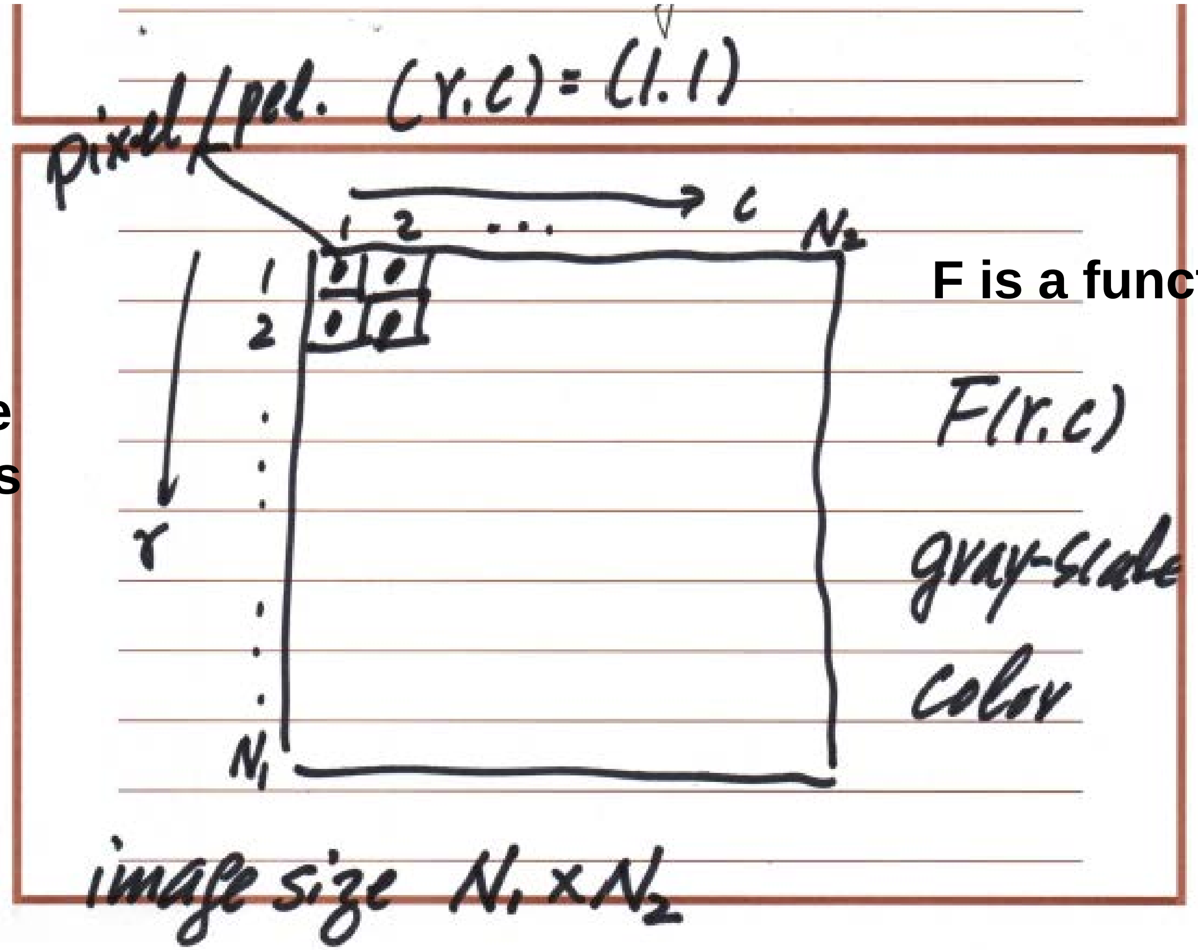
Digital Imaging Pipeline

C.-C. Jay Kuo

University of Southern California

Digital Image Representation (1)



F is a function

(r,c): image coordinates

Digital Image Representation (2)

- Color images:
  - Red channel: 8 bits per pel
  - Green channel: 8 bits per pel
  - Blue channel: 8 bits per pel
  - Total: 24 bits per pel
- Another color image representation:
  - Luminance (brightness) – highly correlated with green
  - Chrominance – two chrominance channels Cb and Cr
- Gray-scale images (i.e. the luminance channel of a color image)
  - Black-Gray-White: 8 bits per pel

Parts 1 and 2 of Pratt's Book

- Part 1: Continuous Image Characterization
  - Chapter 1: Continuous Image Mathematical Characterization
  - Chapter 2: Psychophysical Vision Properties
  - Chapter 3: Photometry and Colorimetry
- Part 2: Digital Image Characterization
  - Chapter 4: Image Sampling and Reconstruction
  - Chapter 5: Image Quantization

Traditional Viewpoint:

- **Digital images are obtained by scanning analogy images – film photos**
- **Scanner is a A/D conversion process**
- **First scanned digital image (1957)**

First Scanned Digital Image (1957)

Modern Viewpoint

- Digital images are simply acquired by digital cameras
  - No more films
  - No more A/D conversion
- ISP (Image Signal Processor) chips
  - Hardware/software
  - Also known as (a.k.a) digital imaging pipeline

Digital Imaging Pipeline

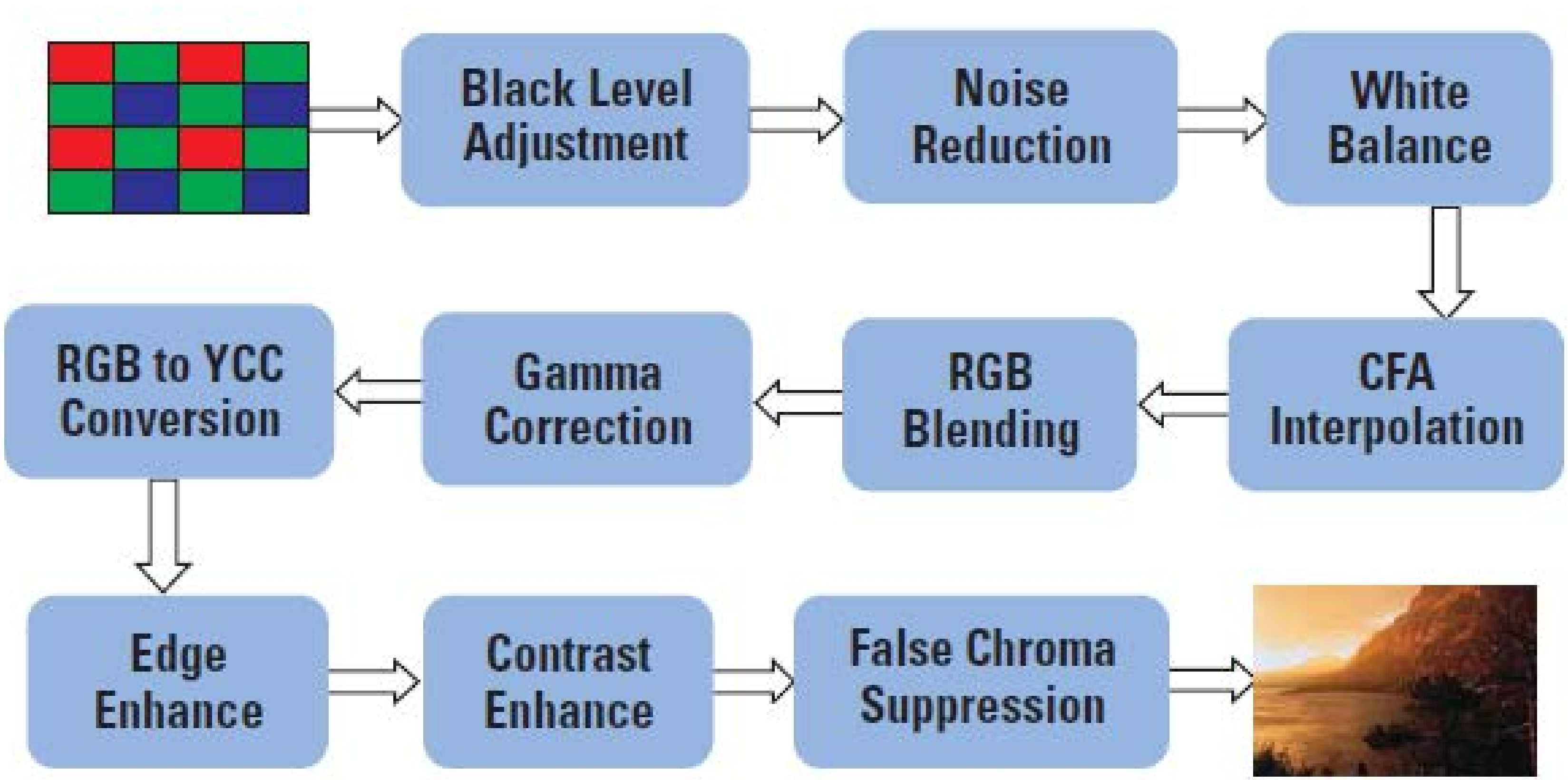
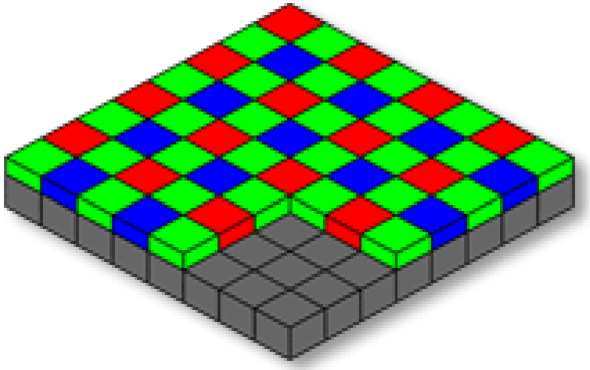


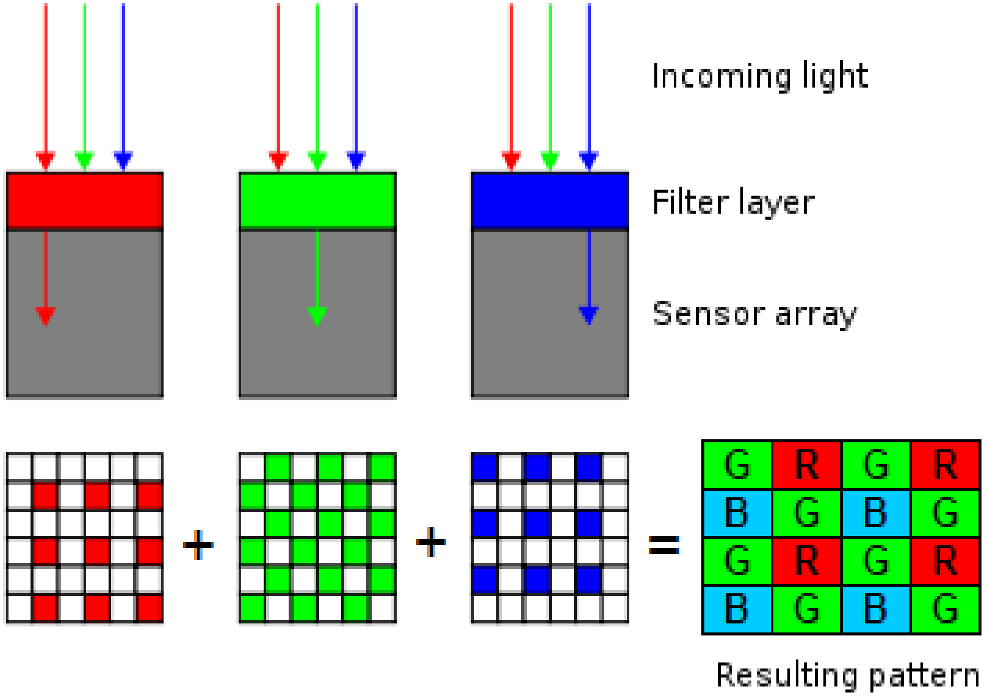
Image Signal Processors (ISP)

Image signal processors (ISP) transform camera sensor data into images via several digital image processing operations:

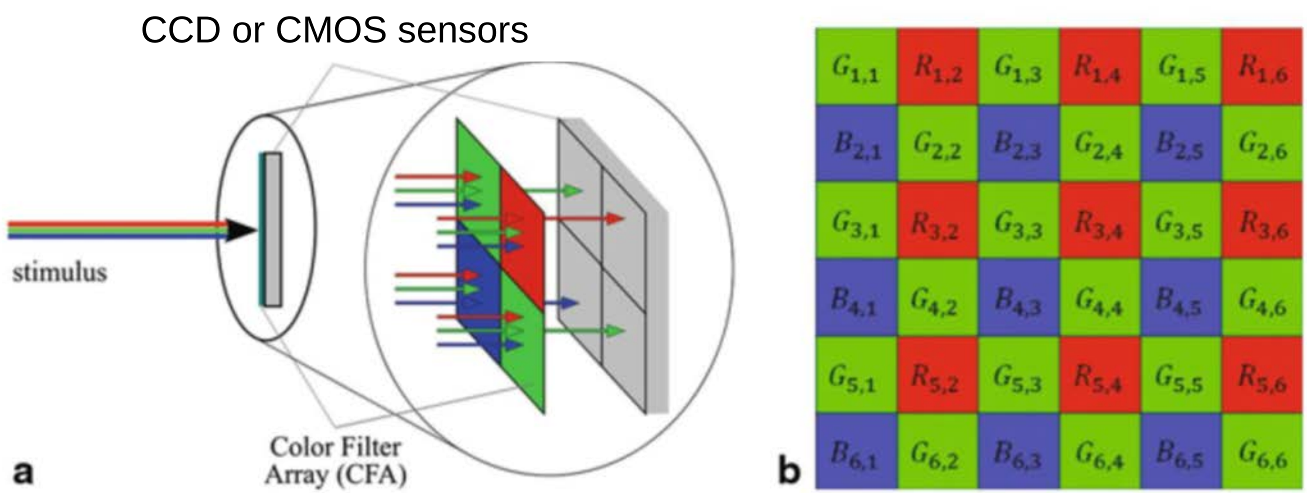
- Demosaicing
- Histogram Equalization
- Intensity & Contrast Adjustment
- Smoothing & Sharpening
- 3 A's
  - Auto Exposure (AE)
  - Auto Focus (AF)
  - Auto White Balancing (AWB)

Bayer Transformation





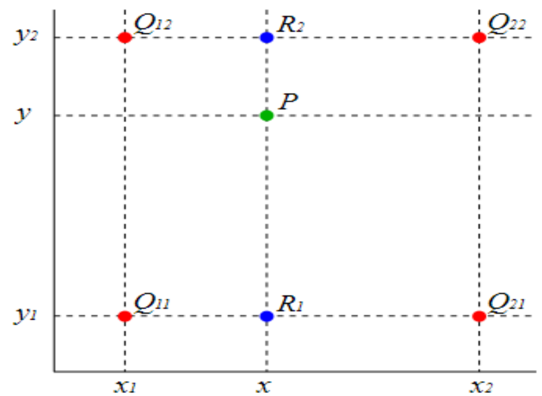
Another View



(a) Single CCD sensor covered by a CFA and (b) Bayer pattern

Basic Demosaicing

- How to reconstruct missing color values at a particular position
- A simple solution: bilinear interpolation

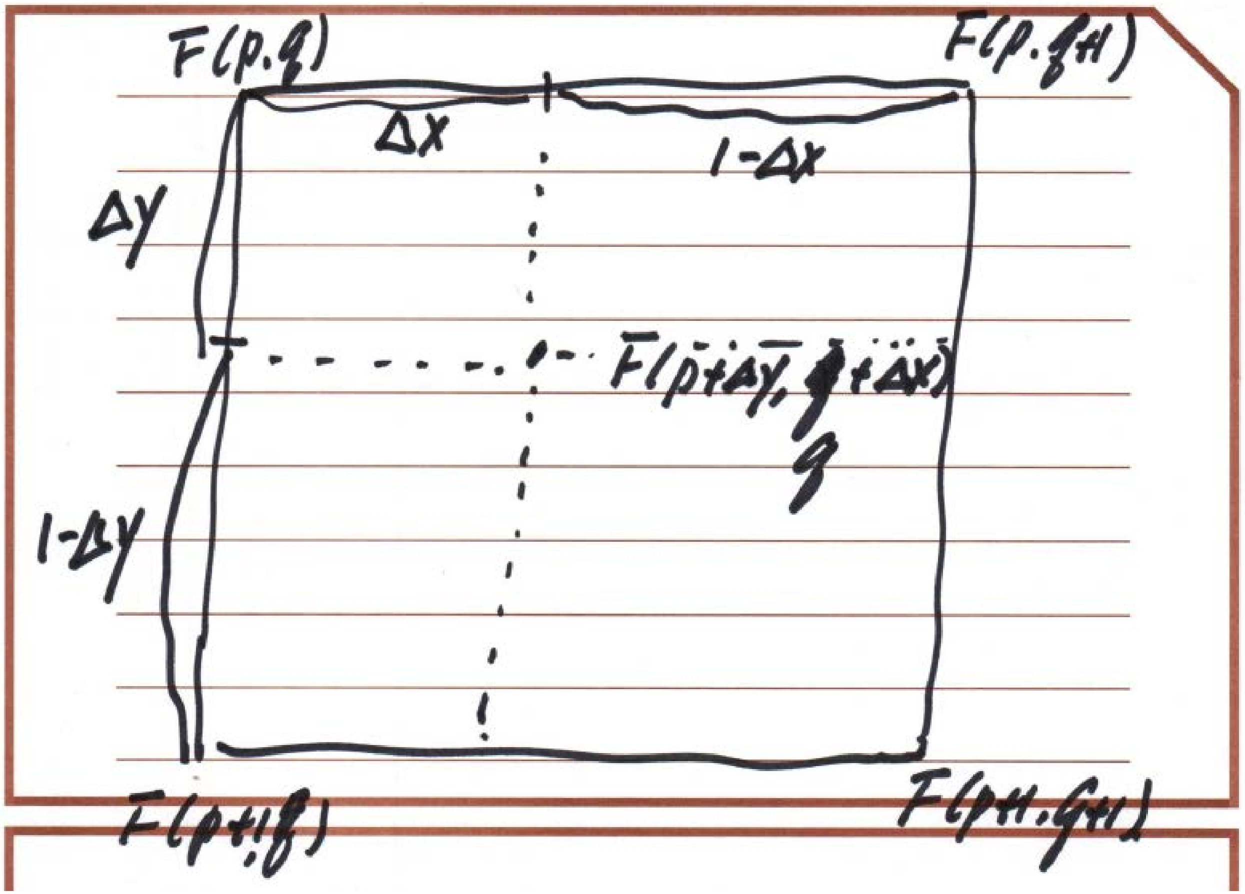


  - Red/Blue: horizontal followed by vertical interpolation (or vice versa)
  - Green: four-side interpolation

Application of Bilinear Interpolation

- Image zoom-in with a flexible factor

Bilinear Interpolation (1)



Bilinear Interpolation (2)

4 corner points

(p, q), $(p, q+1)$, $(p+1, q)$ $(p+1, q+1)$

F values are known

$$F(x, y) = (ax+b)(cy+d)$$

Bilinear Interpolation (3)

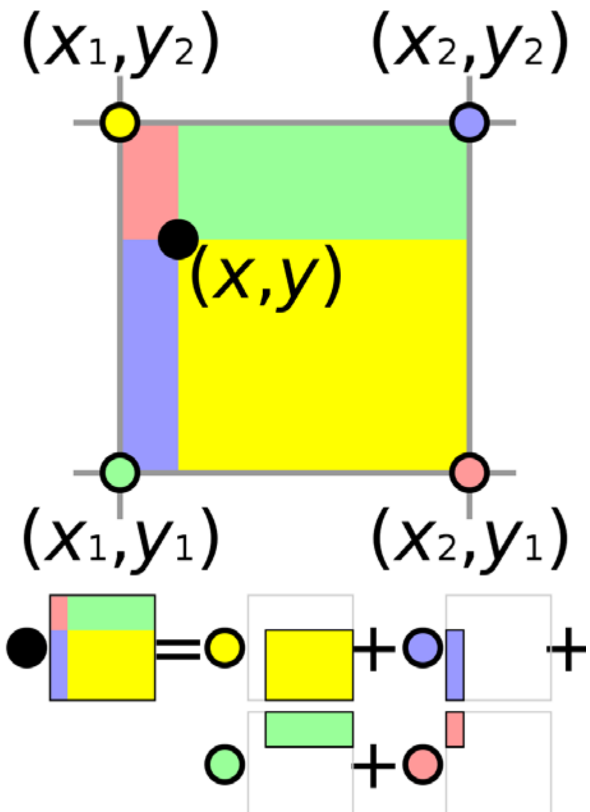
4 Equations ⟹ 4 parameters

a. b. c. d

Solution:

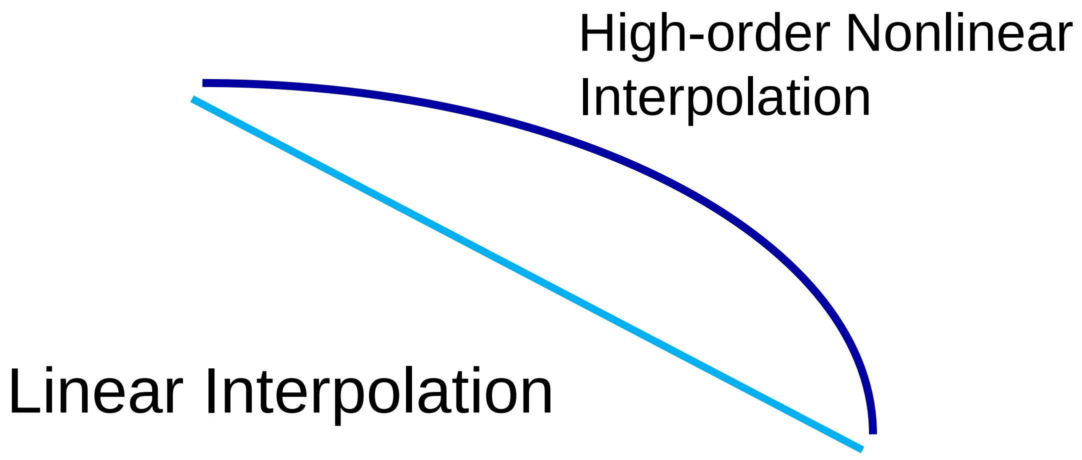
$$F(p+\Delta y, q+\Delta x) = (1-\Delta x)(1-\Delta y)F(p,q)$$
$$+ \Delta x(1-\Delta y)F(p,q+1)$$
$$+ (1-\Delta x)\Delta y\, F(p+1,q)$$
$$+ \Delta x \Delta y\, F(p+1,q+1)$$

Visualization of Bilinear Interpolation



By Cmglee - Own work, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=21409164

Insufficiency of Bilinear Interpolation



Advanced Demosaicing (MHC)

- Malvar-He-Cutler (MHC) Demosaicing

Demosacing results of Fruit_Shop image: the CFA input (left), the bilinear demosaicing result (middle) and the MHC demosaicing result (right).

MHC Demosaicing

To estimate a green component at a red pixel location, we have

$$\hat{G}(i,j) = \hat{G}^{bl}(i,j) + \alpha\Delta_R(i,j)$$

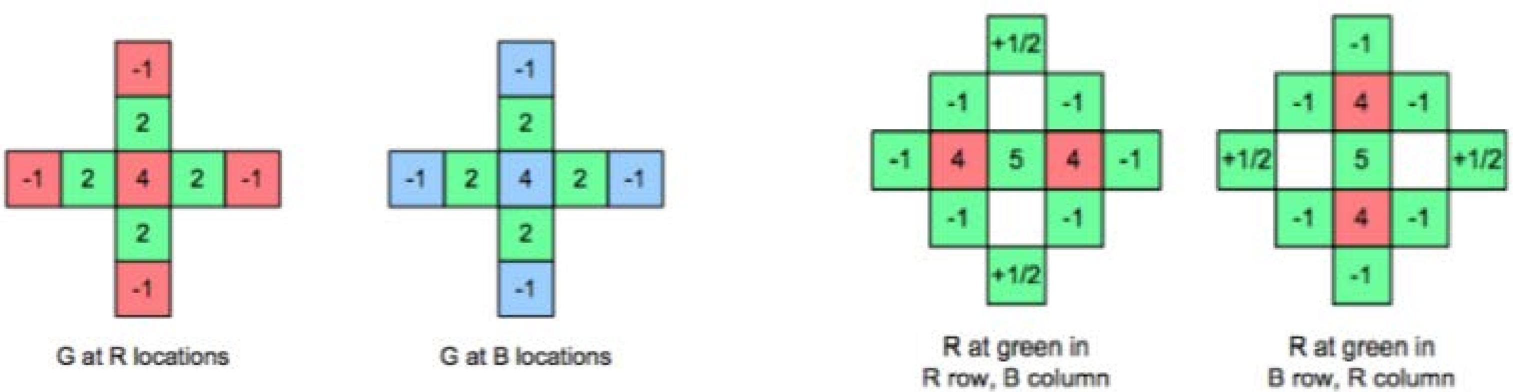
where $\hat{G}^{bl}$ is the bilinear interpolation result and the 2nd term is a correction term. For the 2nd term, α is a weight factor, and Δ_R is the discrete 5-point Laplacian of the red channel:

$$\Delta_R(i,j) = R(i,j) - \frac{1}{4}\big(R(i-2,j) + R(i+2,j) + R(i,j-2) + R(i,j+2)\big)$$

To estimate a red component at a green pixel location, we have

$$\hat{R}(i,j) = \hat{R}^{bl}(i,j) + \beta\Delta_G(i,j)$$

where Δ_G is a discrete 9-point Laplacian of the green channel.



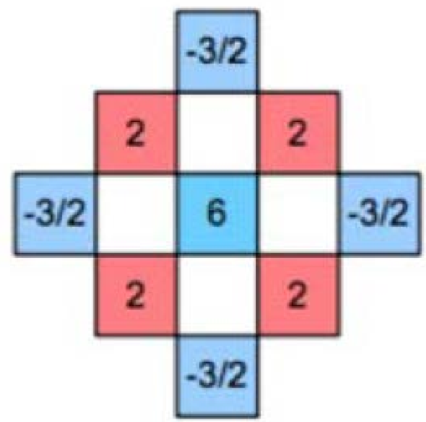
MHC Demosaicing

To estimate a red component at a blue pixel location,

$$\hat{R}(i,j) = \hat{R}^{bl}(i,j) + \gamma \Delta_B(i,j)$$

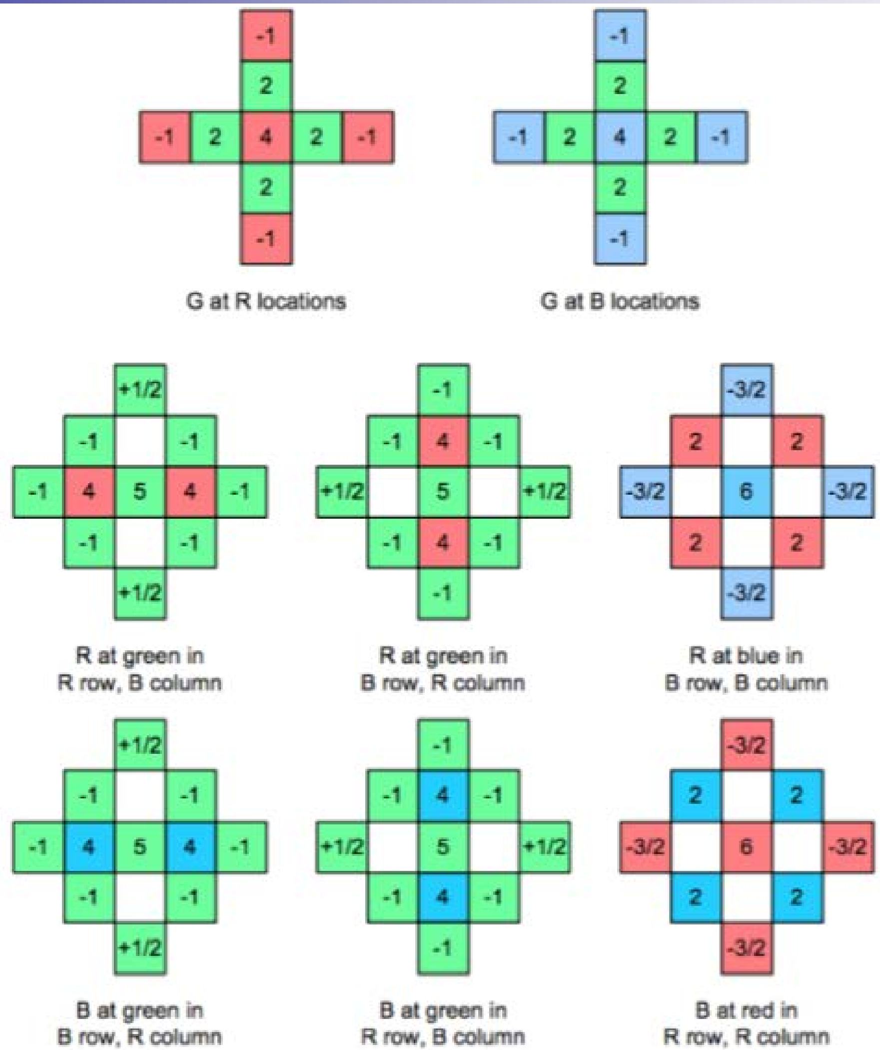
where Δ_B is a discrete 5-point Laplacian of the blue channel.

$$\alpha = \frac{1}{2}, \beta = \frac{5}{8}, \gamma = \frac{3}{4}$$



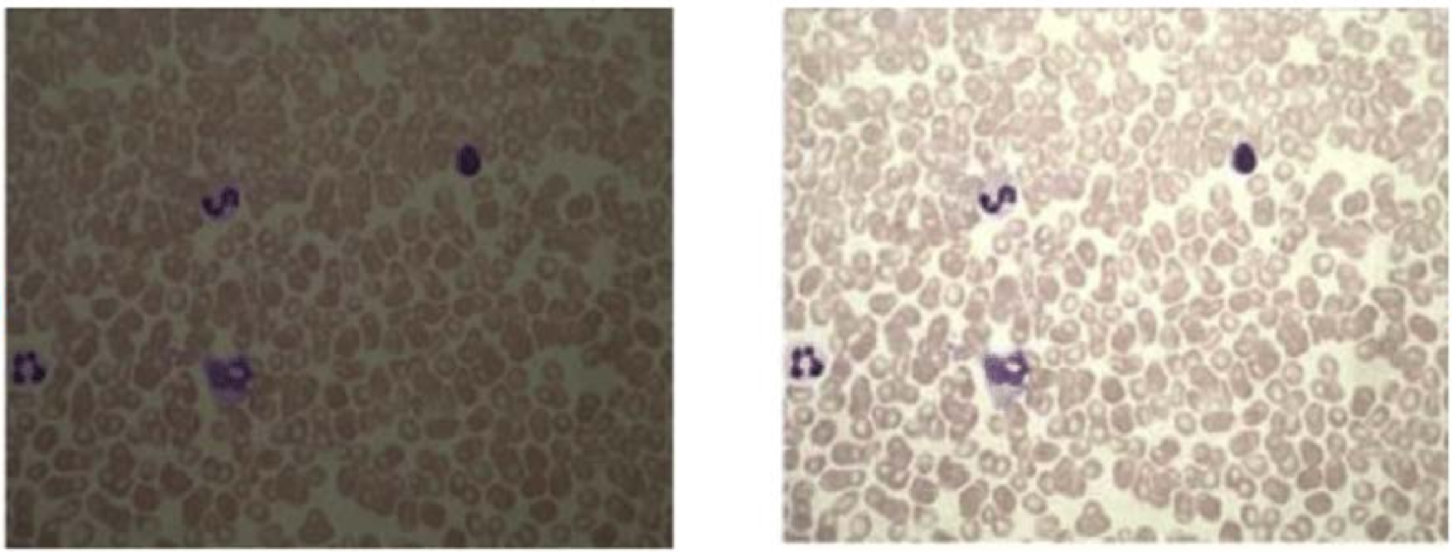
R at blue in
B row, B column

Summary of MHC Demosaicing



Contrast Enhancement

- 8-bit Gray-Scale Images
- Gray-scales: 0, 1, …, 255
- 0 -> black (darkest), 255 -> white (brightest)

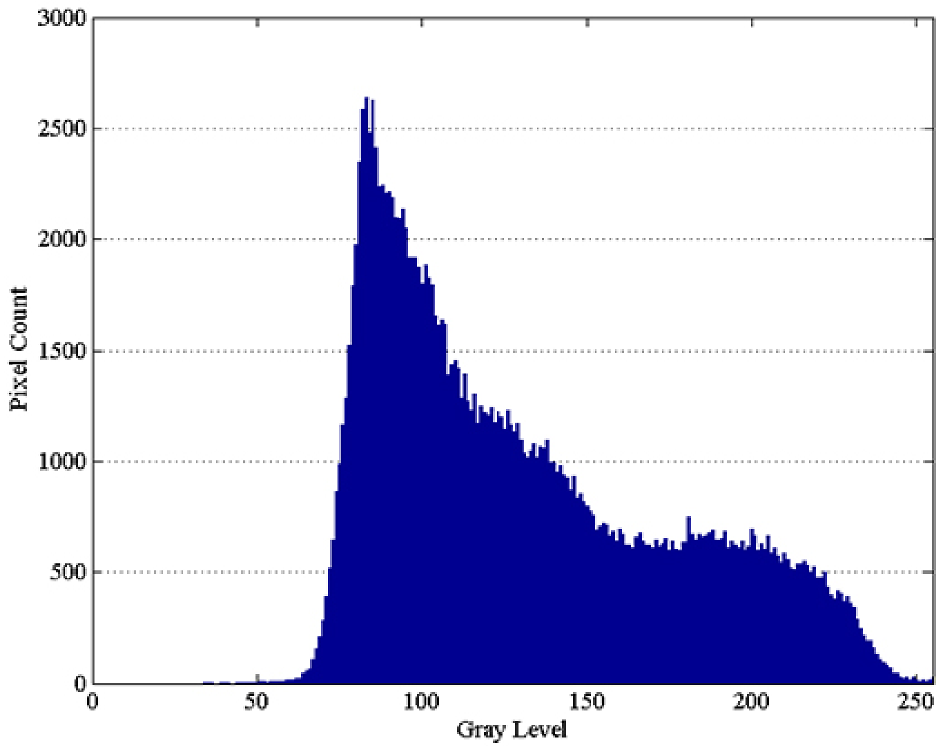


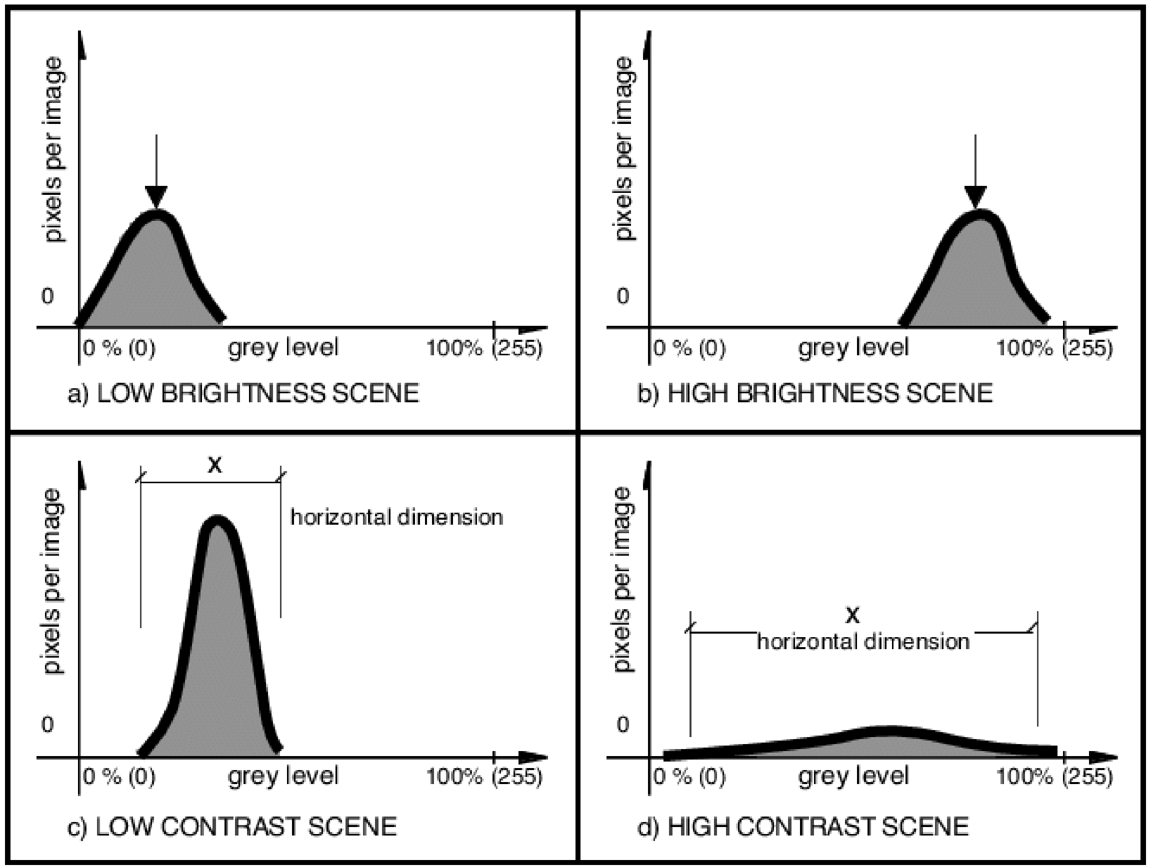
(a) (b)

(a) Original low contrast image from dataset, (b) Contrast enhanced image by proposed method.

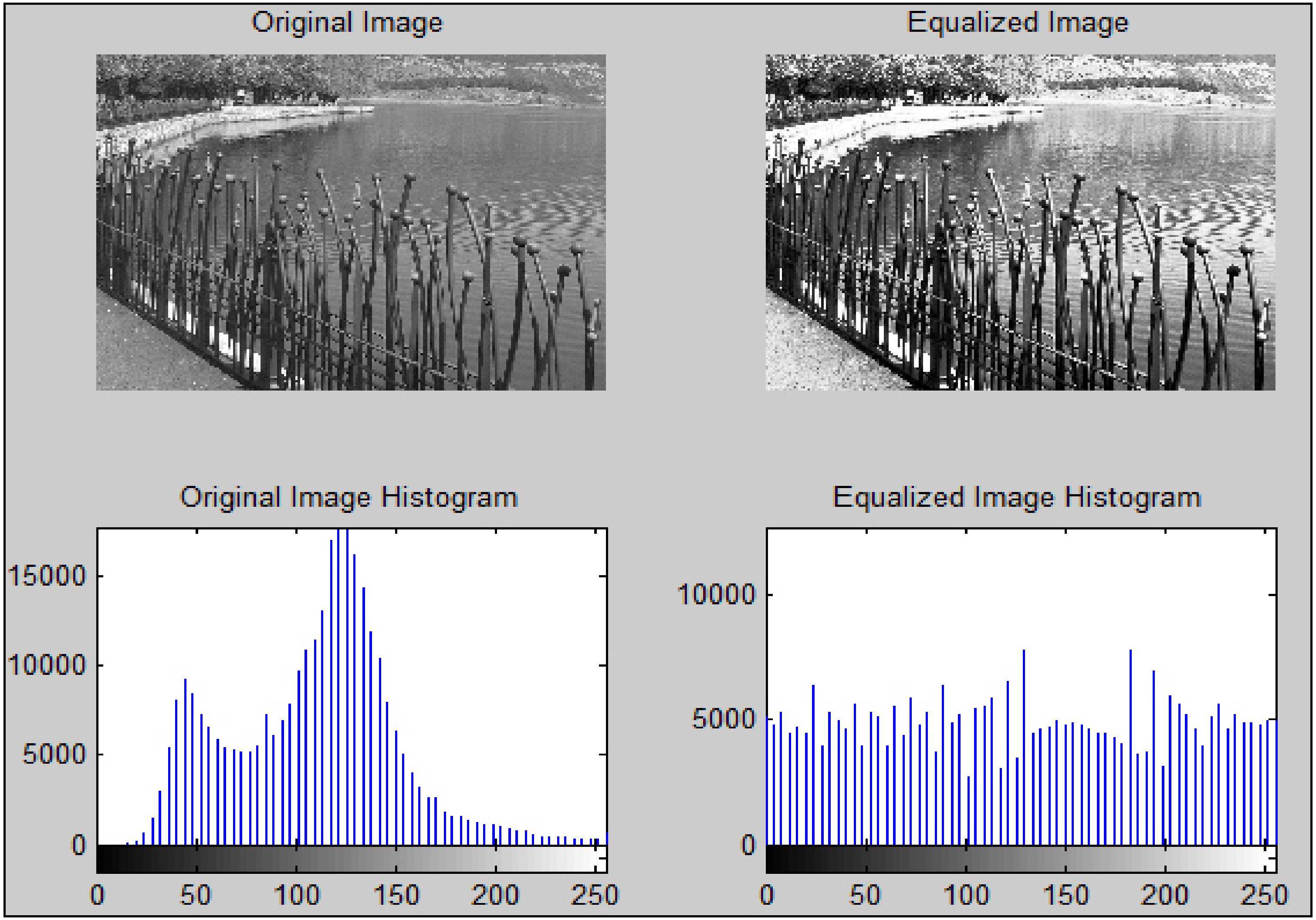
Image Histogram

An Example



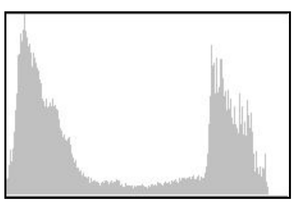

pixels per image
0
0 % (0)
grey level
100% (255)
a) LOW BRIGHTNESS SCENE
b) HIGH BRIGHTNESS SCENE
x
horizontal dimension
c) LOW CONTRAST SCENE
d) HIGH CONTRAST SCENE

Histogram Equalization

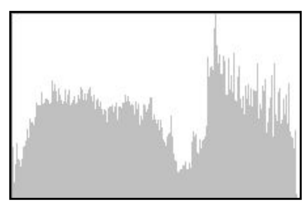


Color Histogram Equalization

Luma
Hist.

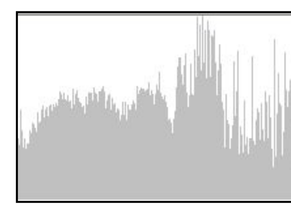


Original



Each color plane of RGB

Detailed enhanced,
but color distorted



Intensity component of HSI

Detailed enhanced with
more correct colors

Intensity (or Luminance) Adjustment

original

Reduce
Intensity
-30

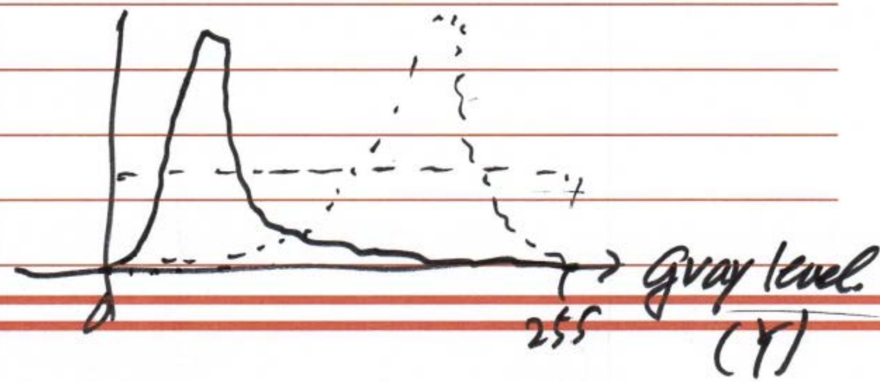
Each color plane of RGB

Intensity component of HSI

Increase
20% contrast

Image Enhancement via Contrast Manipulation

the output looks more pleasant



$(R, G, B) \rightarrow (Y, U, V)$

luminance

brightness

chrominance

Histogram Equalization: Derivation

histogram equalization

$P(x_0)$ ← density function

$x_0 \le x \le x_0 + \Delta x$

local view

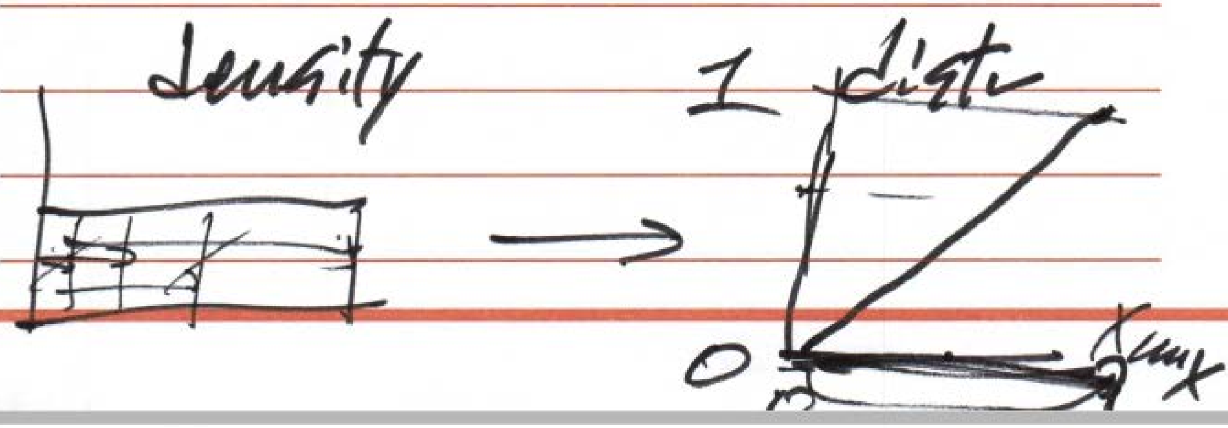
$P(x_0)$ distribution function

$0 \le x \le x_0$

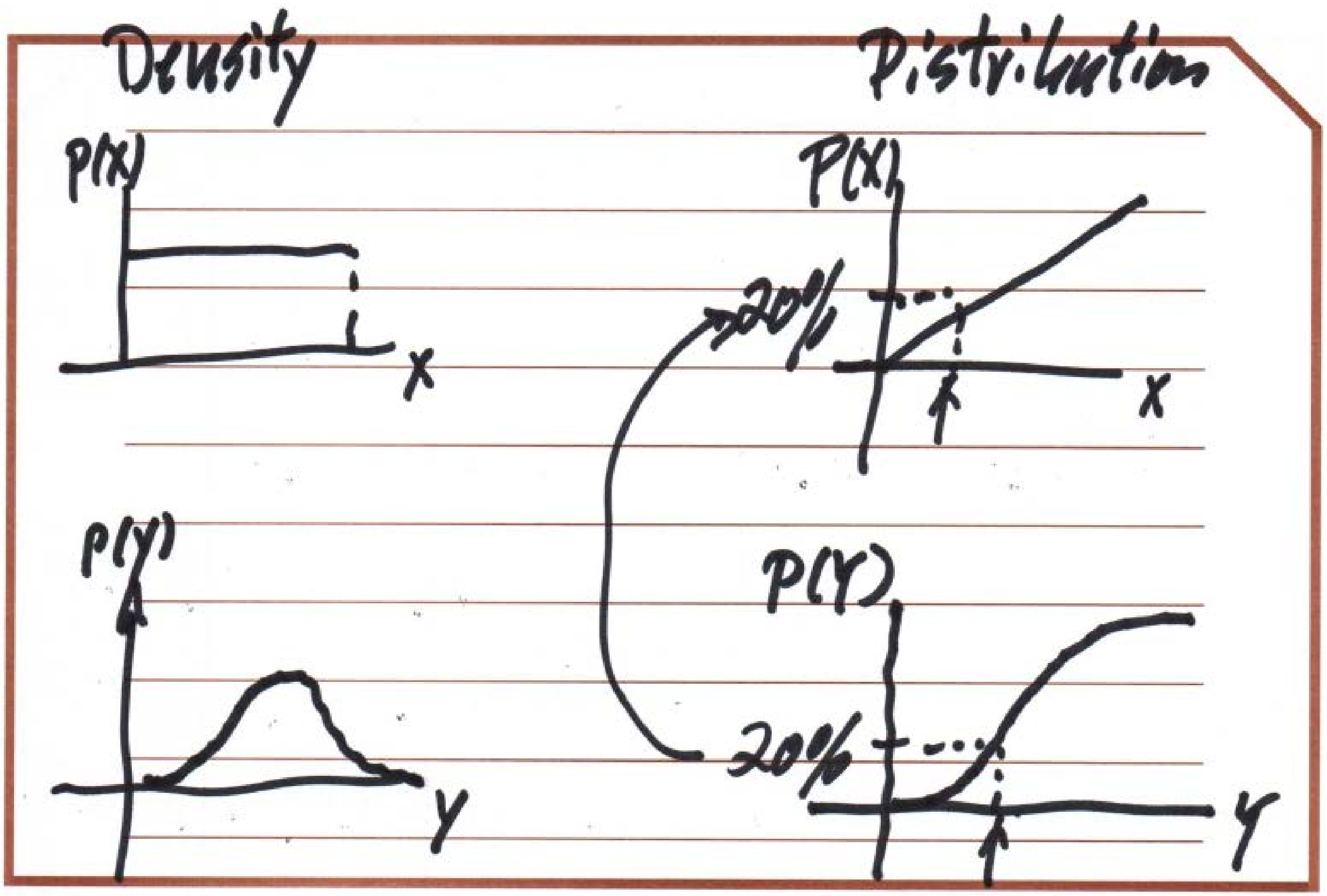
global view

Relationship between Density and Distribution Functions

$$P(x_0) = \int_0^{x_0} p(x)\,dx$$



Change of Random Variables



Transfer Function

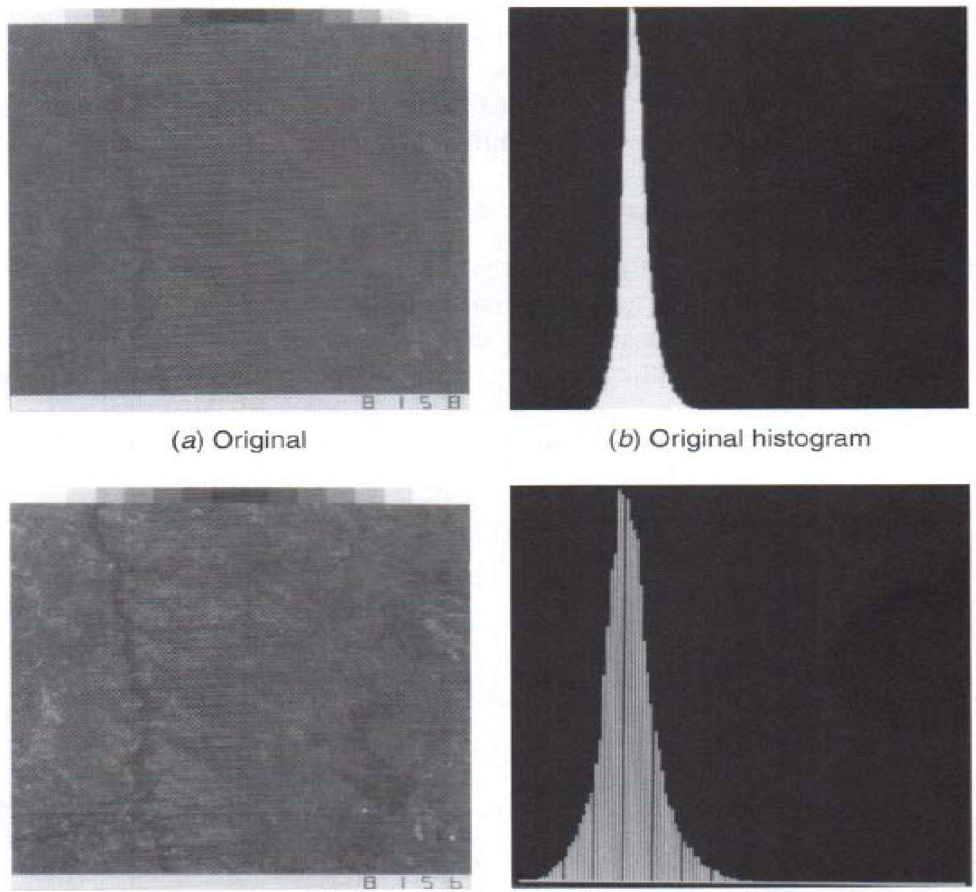
$$Y \longrightarrow X^{(\text{uniform.})}$$

$$P(Y) = P(X)$$

$$D_Y(y) = D_X(x)$$

$$x = D_X^{-1}(D_Y(y)).$$

Contrast Enhancement



(*a*) Original

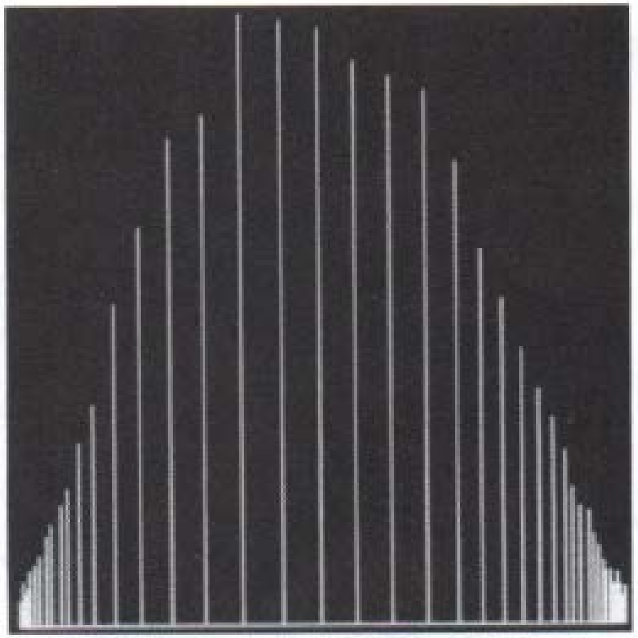
(*b*) Original histogram

(*c*) Min. clip = 0.17, max. clip = 0.64

(*d*) Enhancement histogram

Transfer-Function-Based Contrast Equalization

(*e*) Min. clip = 0.24, max. clip = 0.35

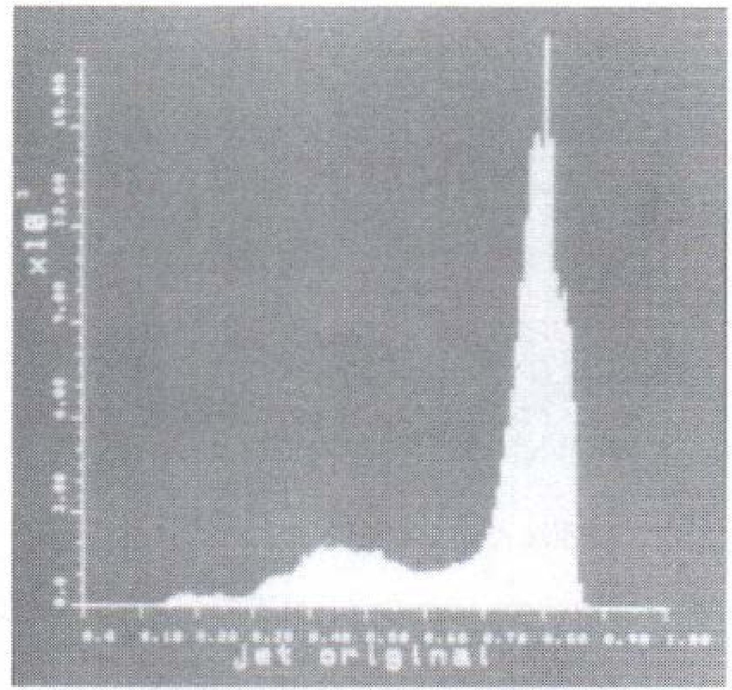


(*f*) Enhancement histogram

Artificial Contours
Caused by big gray-scale gaps

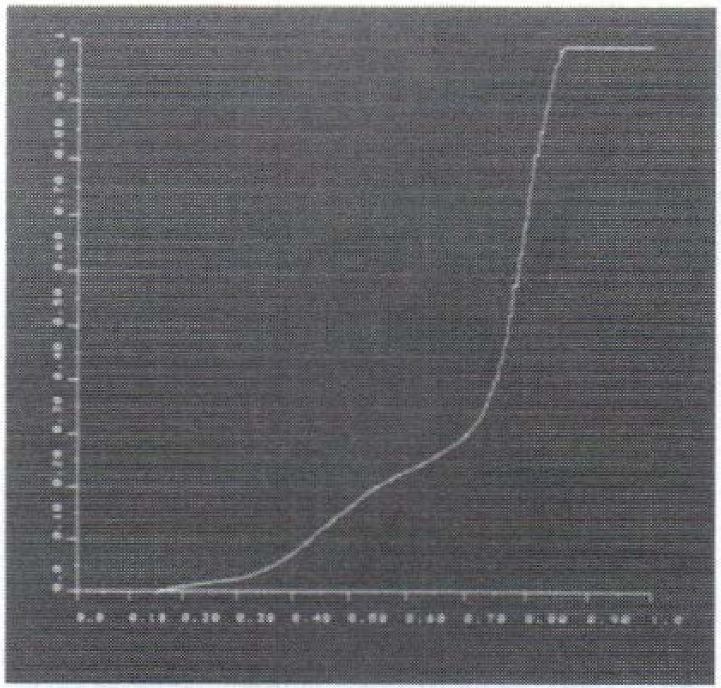
Example 2: Transfer-Function-Based Histogram Equalization

(*a*) Original



(*b*) Original histogram

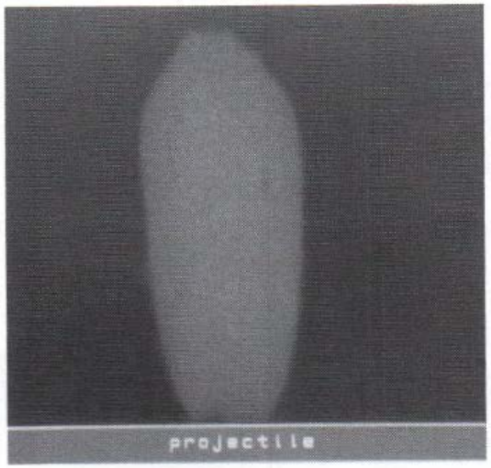
Example 2: Transfer-Function-Based Histogram Equalization



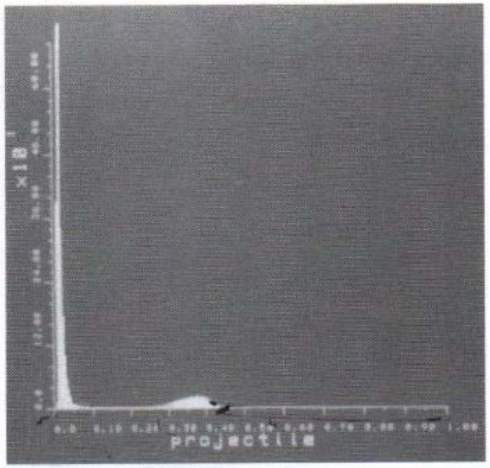
(c) Transfer function

(d) Histogram equalized

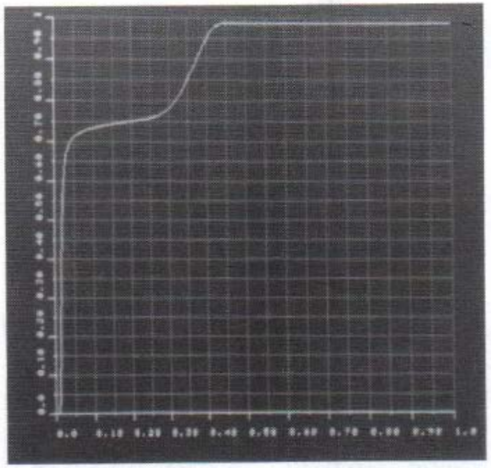
Example 3: Transfer-Function-Based Histogram Equalization



(*a*) Original



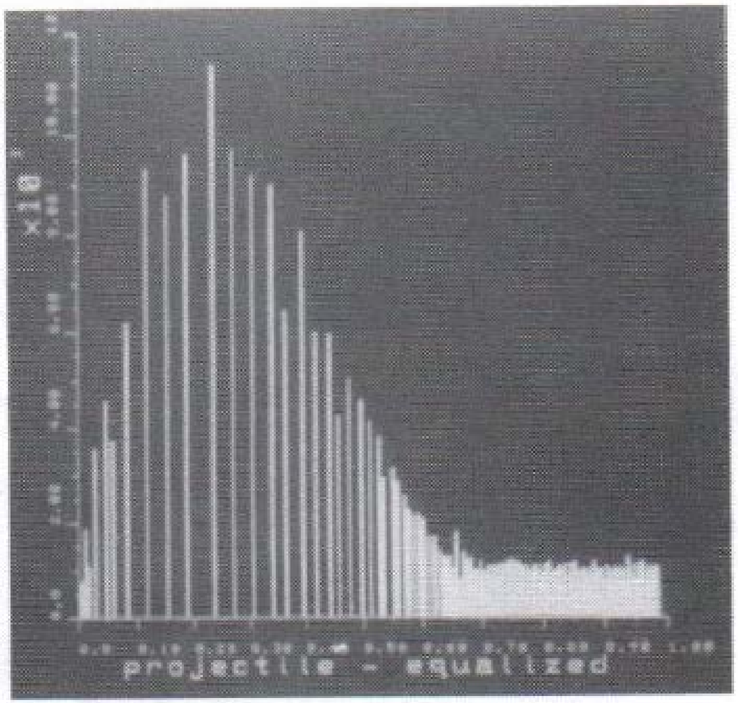
(*b*) Original histogram



(*c*) Transfer function

Example 3: Transfer-Function-Based Histogram Equalization

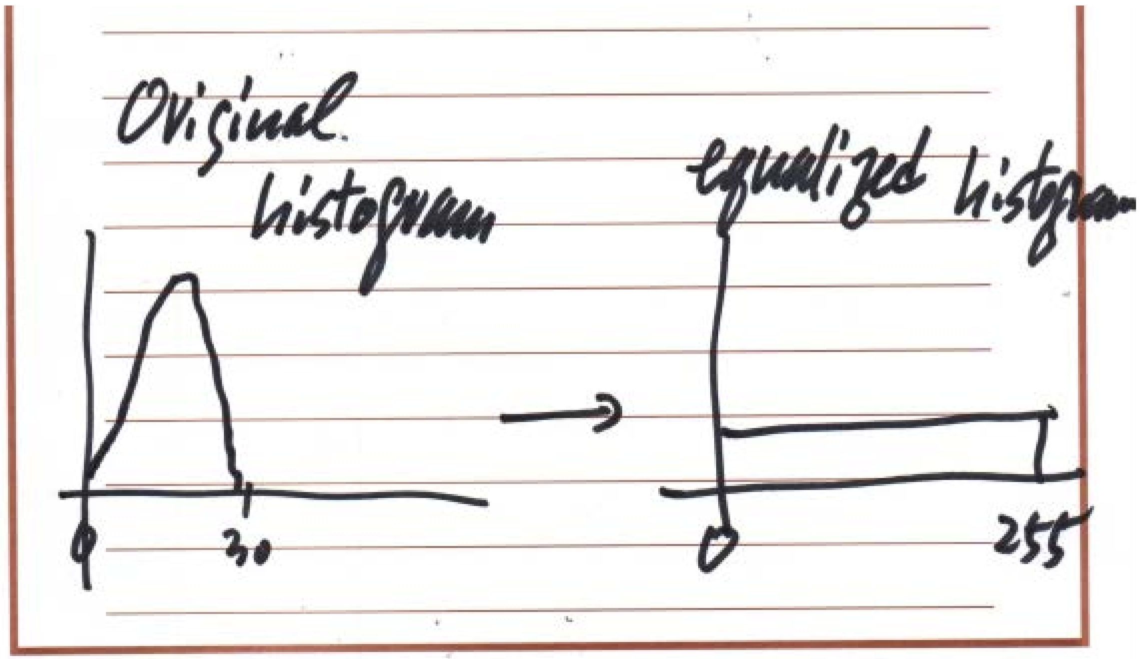
(*d*) Enhanced



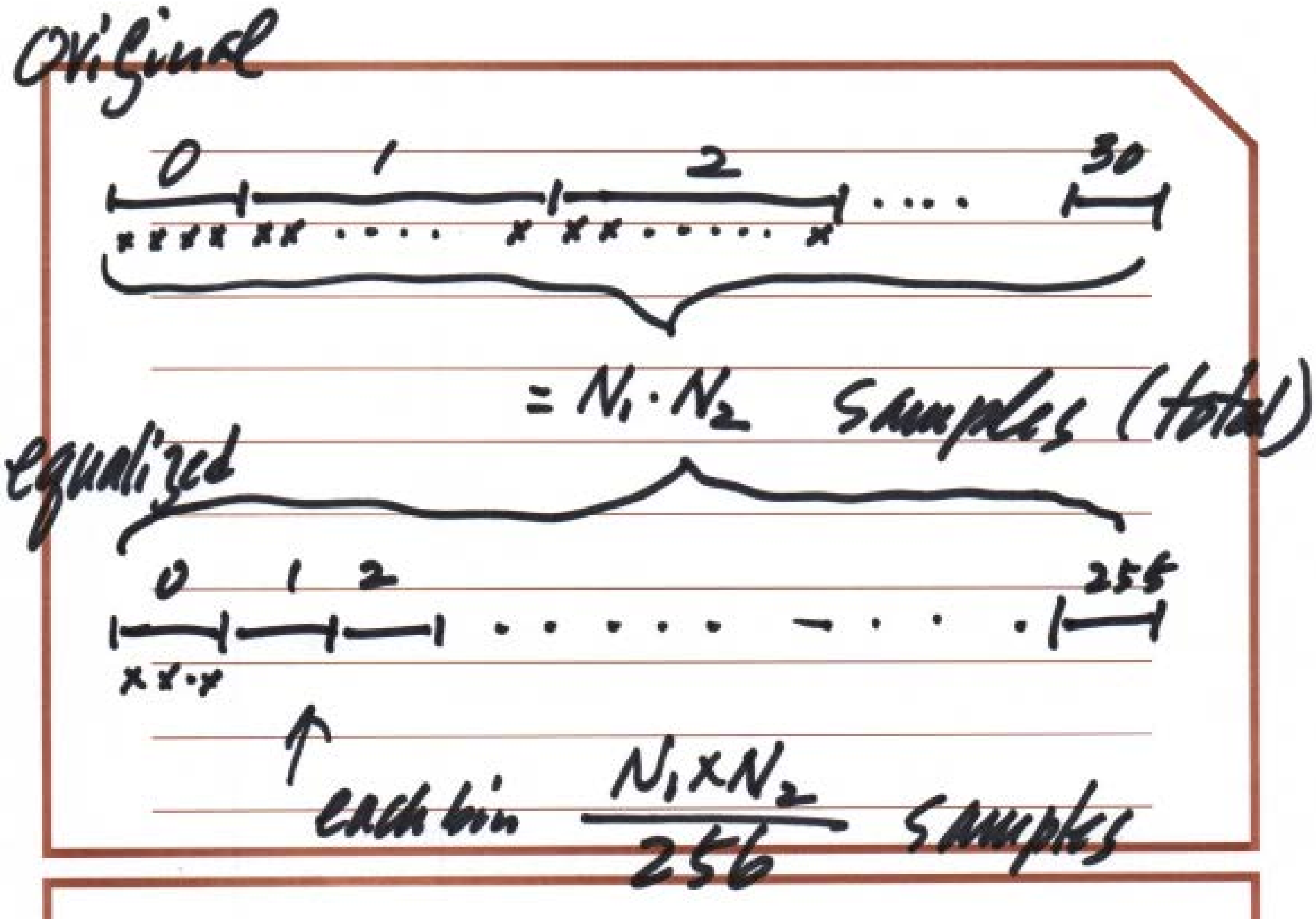
(*e*) Enhanced histogram

2nd Histogram Equalization Method (1)

- It allows one-to-many mapping



2nd Histogram Equalization Method (2)



Smoothing & Sharpening

original

Smooth
5x5 mean

Each color plane of RGB

Intensity component of HSI

sharpening

Auto Exposure (AE)

Auto Focus (AF)

- Autofocus (AF) points are what you use to determine where the camera will be focusing the image.
  - When you look through your viewfinder, these are the rectangles or circles that you see.

Color Correction- Auto White Balancing (AWB)

- Algorithms:
  - Simple: Max RGB, Grey World, and other statistical methods
  - Advanced: gamut constraint , neural network, etc.
- Simplest method - grey world theory
  - Assumption: average surface color is achromatic
  - Calculate the averages of each R,G, B channel for the entire image
  - Match the average to the mean grey value of standard illuminant

Another AWB Example

http://www.ieee.org