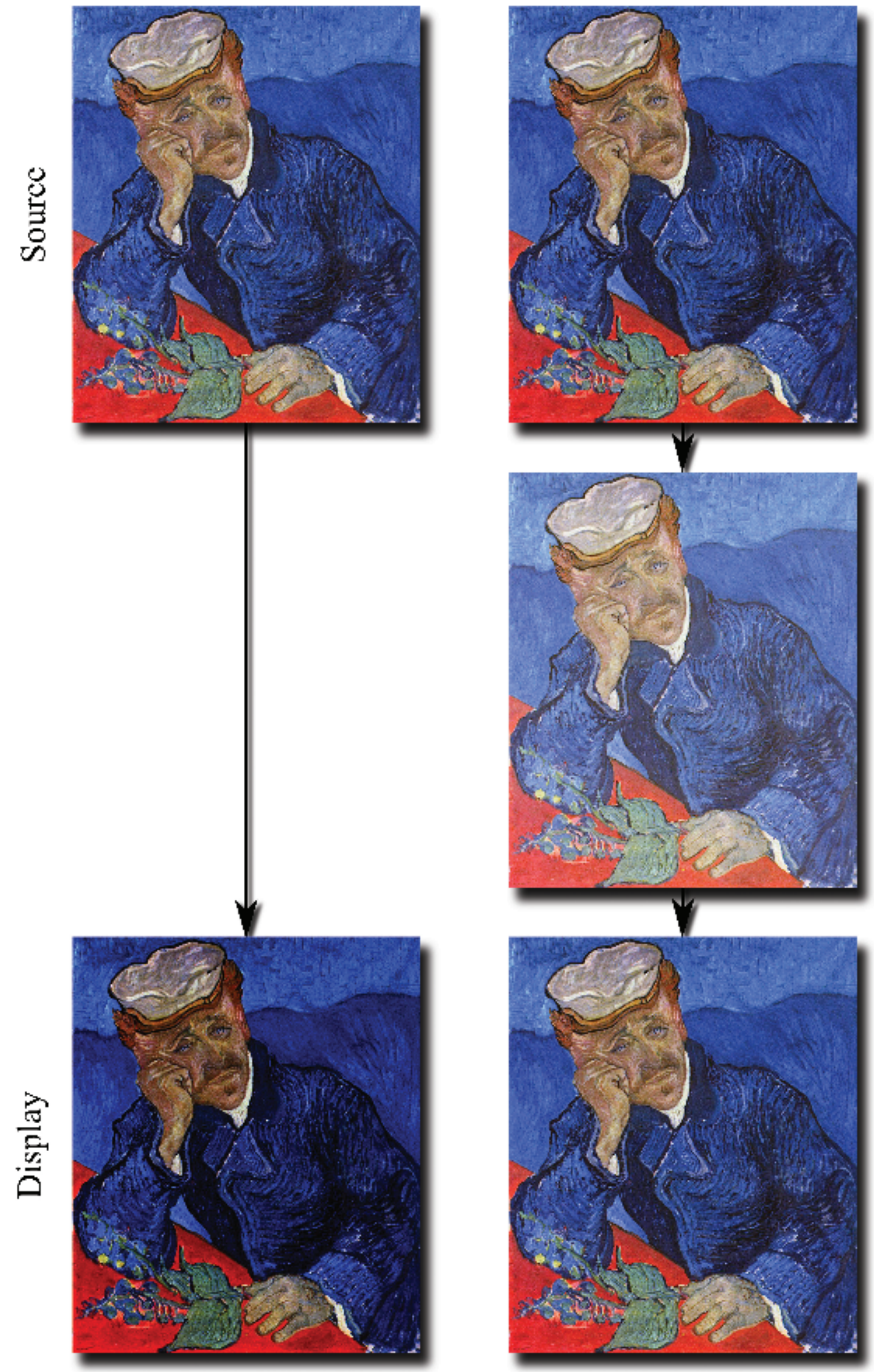


Figure 5.5. Gamma correction, as shown in the middle of the column on the right.

Implementing Gamma Correction

- Consider the effects of gamma correction on the intended image as it is displayed.

$$
\begin{aligned}
\hat{S}_{\text{displayed}} &= (\hat{S}_{\text{corrected}})^{\gamma}, \\
\hat{S}_{\text{displayed}} &= \left((\hat{S}_{\text{intended}})^{1/\gamma}\right)^{\gamma}, \\
\hat{S}_{\text{displayed}} &= \hat{S}_{\text{intended}}.
\end{aligned} \tag{5.9}
$$

Different ɣ's!

- Gamma correction can be encoded in a digital file format.
- Example: PNG supports gamma correction since it allocates the "gAMA" chunk that "specifies the relationship between the image samples and the desired display output intensity".

Rescaling Acceleration with Lookup Tables

- Consider linear rescaling an 8-bit image.

- Without using lookup tables we compute the value clamp(gain*S+bias, 0, 255) for every sample S in the input.

  - For an image of width W and height H there are W*H samples in the input and each of the corresponding output samples requires one multiplication, one addition, and one clamp function call.

  - But with a color depth of [0, 255] we need only compute the 256 possible outputs exactly once and then refer to those pre-computed outputs as we scan the image.

- Lookup tables are effective when the image is large, the color depth is not too great, and the complexity of the filtering operation is large enough.

- The same is true for gamma correction (even more so — pow() is expensive!)

Image Filtering

Filters

- Point processing generalizes to filters.

- **Filters** are operations that modify the intensities or color content of an image by examining a region of data.

- Can you think of any examples other than rescaling, clamping, and gamma correction?

Filtering (Some Math)

Output Color / Intensity

Filter Function

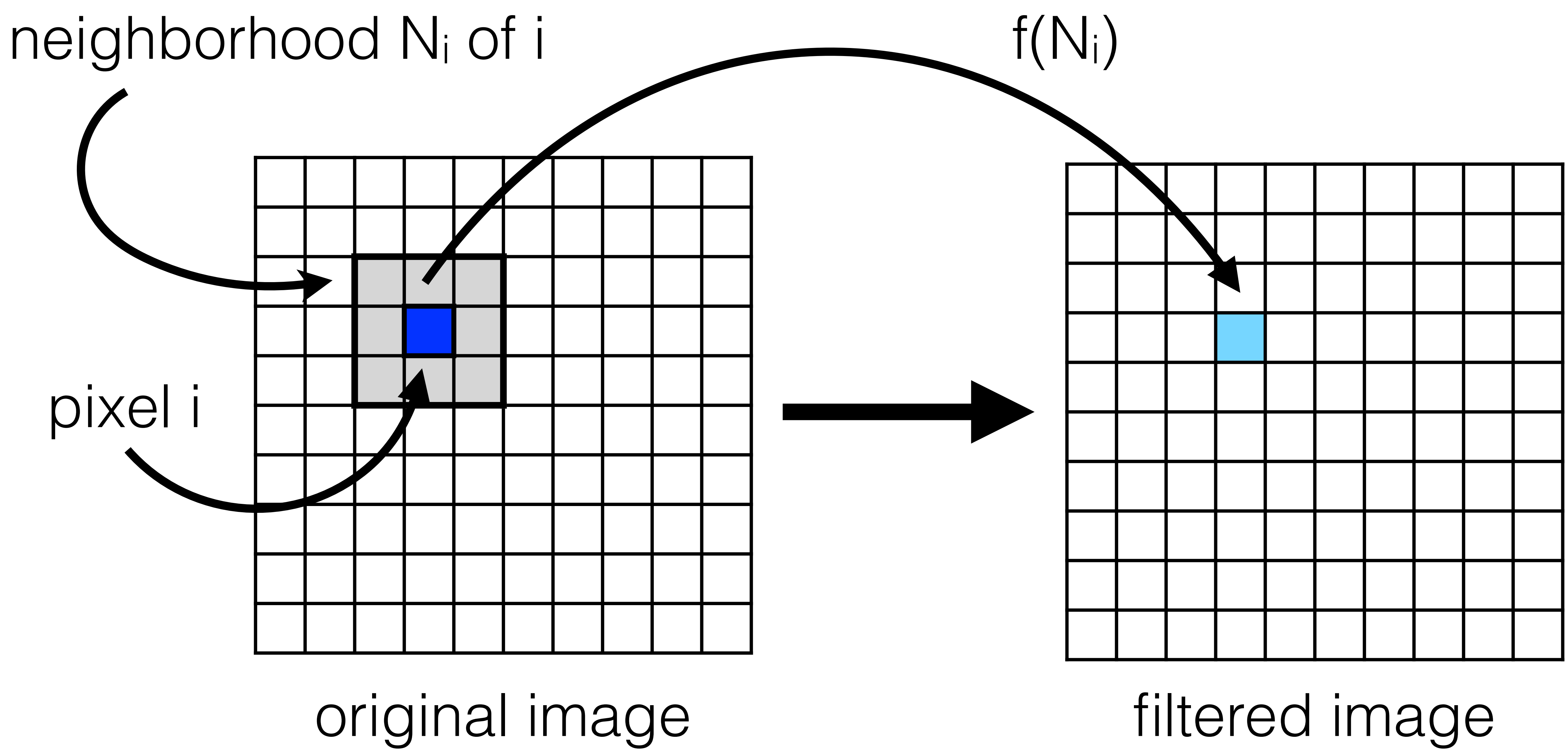
$$C_{out} = f(N_{in})$$

Some pixel

A **neighborhood** of the pixel: region of nearby colors

Filtering (Schematic)

$$C_{out} = f(N_{in})$$



Filtering (Algorithmic)

```
//given input: image
//produces output image: output


for (row = 0, row < H; row++) {
   for (col = 0; col < W; col++) {
      N = compute_neighborhood(image, row, col);


      new_color = filter(N);


      output[row][col] = new_color;
   }
}
```

Global Filtering

Global Filtering

- Point processing uses the smallest possible neighborhoods $N_i = P_i$. What about using the largest possible?
- Global filters use N_i = the whole image

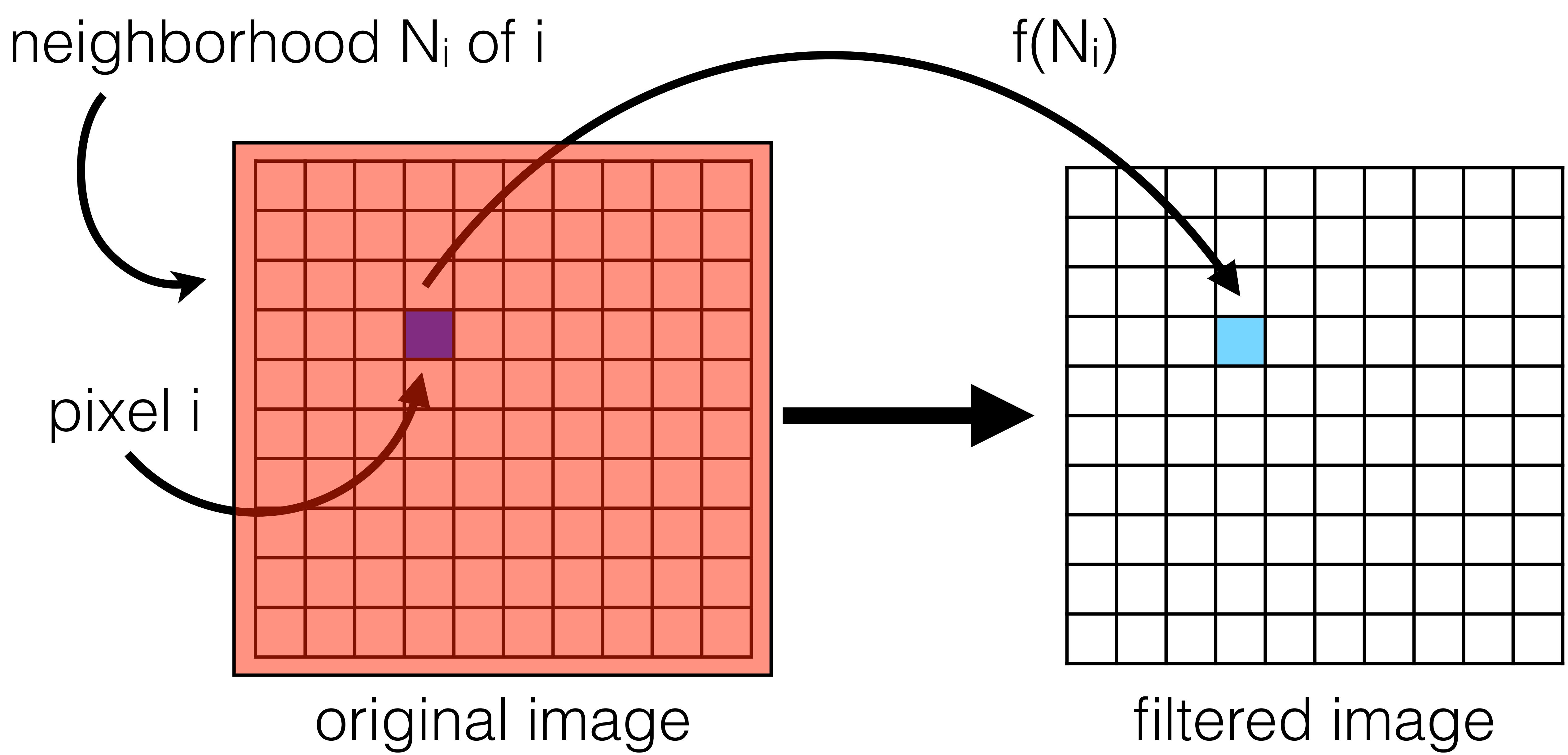


Image Normalization

- Goal: Adjust the image so that the range of colors used falls within the range of possible colors in the image.

- Why? Many filters produce images which don't use the full space

- Computing the minimum and maximum of the image requires N_i to be the whole image

$$C_{ij} = \frac{C_{ij} - C_{\min}}{C_{\max} - C_{\min}}$$

Example: Image Normalization

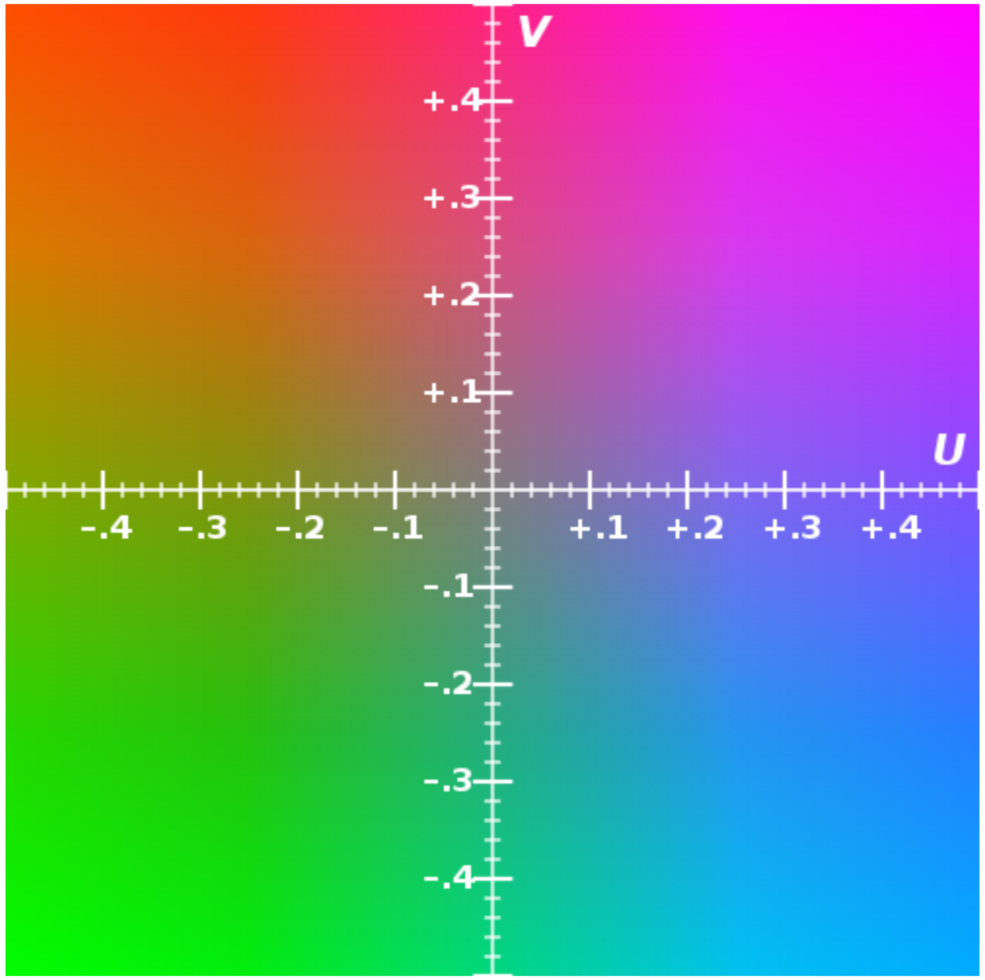
a) original image

b) image at 1/2 brightness

c) image renormalized

Sidebar: YUV Images

- YUV color space is common in broadcast applications. Most similar to xyY and CIELuv
- Y is luminance, UV are chrominance components
- Legacy Idea: B&W TVs converted to Color
  - We already could transmit a Y channel
  - Added two color channels (U,V)



http://en.wikipedia.org/wiki/YUV

RGB to Y'UV

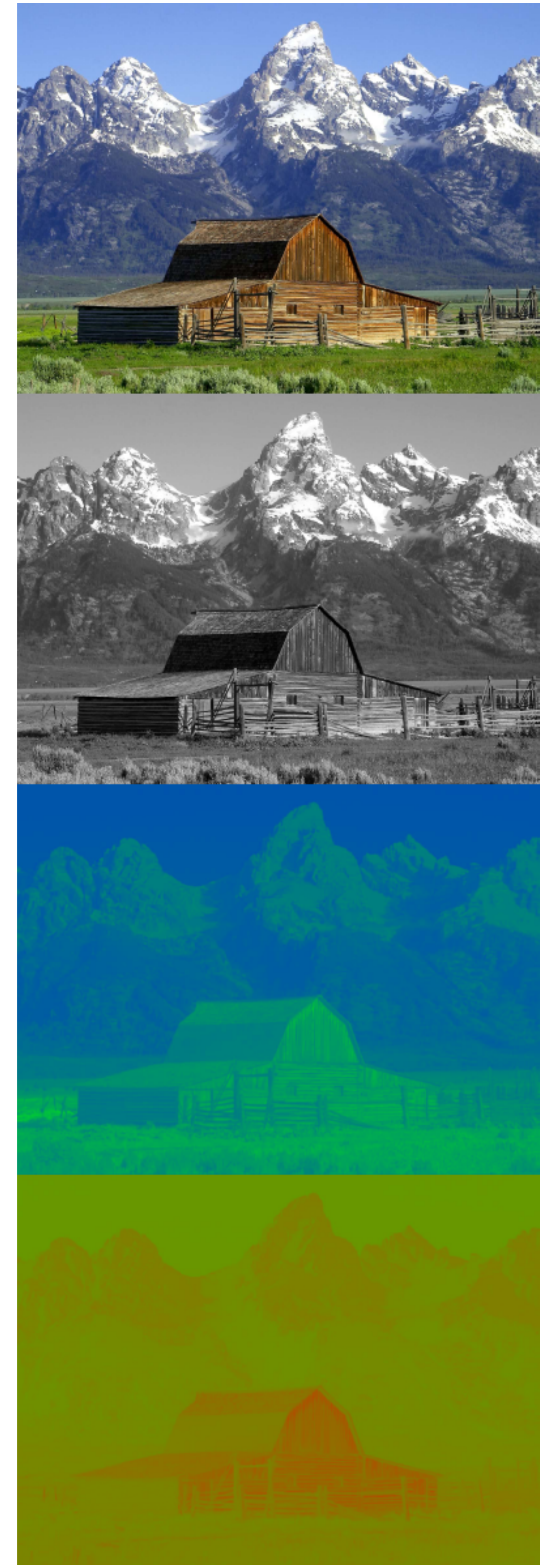
- Y' = 0.3R + 0.59G + 0.11B
- Good measure of human luminance (application: reading)
- Scale for 8-bit:

$$\bar{Y}_i = \text{round}(255 Y_i)$$

- General conversion:

$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

http://en.wikipedia.org/wiki/YUV



Histogram Processing

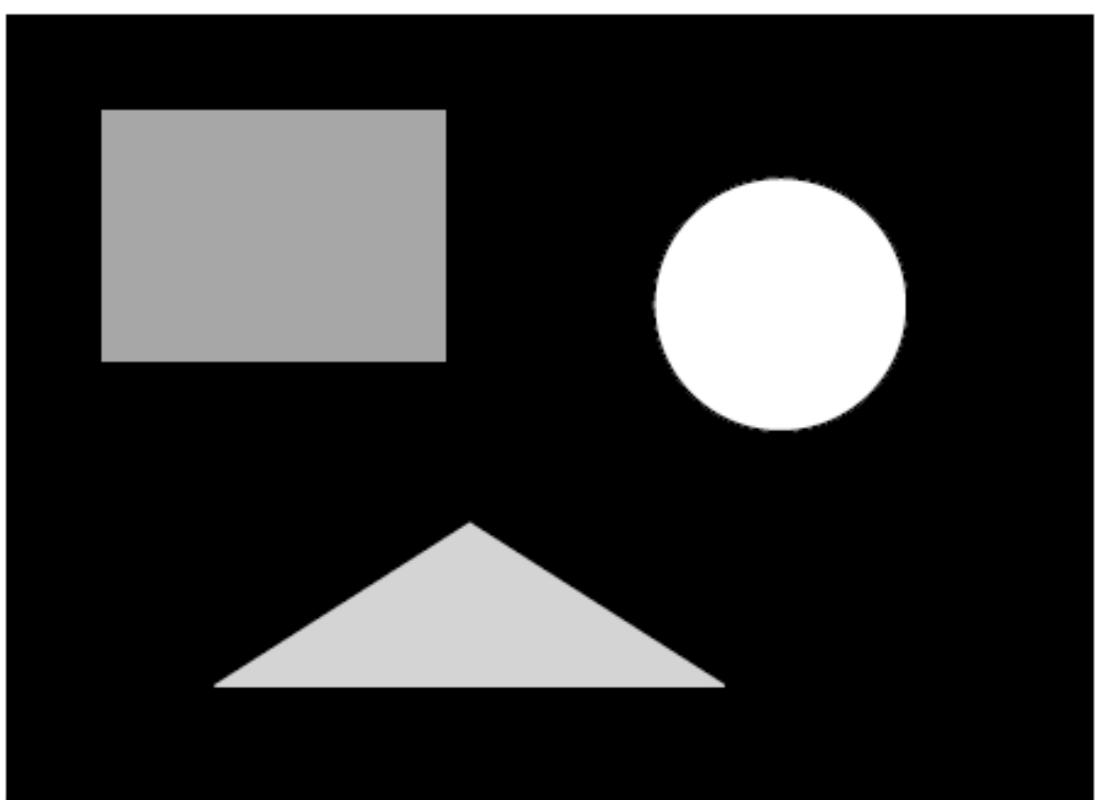
Histograms

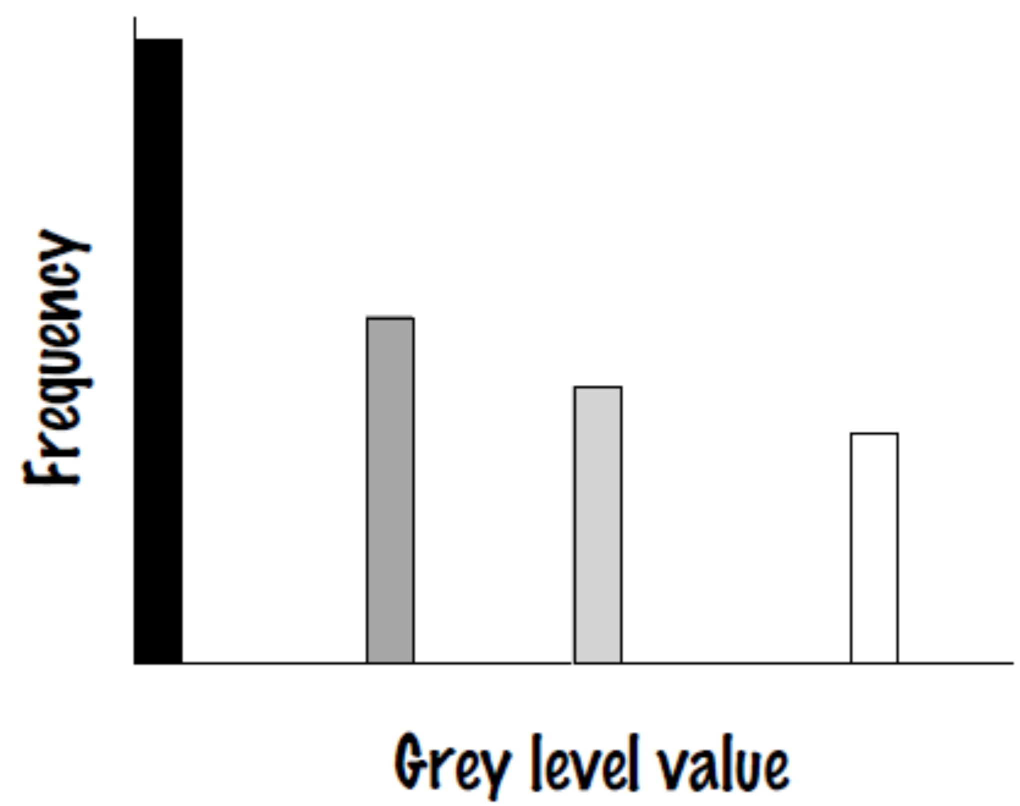
- A **histogram** is a table that simply counts the number of times a value appears in some data set.
  - In image processing, a histogram counts the image samples by color channel values (often, luminance).
  - For an 8-bit channel there will be 256 possible values a sample can be, so the histogram will store how many times each sample occurs.
  - In other words, the histogram gives the frequency distribution of sample values within the image.

Luminance Histograms

- Construct a histogram of an image by counting the luminances of each pixel

- Can be counts or normalized to frequencies

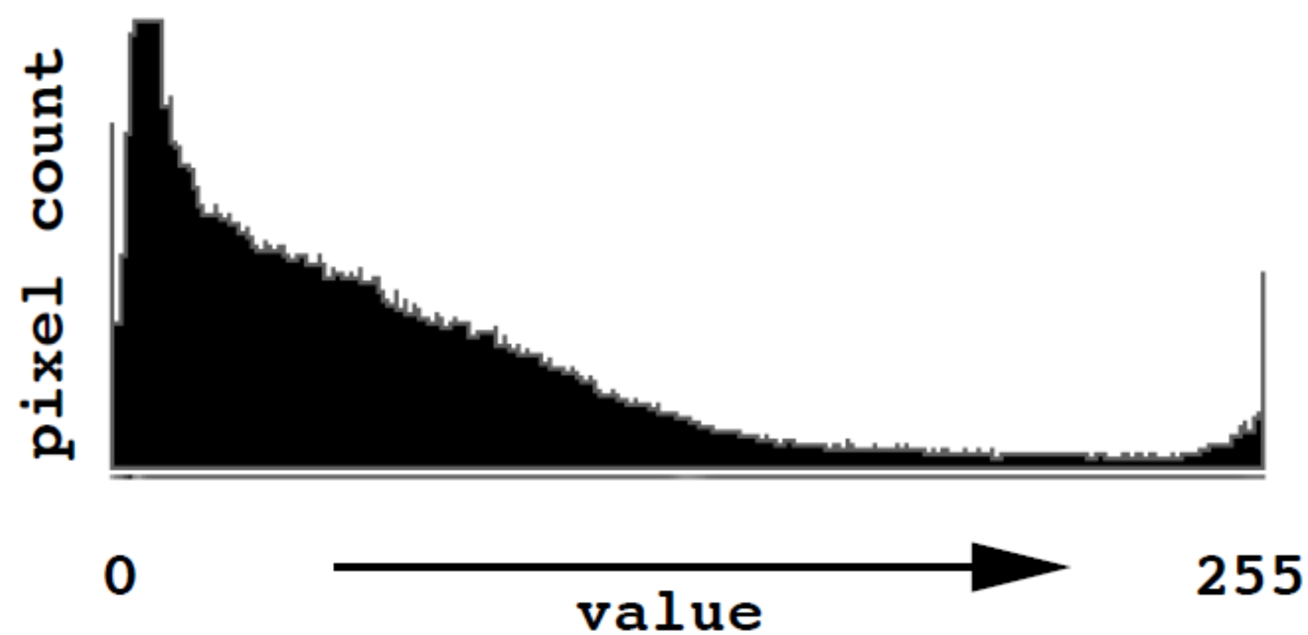




More Realistic Example

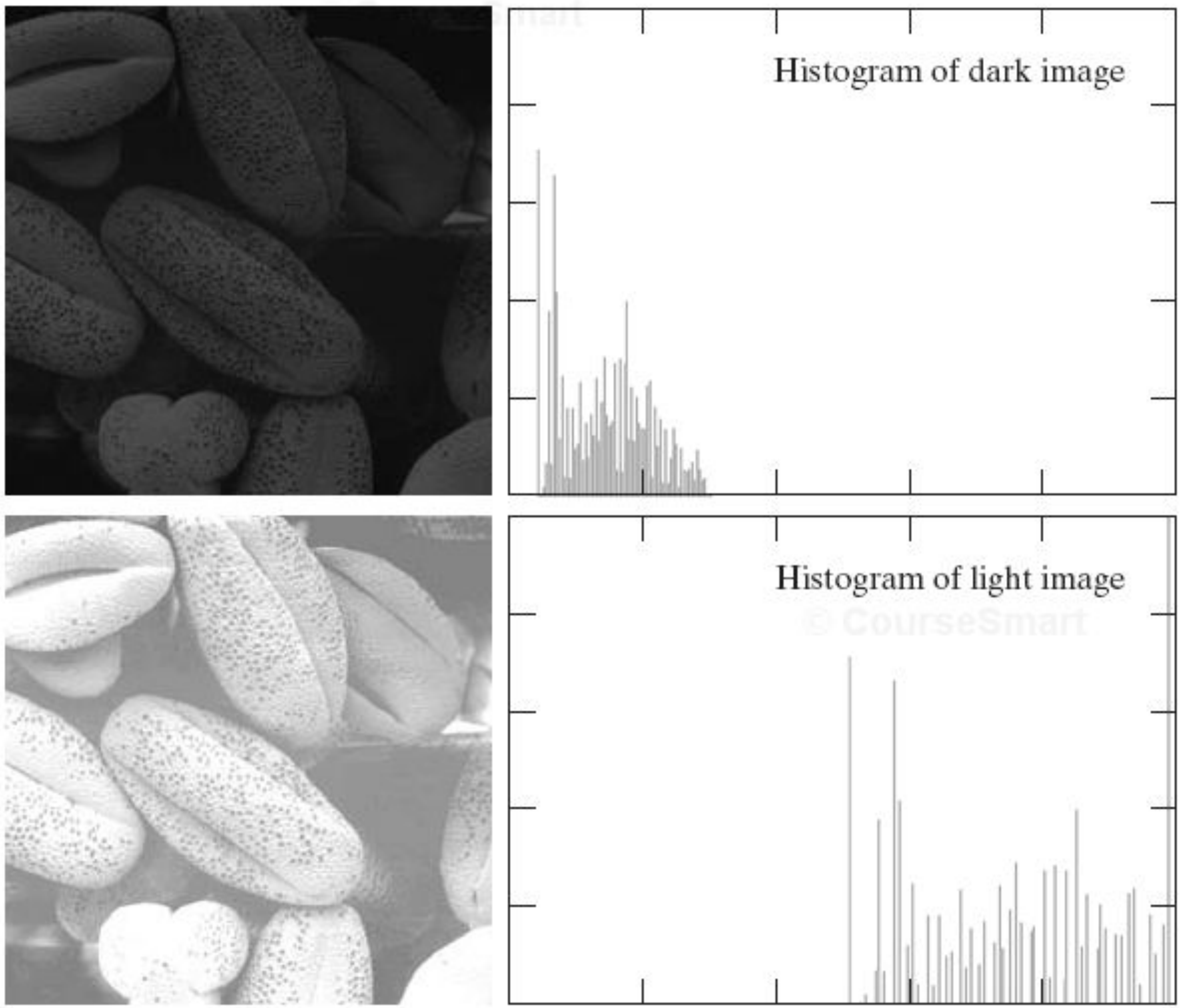
- A **bin** for each possible pixel value
- Each bin has a **count** of the number of pixels having that value

a) original image



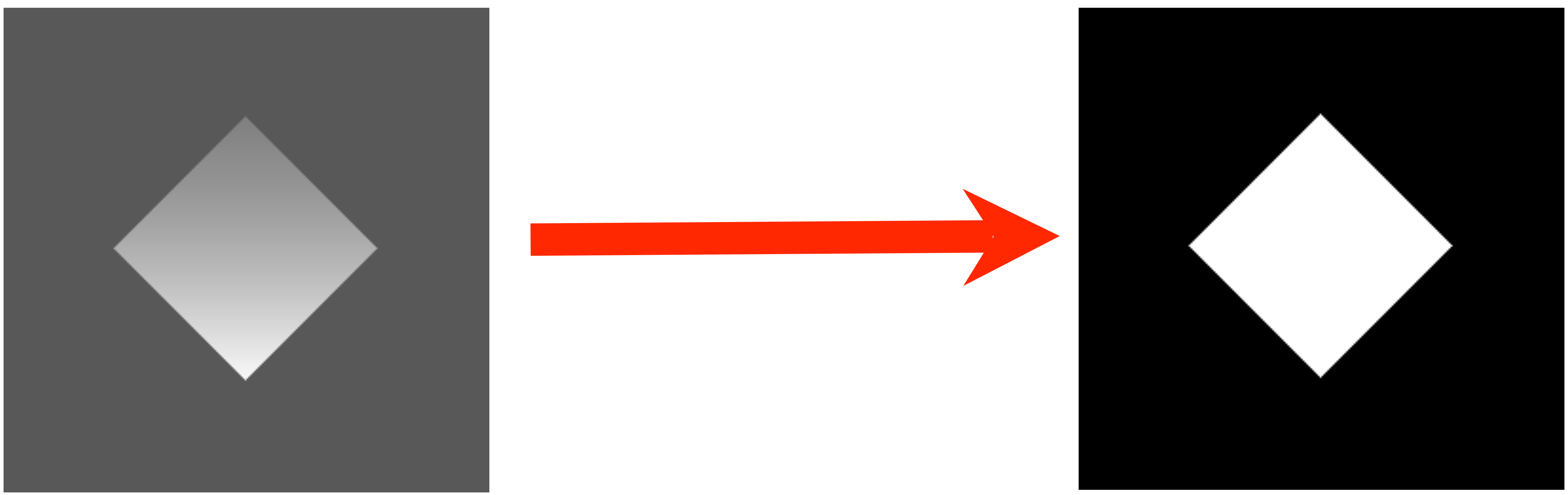
b) histogram

Histogram Examples



What is image segmentation?

- The process of subdividing an image into its constituent regions or objects.

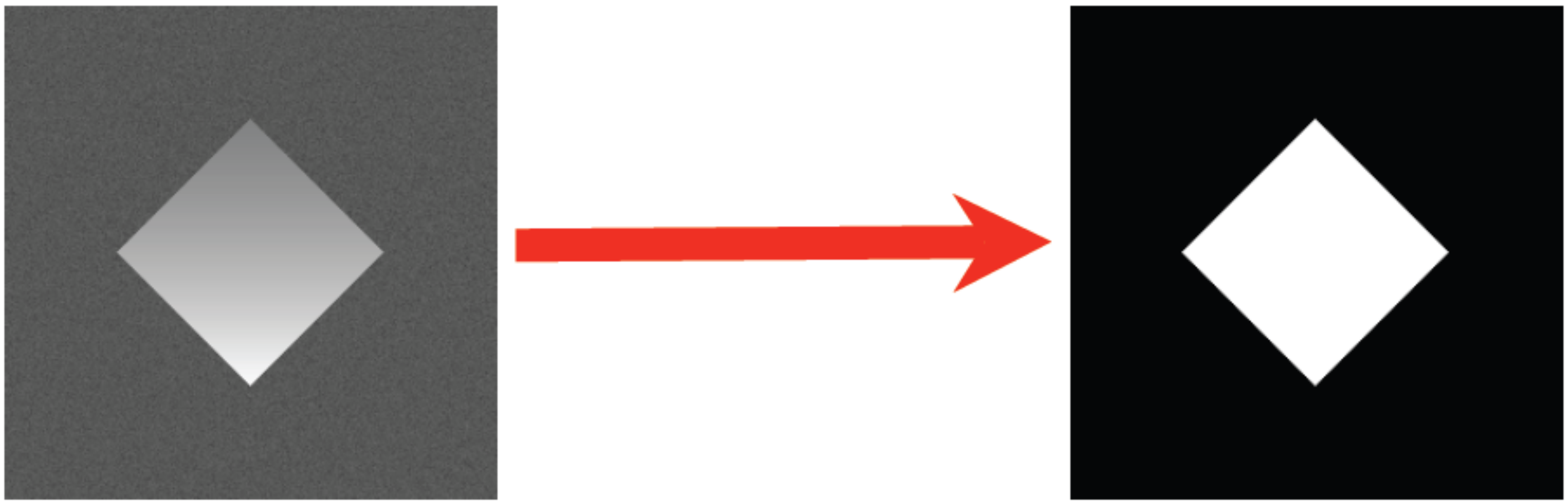


Input image
intensities 0-255

Segmentation output
0 (background)
1 (foreground)

Thresholding Based on Histogram

$$g(x,y) = \begin{cases} 1 & if \quad f(x,y) > T \\ 0 & if \quad f(x,y) \leq T \end{cases}$$

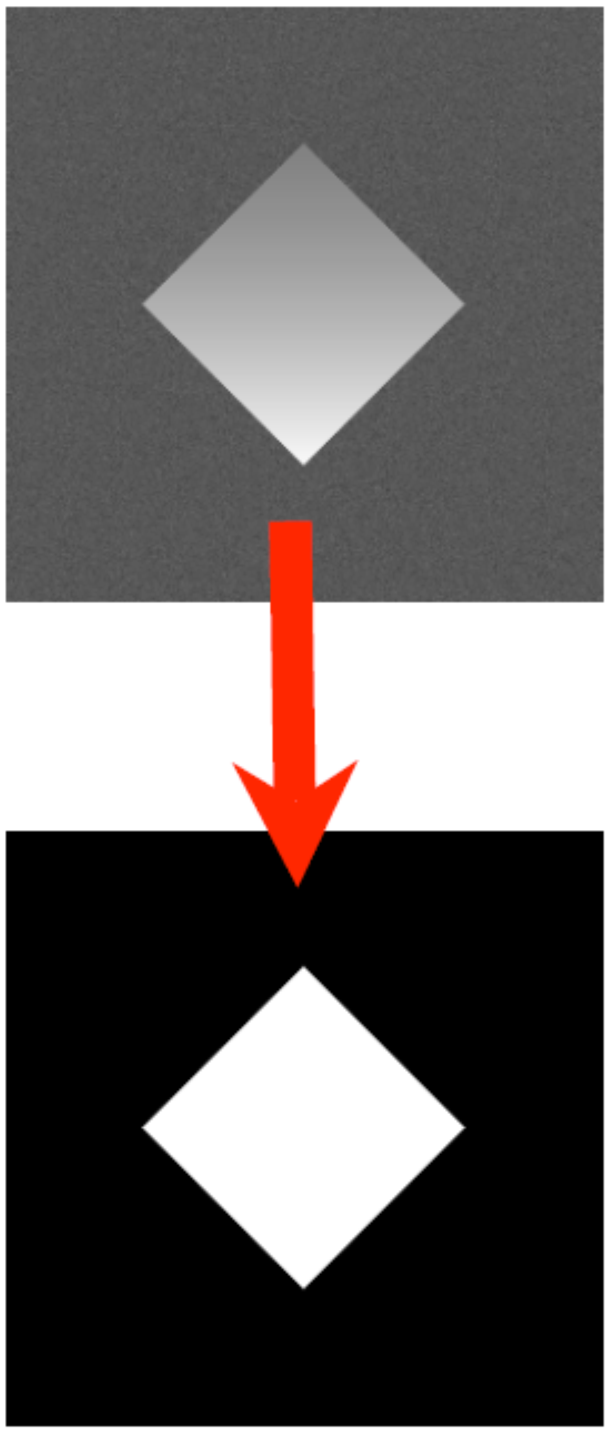


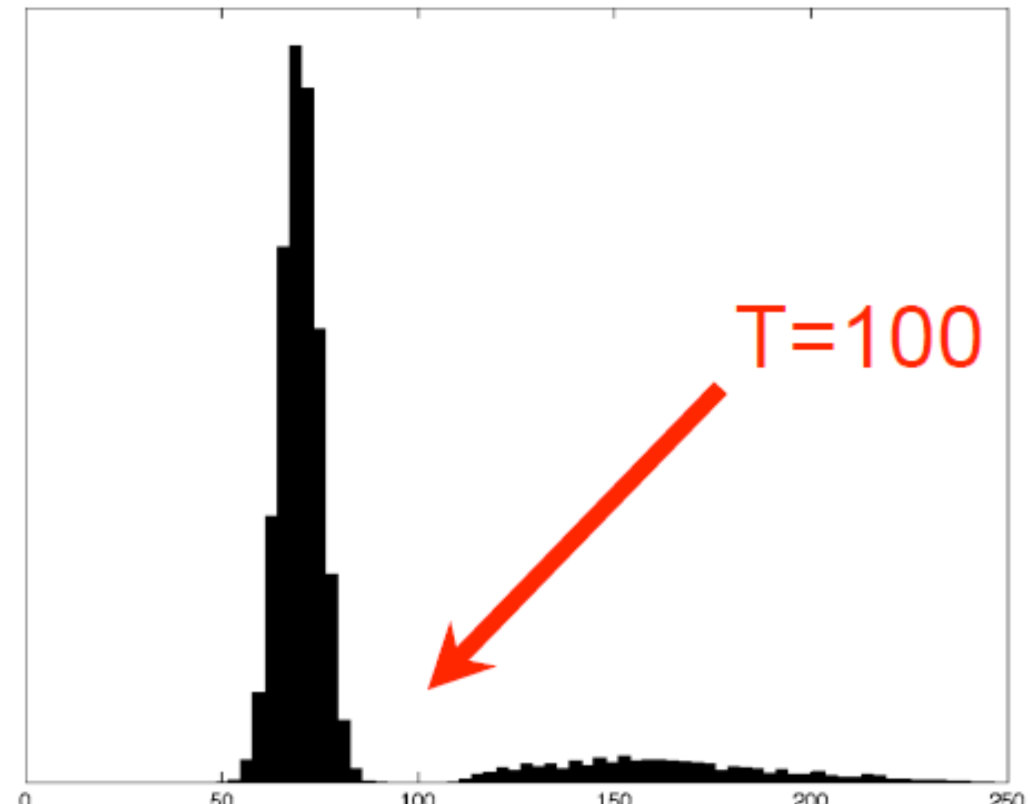
Input image f(x,y)
intensities 0-255

Segmentation output g(x,y)
0 (background)
1 (foreground)

- How to choose T is the key question:
  - Could use the color information (like in Lab03!), Trial and Error, etc.
  - Or you could use the histogram

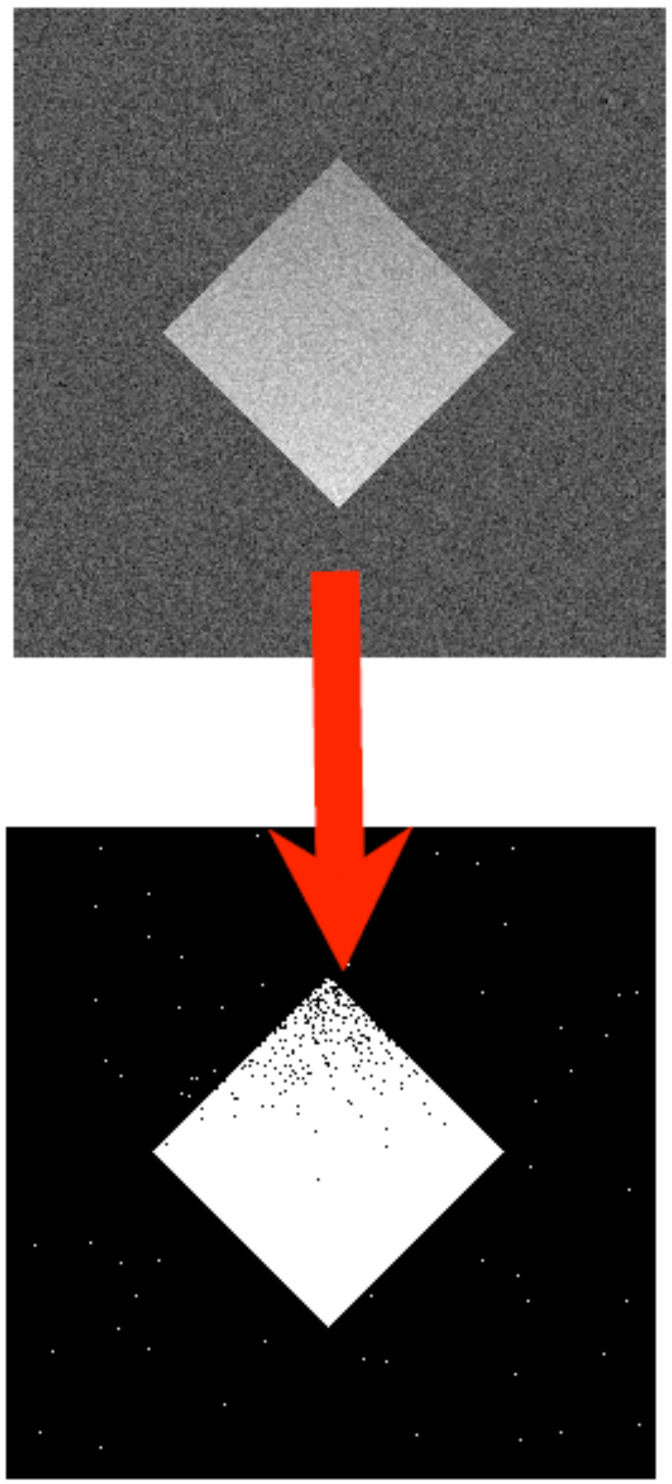
Choosing a Threshold

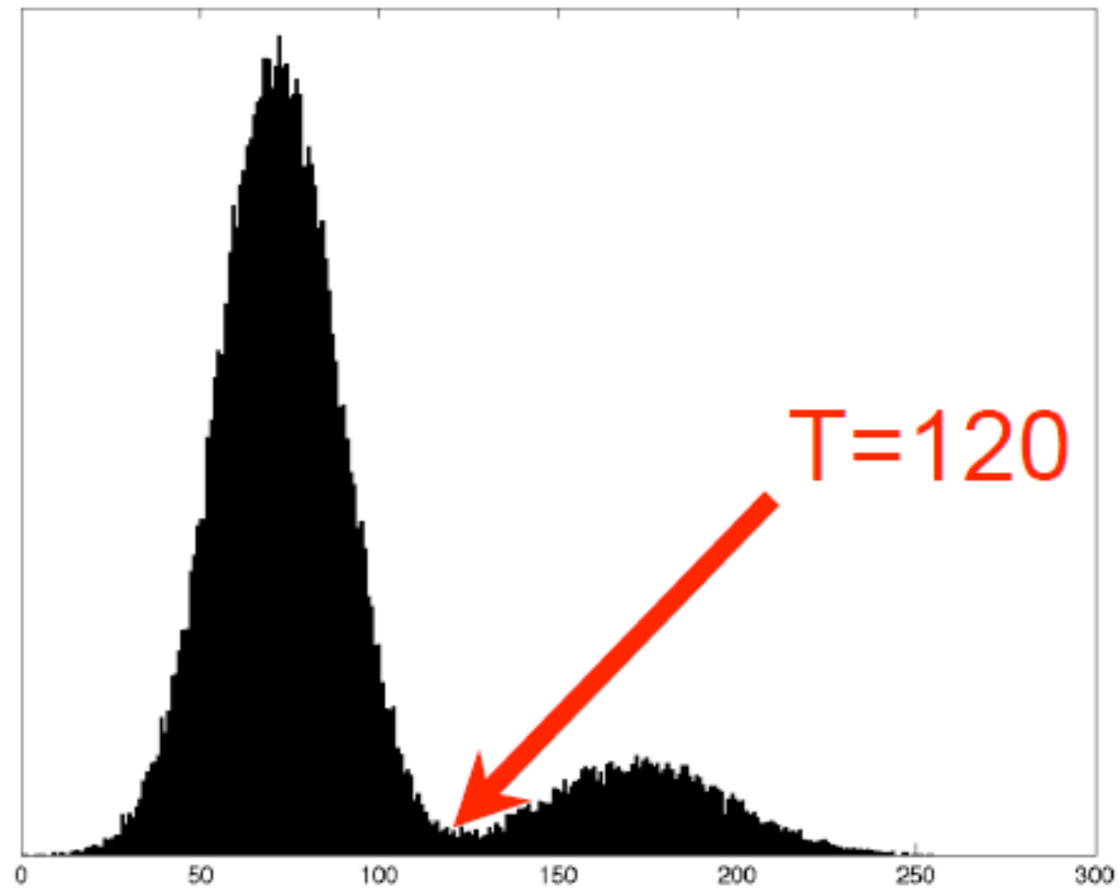




Histogram

Finding Thresholds Can Be Challenging if the Image is Noisy





Lec11 Required Reading

- House, 8.2
- Hunt, 5.6-5.10