[2016 1학기 확률 및 통계]

Image Processing

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2016년 4월 19일

What is Image?

- Image is a 2-D spatially sampled signal of 3-D world.
  - Sampling grid: pixel
  - (x,y) : spatial coordinate
  - t : temporal coordinate (video sequence)
- Image signal is a function of (x,y).
  - 3-D surface on the x-y plane
  - $0 \leq f(x,y) \leq L(=255)$: gray - 8bit/pixel, color level- 24bit/pixel
  - Video signal is a function of (x,y,t).

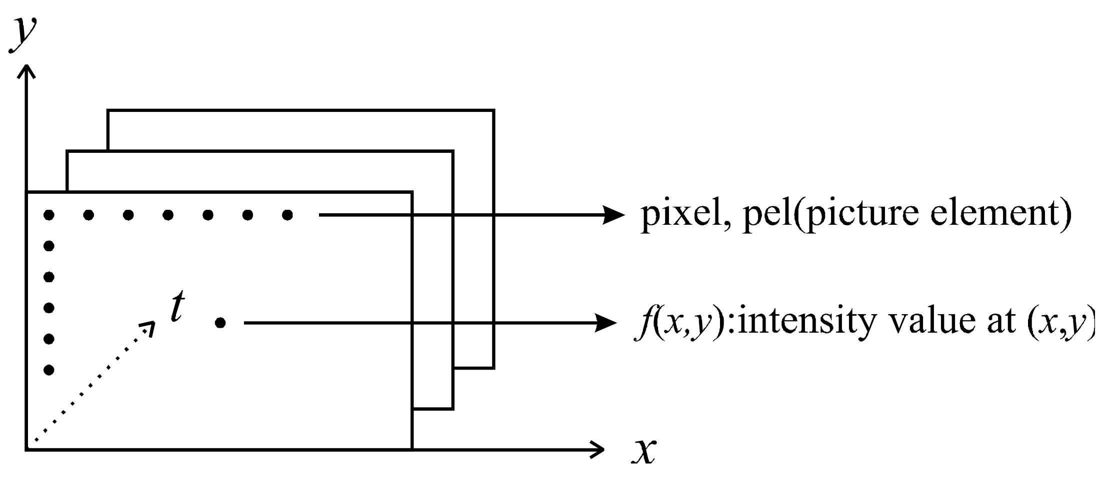
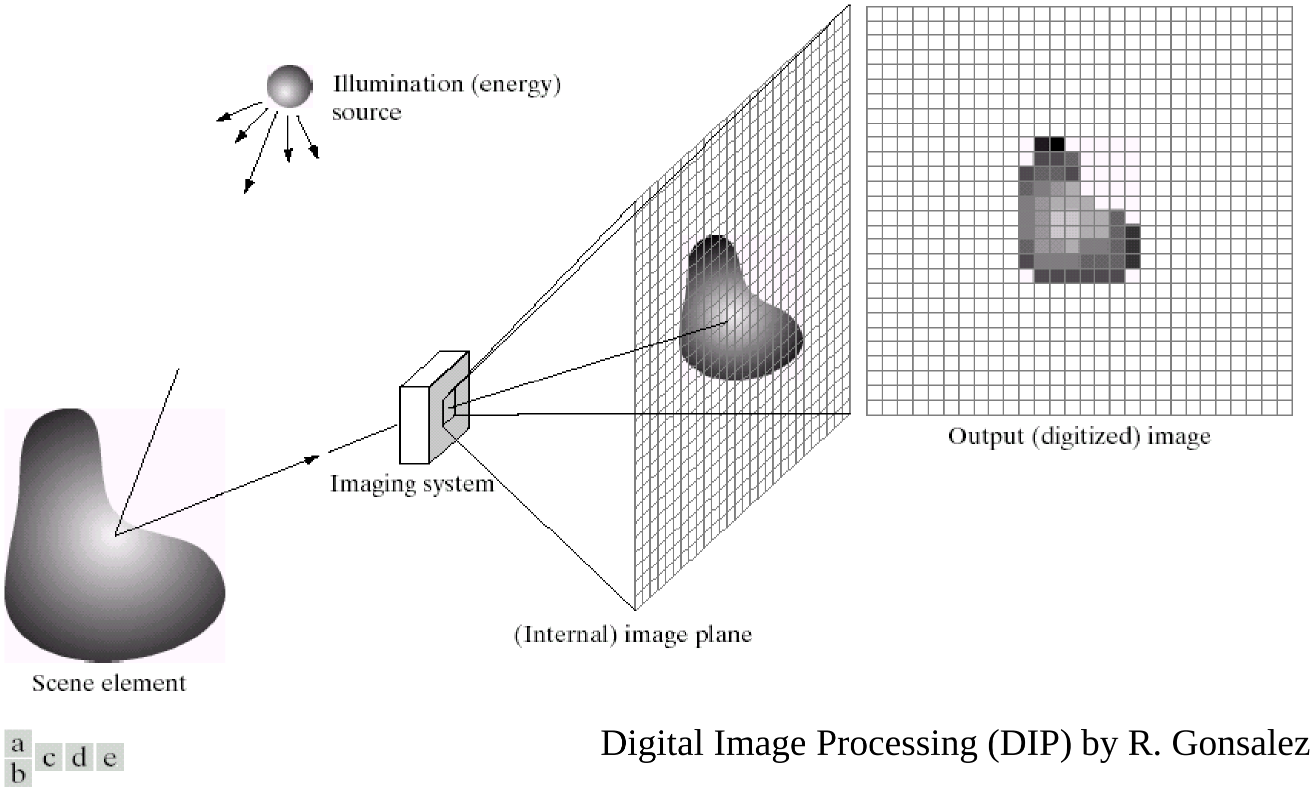


Image Generation (1)

- Classical imaging system
  - Reflected light from object surface is accumulated in the electronic sensor.
  - The 3-D points are spatially sampled on the pixels.

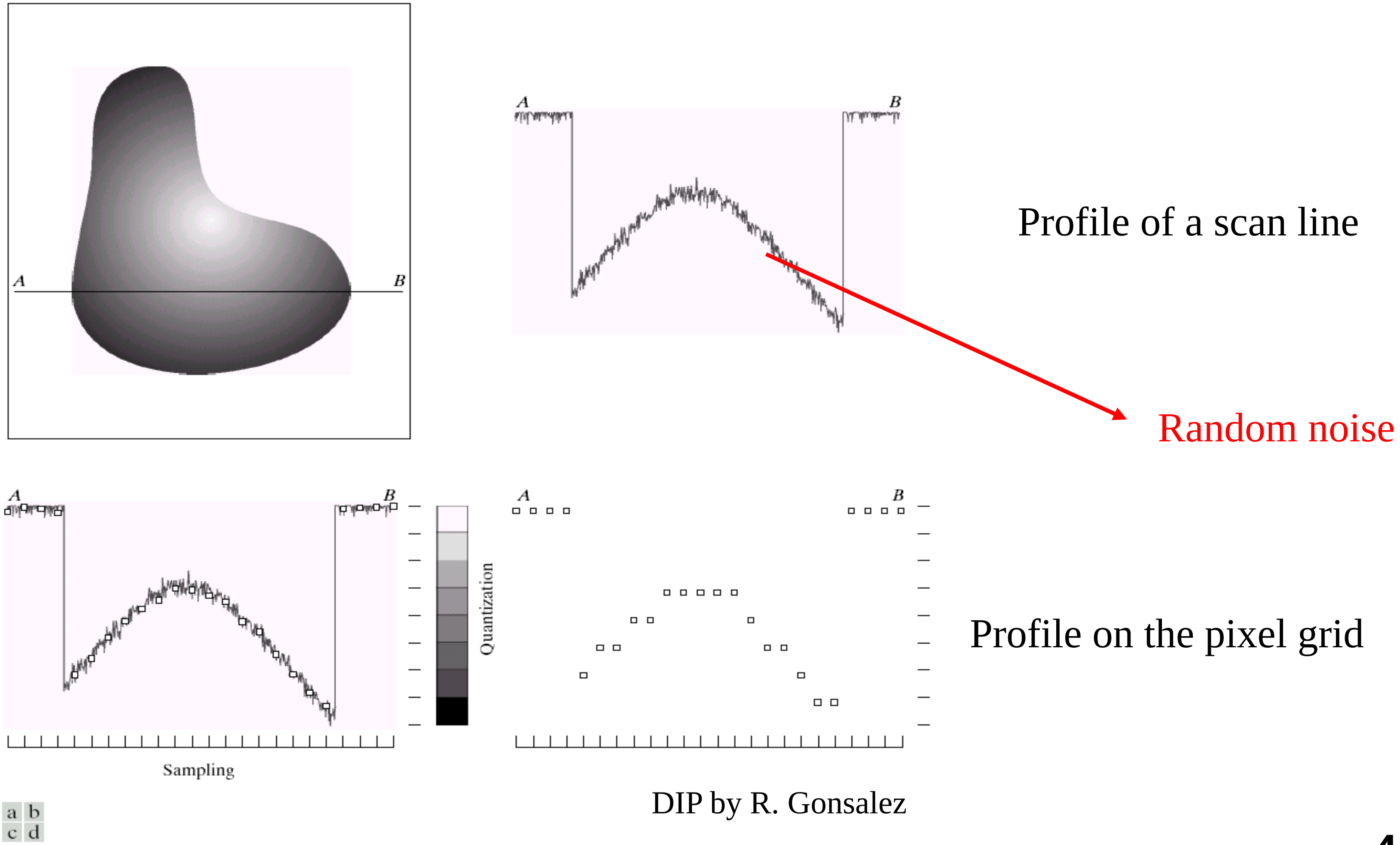


Digital Image Processing (DIP) by R. Gonsalez

FIGURE 2.15 An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

Image Generation (2)

- Image signal is vey noisy unlike the visual appearance.

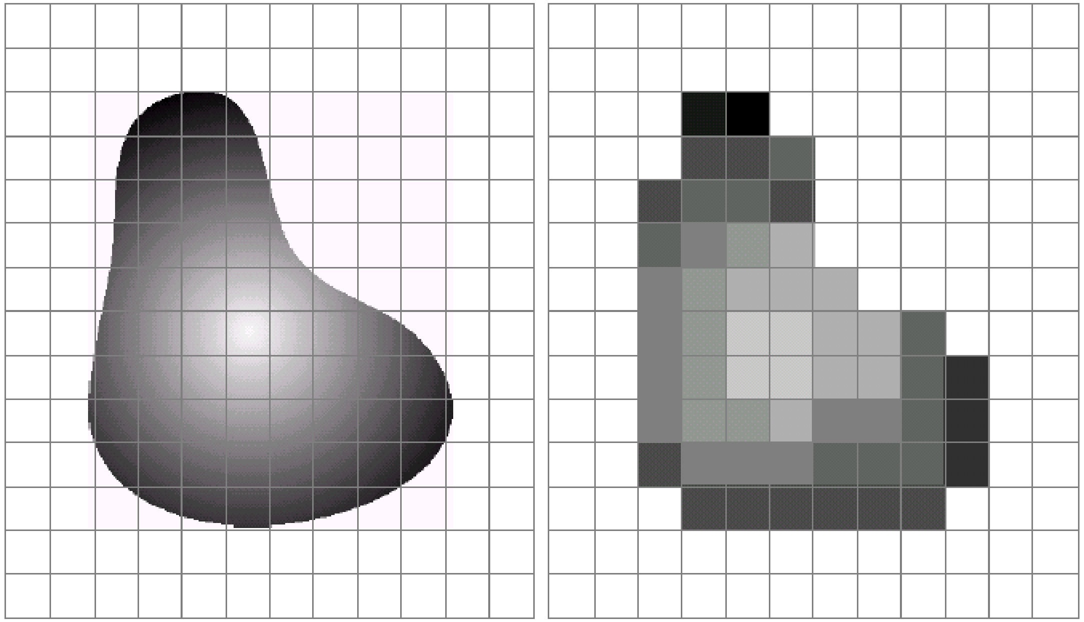


DIP by R. Gonsalez

FIGURE 2.16 Generating a digital image. (a) Continuous image. (b) A scan line from A to B in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

Image Generation (3)

- Image spatial sampling and quantization
  - By sampling on the sensor grid: loss of detailed visual information
  - By quantization: loss of continuous values of original intensities



a b

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FIGURE 2.17 (a) Continuos image projected onto a sensor array. (b) Result of image sampling and quantization.

Image Coordinates

◆ Image representation for digital processing: 2D array

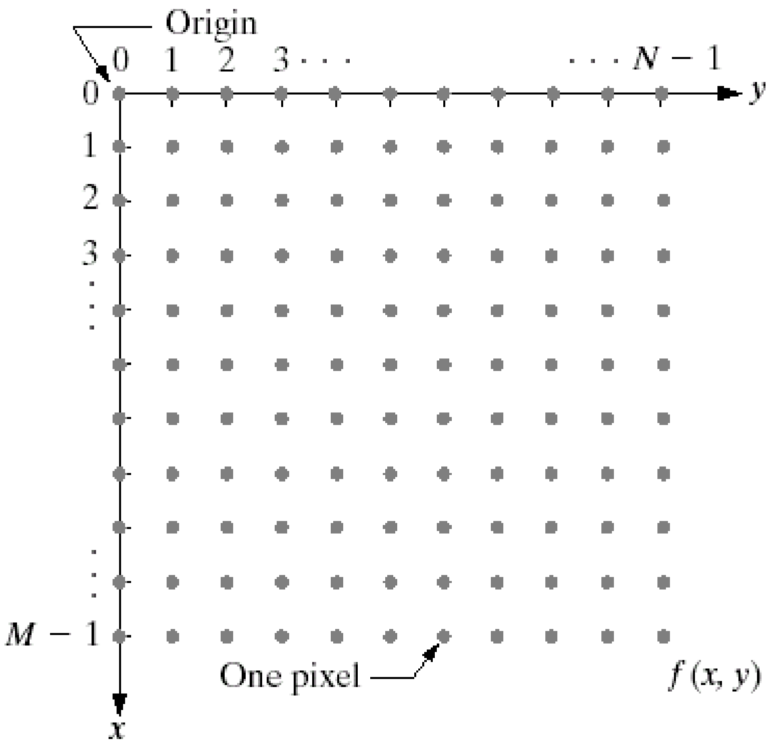


FIGURE 2.18 Coordinate convention used in this book to represent digital images.

DIP by R. Gonsalez

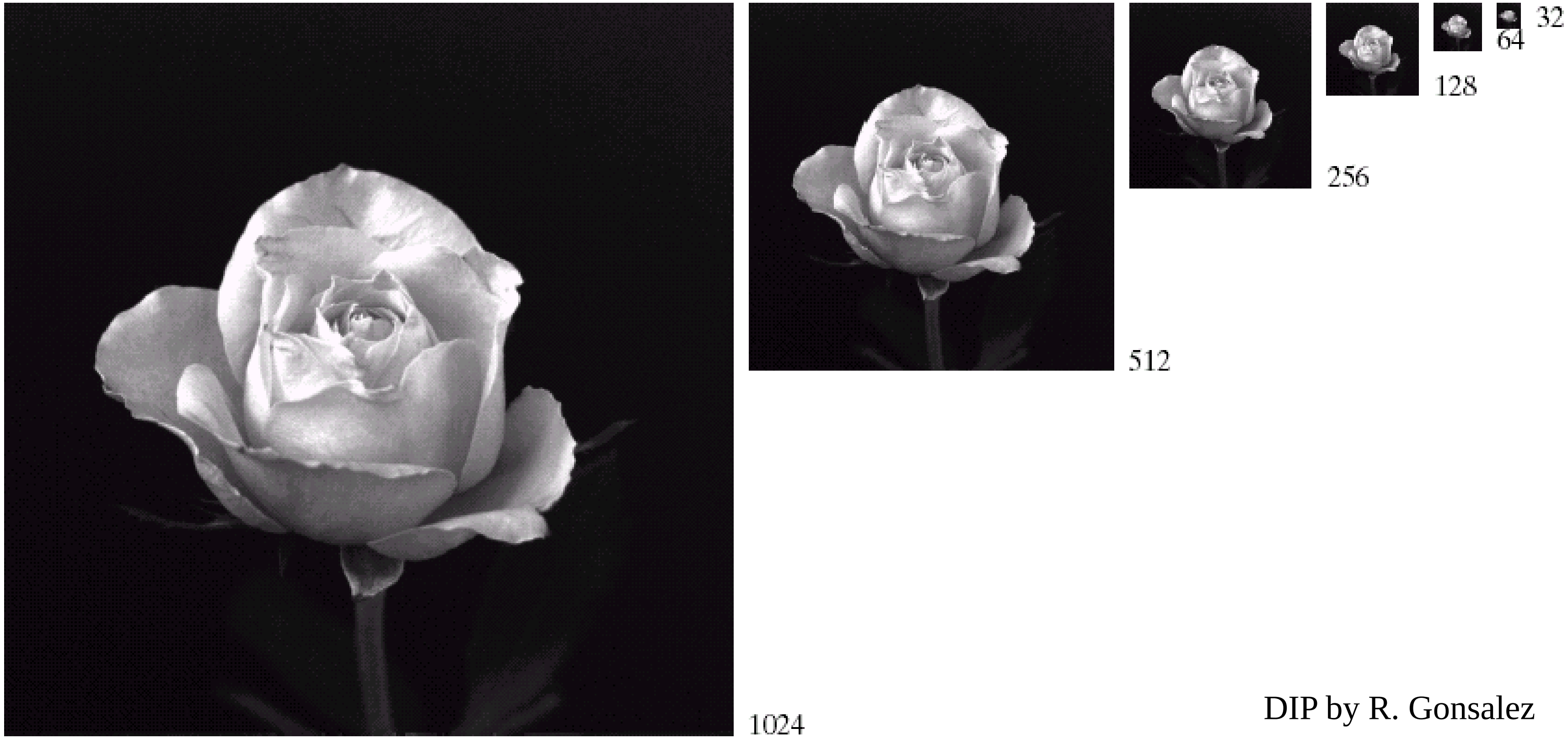
$M \times N$ matrix or array

$$\mathbf{A} = \begin{bmatrix} a_{00} & a_{01} & \cdots & a_{0,N-1} \\ \vdots & & & \\ \vdots & & & \\ a_{M-1,0} & \cdots & \cdots & a_{M-1,N-1} \end{bmatrix}$$

$$a_{ij} = f\,(x=i,\, y=j)$$

Image Resolution (# of Pixels)

- Image resolution is usually better when pixels are increased.

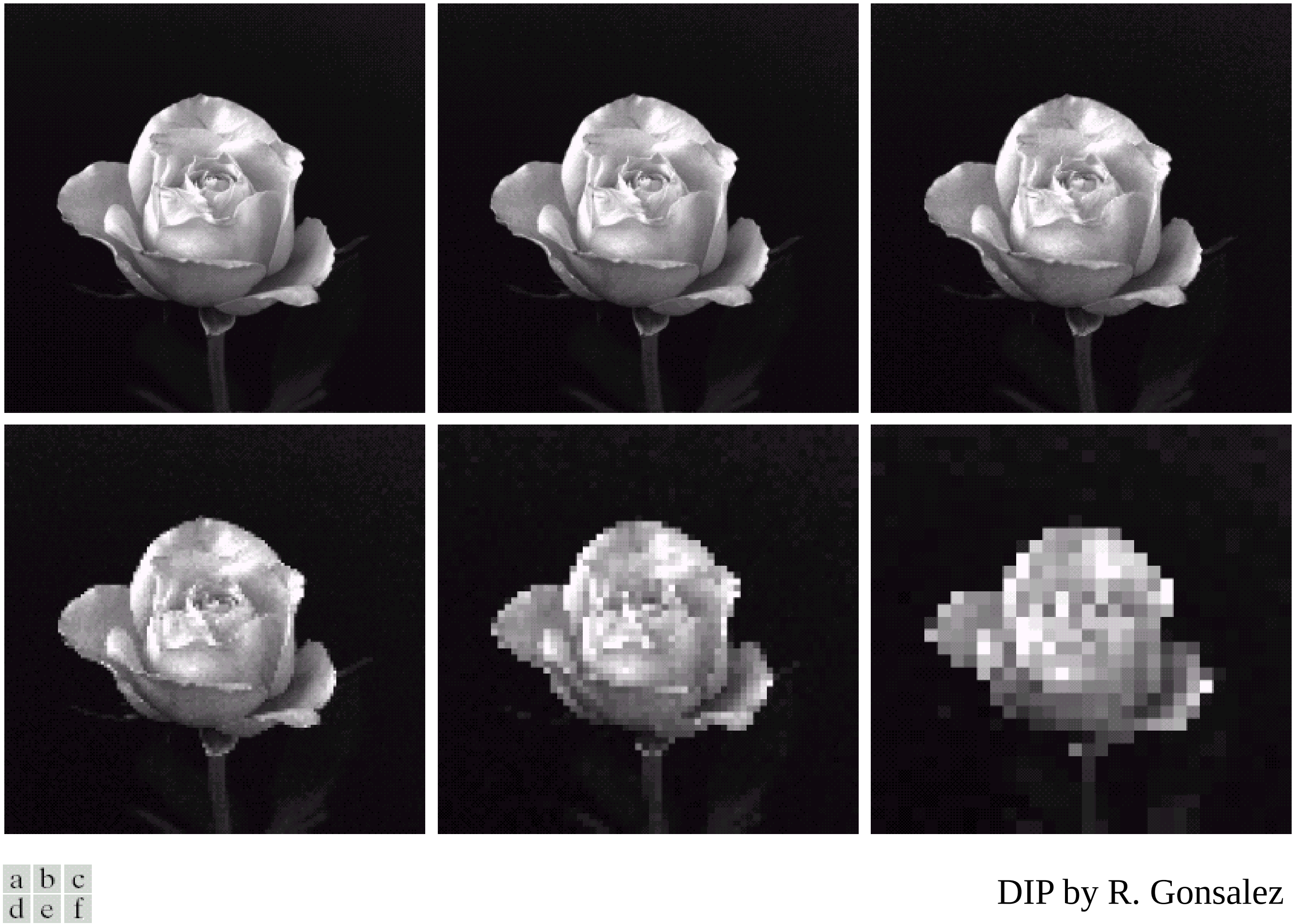


DIP by R. Gonsalez

FIGURE 2.19 A 1024 × 1024, 8-bit image subsampled down to size 32 × 32 pixels. The number of allowable gray levels was kept at 256.

Image Resolution (Precision)

- Image resolution is better when spatial sampling is finer.

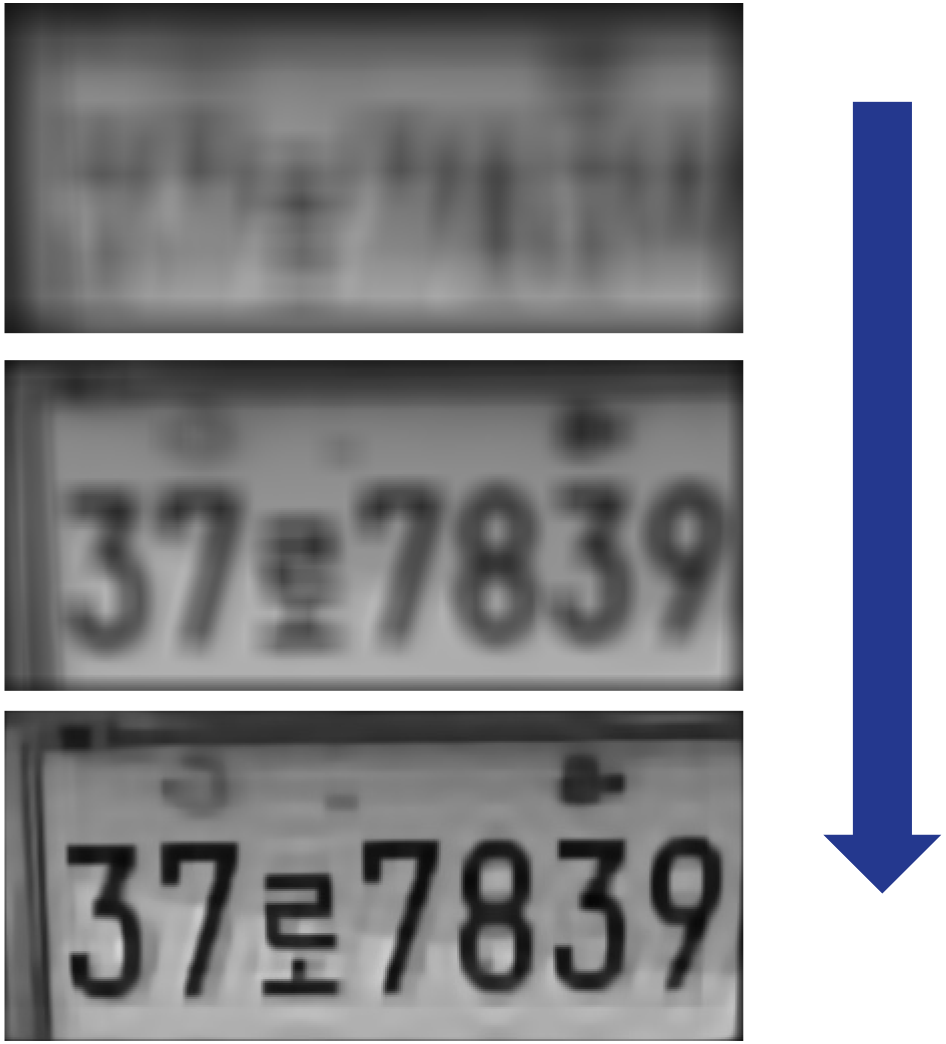


DIP by R. Gonsalez

FIGURE 2.20 (a) 1024 × 1024, 8-bit image. (b) 512 × 512 image resampled into 1024 × 1024 pixels by row and column duplication. (c) through (f) 256 × 256, 128 × 128, 64 × 64, and 32 × 32 images resampled into 1024 × 1024 pixels.

Image Resolution (Blurring)

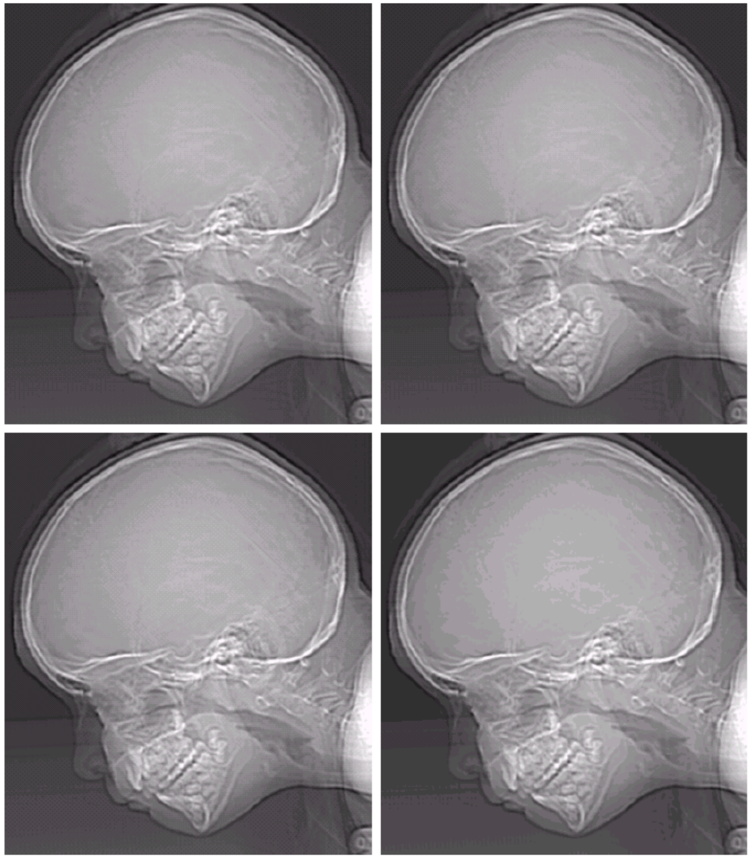
◆ Image resolution is better when blurring is less.



해상도 개선
(deblurring)

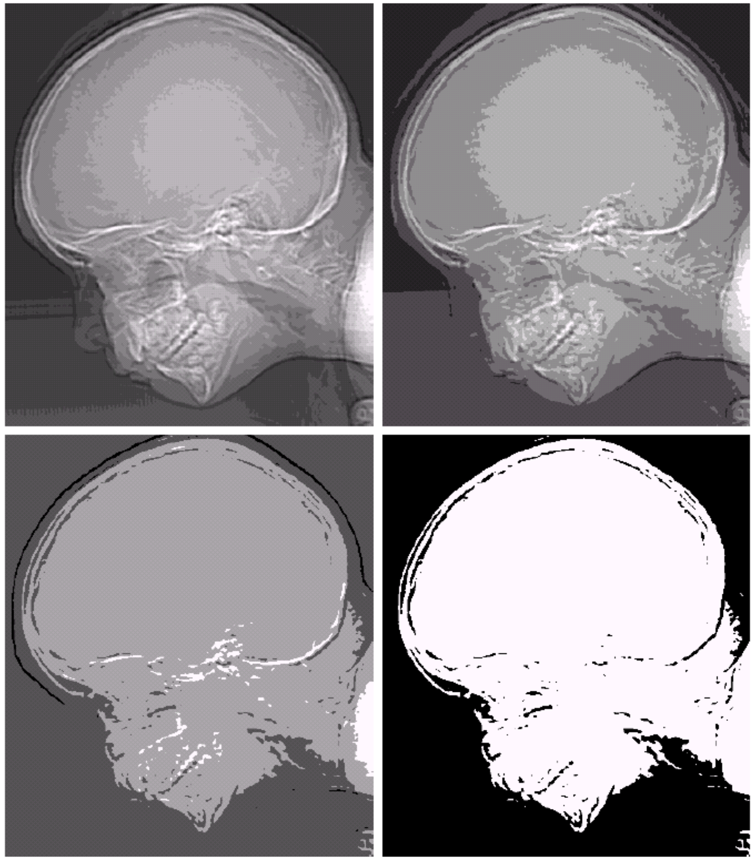
Image Levels (Quantization Levels)

- The more intensity levels, the better the detailed contents.
- Quantization error – information loss – random noise



a b
c d

FIGURE 2.21 (a) 452 × 374, 256-level image. (b)–(d) Image displayed in 128, 64, and 32 gray levels, while keeping the spatial resolution constant.



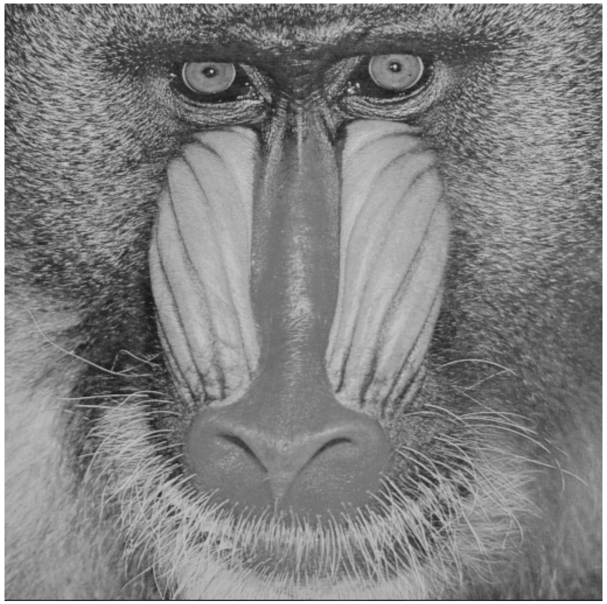
How to Obtain Images?

- Functional forms
  - $f(x,y)$: 2-D image
  - $f(x,y,t)$, $f(x,y,z)$: video sequence, 3D model
- Methods
  - Brightness(luminance) or color reflected from object surface
  - Absorption or Penetration characteristics of objects
    - X-ray imaging, Ultrasonic imaging, CT
  - Distance between objects and measuring instrument
    - sonar imaging, radar imaging, range camera, Lidar imaging
  - Temperature of an object
    - Thermal IR camera
  - Everything to generate 2-D signals: MRI, ….

Famous Still Images

- For image processing and image compression (JPEG)

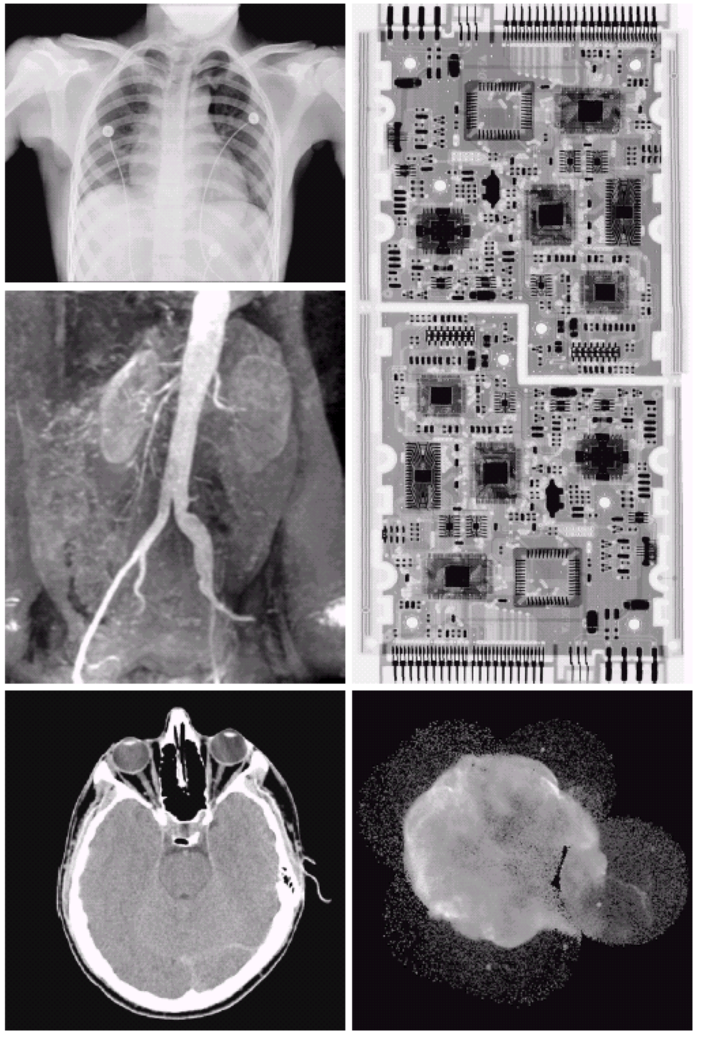
Lena



Barboon

Boat

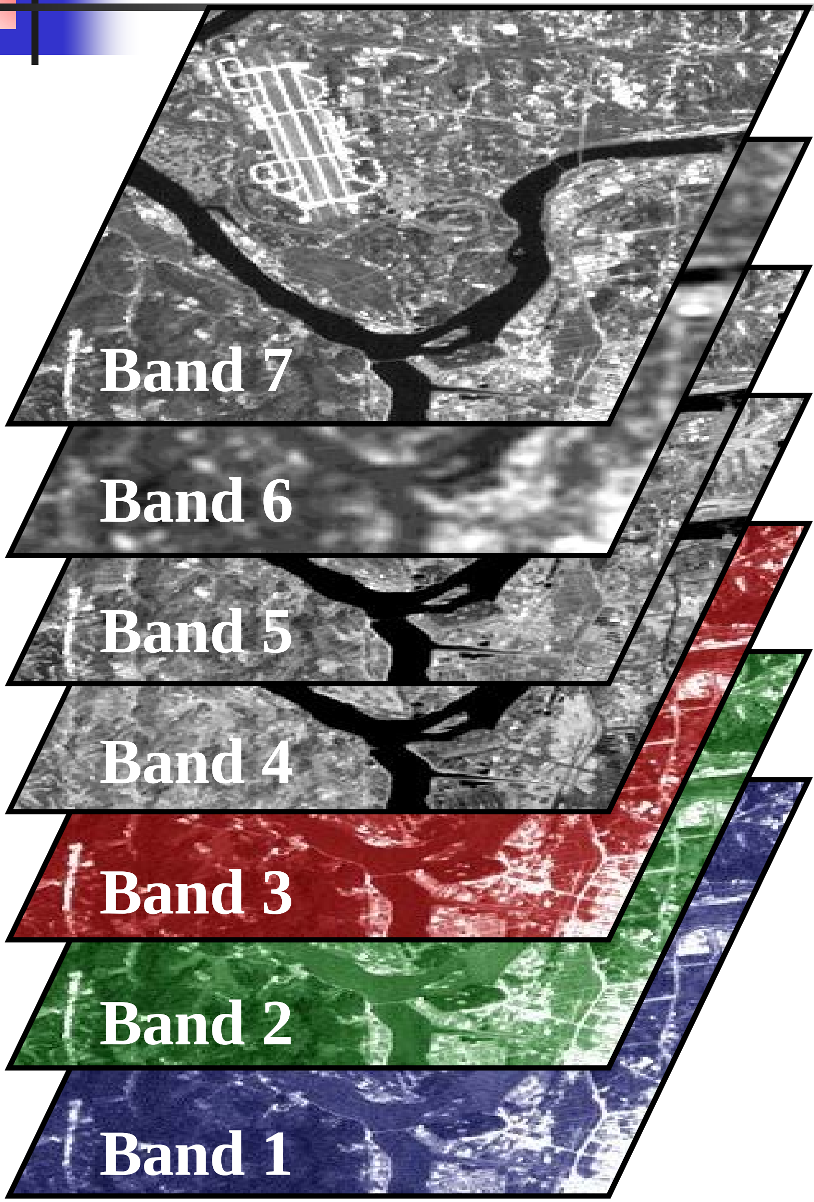
X-ray Images



a d
b
c e

FIGURE 1.7 Examples of X-ray imaging. (a) Chest X-ray. (b) Aortic angiogram. (c) Head CT. (d) Circuit boards. (e) Cygnus Loop. (Images courtesy of (a) and (c) Dr. David R. Pickens, Dept. of Radiology & Radiological Sciences, Vanderbilt University Medical Center, (b) Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, (d) Mr. Joseph E. Pascente, Lixi, Inc., and (e) NASA.)

Multi-spectral Images (1)



Band No.	Name	Wavelength (μm)	Characteristics and Uses
1	Visible blue	0.45–0.52	Maximum water penetration
2	Visible green	0.52–0.60	Good for measuring plant vigor
3	Visible red	0.63–0.69	Vegetation discrimination
4	Near infrared	0.76–0.90	Biomass and shoreline mapping
5	Middle infrared	1.55–1.75	Moisture content of soil and vegetation
6	Thermal infrared	10.4–12.5	Soil moisture; thermal mapping
7	Middle infrared	2.08–2.35	Mineral mapping

3,2,1
fusion

Natural Color Fusion

Multi-spectral Images (2)

Painting reconstruction

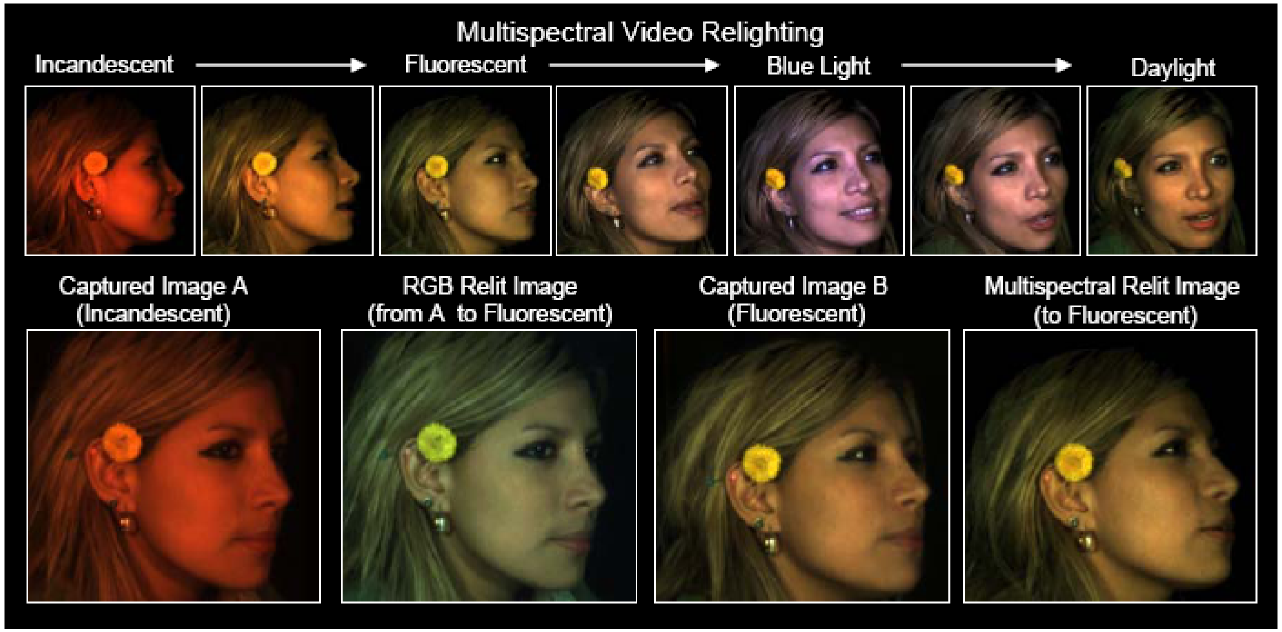
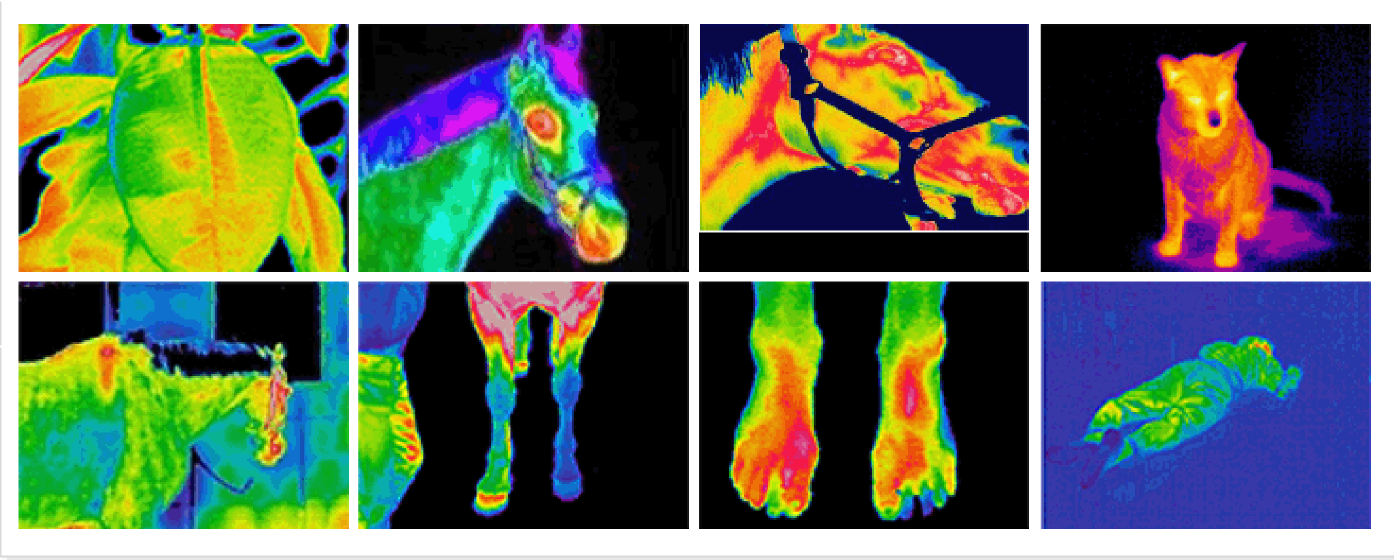
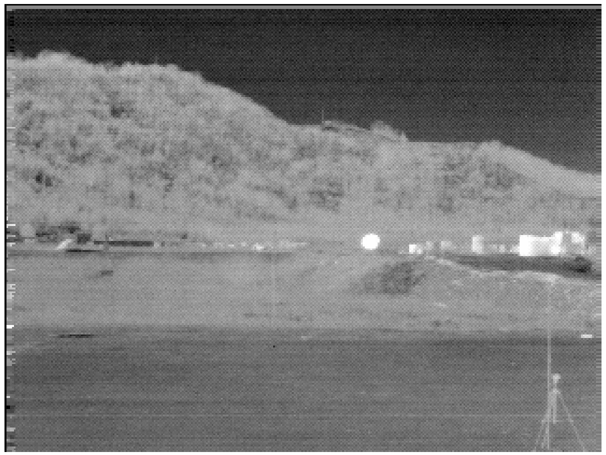


Image relighting

Infrared Images (1)

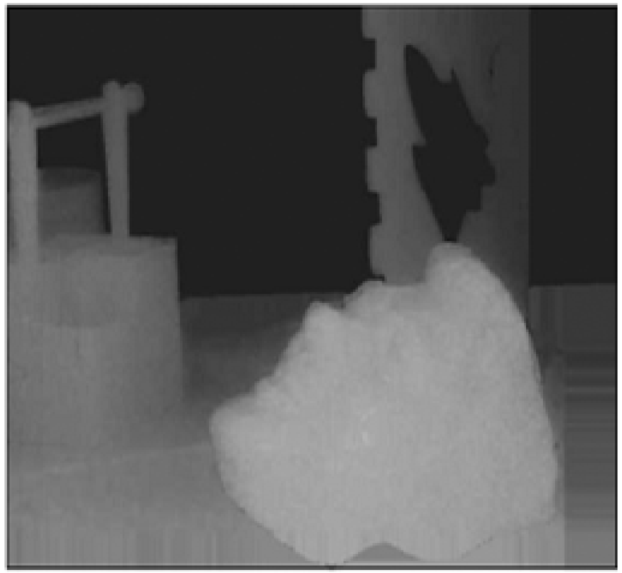
- Thermal IR: Temperature sensing





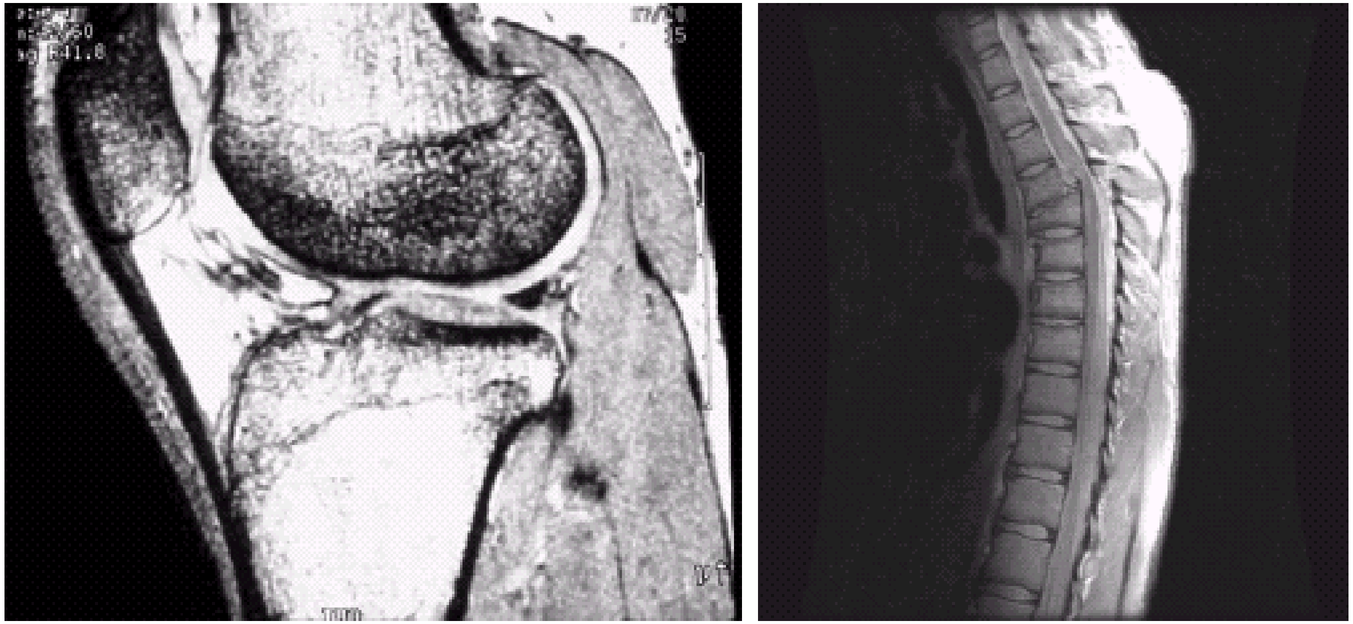
Infrared Images (2)

◆ Range image for 3D modeling and rendering



Kinect sensor for 3-D map

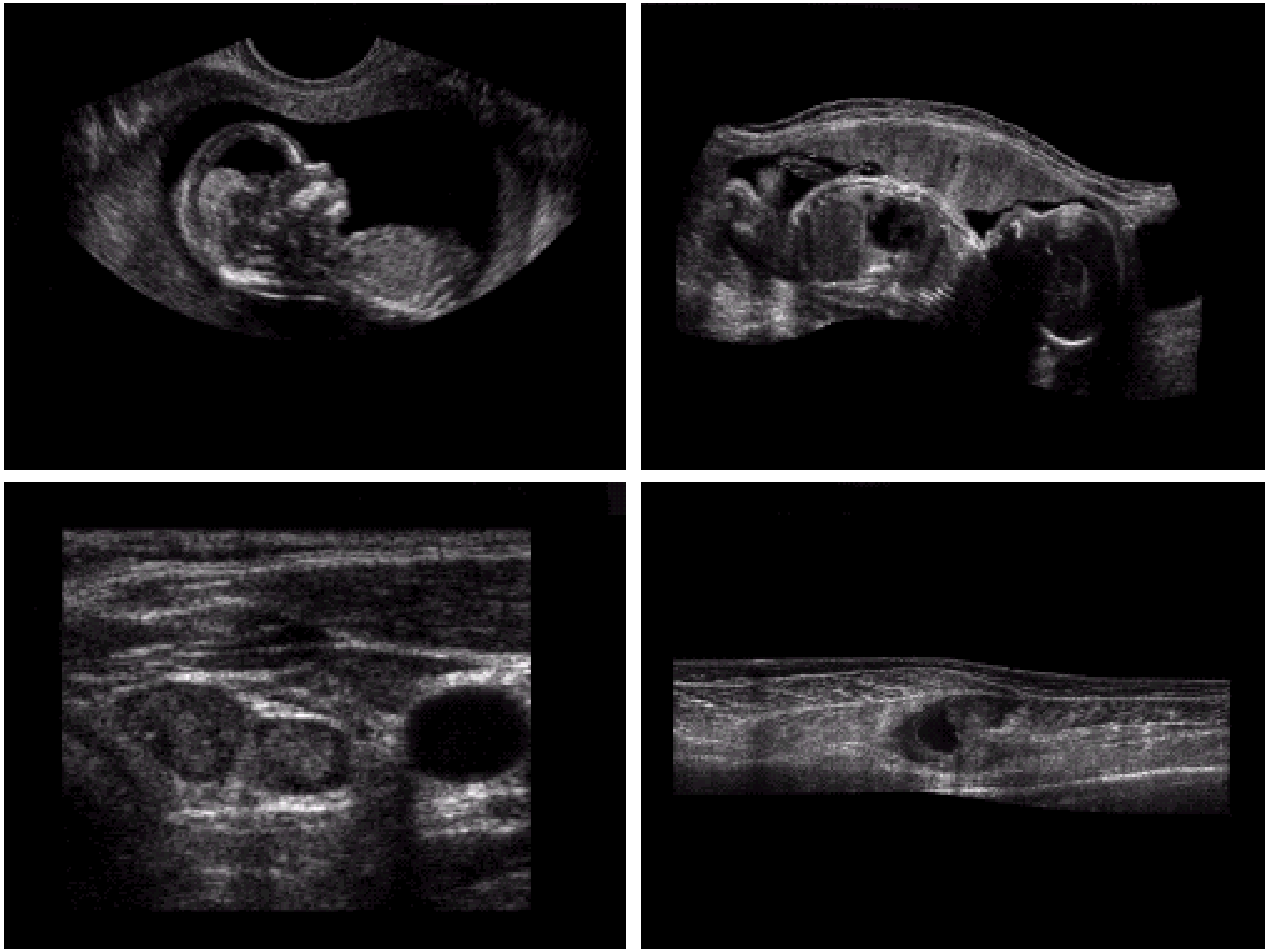
MRI



a b

FIGURE 1.17 MRI images of a human (a) knee, and (b) spine. (Image (a) courtesy of Dr. Thomas R. Gest, Division of Anatomical Sciences, University of Michigan Medical School, and (b) Dr. David R. Pickens, Department of Radiology and Radiological Sciences, Vanderbilt University Medical Center.)

Ultrasonic Images



a b
c d

FIGURE 1.20 Examples of ultrasound imaging. (a) Baby. (2) Another view of baby. (c) Thyroids. (d) Muscle layers showing lesion. (Courtesy of Siemens Medical Systems, Inc., Ultrasound Group.)

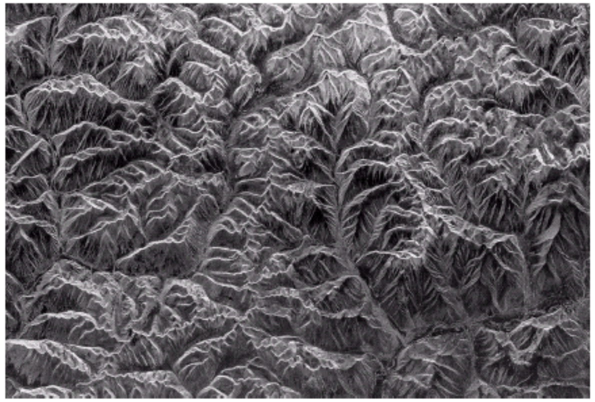
DIP by R. Gonsalez

Laser (range) Image

- Lidar (light detection and ranging)
  - Distance measure, 3D modeling

Depth map

FIGURE 1.16 Spaceborne radar image of mountains in southeast Tibet. (Courtesy of NASA.)

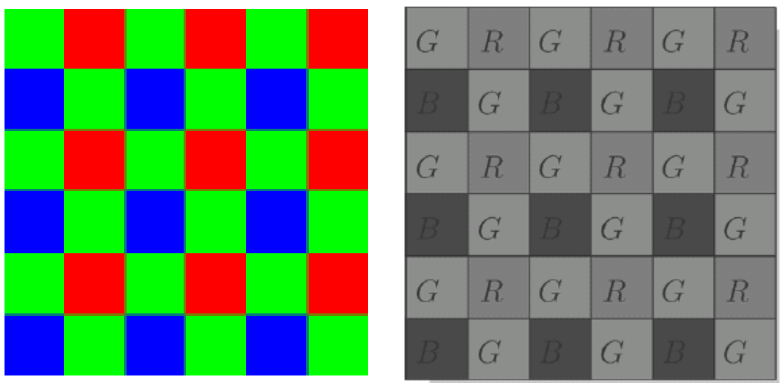


Stereoscopic system

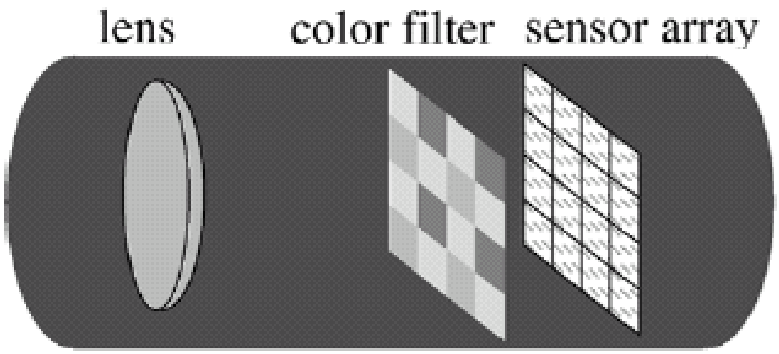
3D model+ image texture mapping

Digital Color Image Generation (1)

- Bayar CFA (color filter array) pattern
  - Each pixel takes only one color component via mosaicked CFA pattern.
  - Green is sampled at a higher rate than red and blue.
  - Resolution reduction.



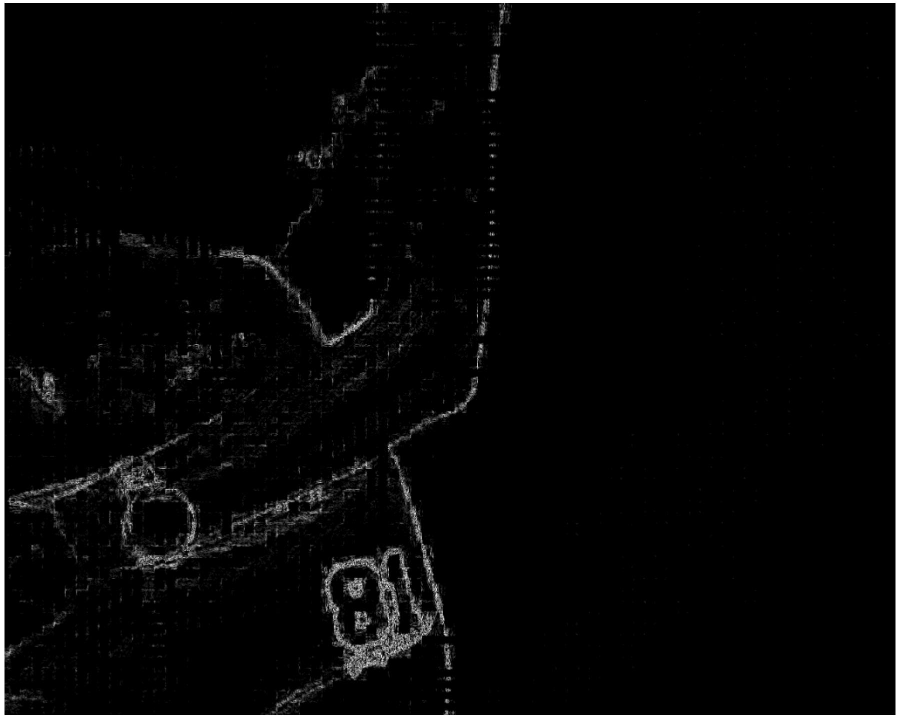
Bayar CFA pattern



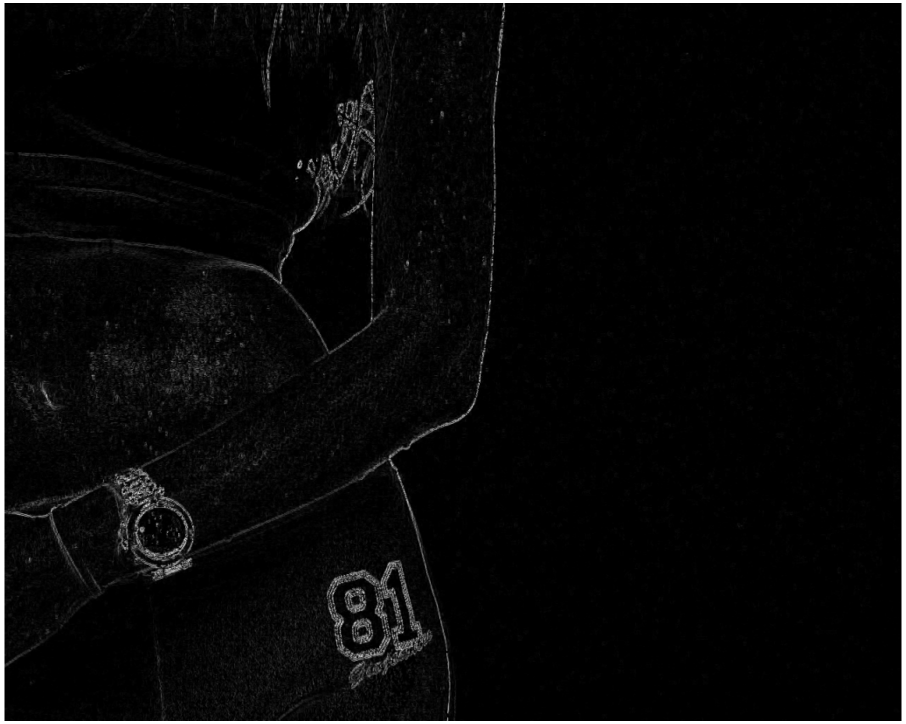
Color image acquisition

Digital Color Image Generation (2)

- Resolution reduction by CFA
  - Comparison of edge maps



Edge map of Cb-Cr (b-R) components



Edge map of Y (green) components

Demosaic

- For full resolution color images
  - Interpolation is required for each color channel.
  - Image Demosaic
- Interpolating each color component, (R,G,B)
  - Independent interpolation
  - Using correlations between colors.
- Artifacts generated from
  - Image contents (high frequency)
  - Interpolation algorithms
  - CFA pattern: zippering

Demosaic Results

- An exemplary artifact

Horizontal interpolation | Vertical interpolation | Directional interpolation

Image Processing for Acquisition

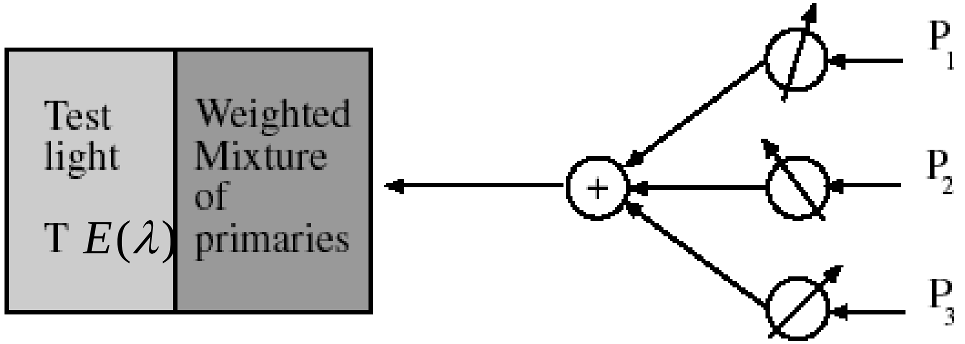
- Spatial sampling by pixel grid
- Quantization of intensities
- Noise reduction
- Demosaic
- Contrast enhancement
- Color enhancement
- Radiometric compensation
  - White balance, anti-vignette
- Lens distortion compensation
- Compression

Color Space

Sang Hwa Lee

Color Representation

- 3 primaries for 3-D color space
  - Reproduct natural colors.
  - Representation in display devices
- Color matching
  - Linear combination of 3 primaries
  - Additive matching: M = aP$_1$+bP$_2$+cP$_3$
    - Non-negative bases
  - Subtractive matching: M+aP$_1$ = bP$_2$+cP$_3$



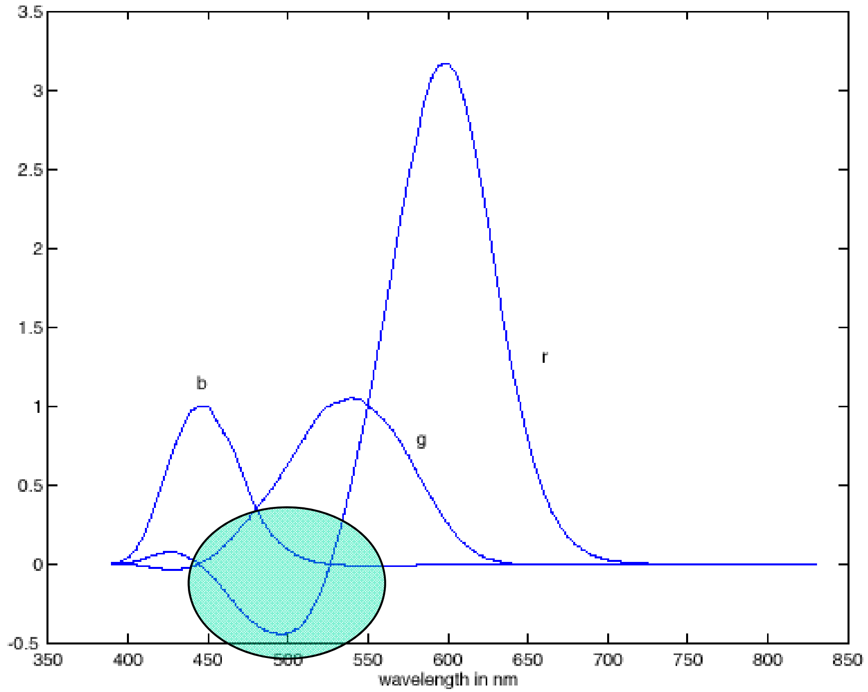
$$a = \int a(\lambda)E(\lambda)d\lambda$$

$$b = \int b(\lambda)E(\lambda)d\lambda$$

$$c = \int c(\lambda)E(\lambda)d\lambda$$

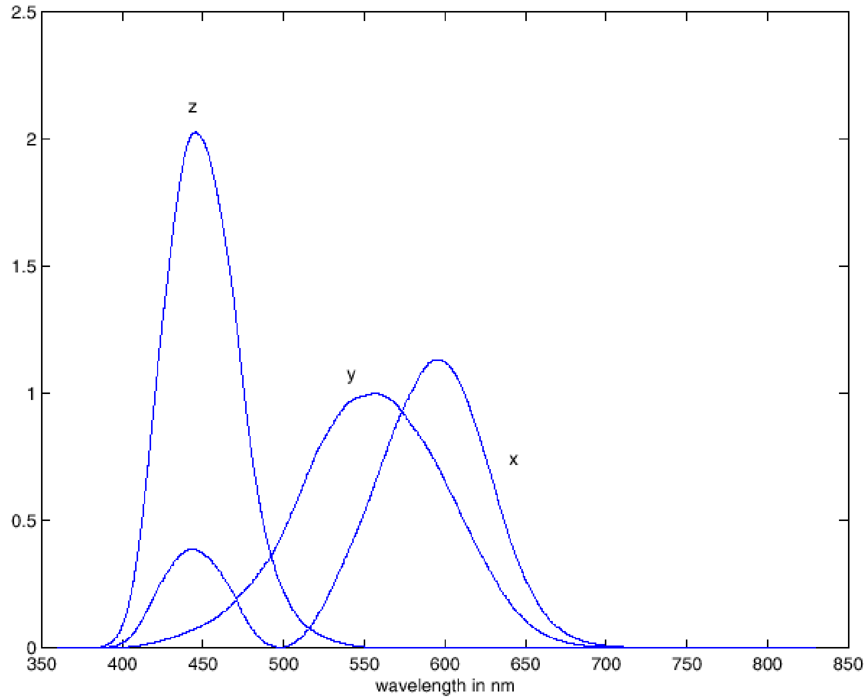
CIE XYZ Color Space (1)

RGB Color matching function



Negative(subtractive)
 - not representable in display

CIE XYZ matching function

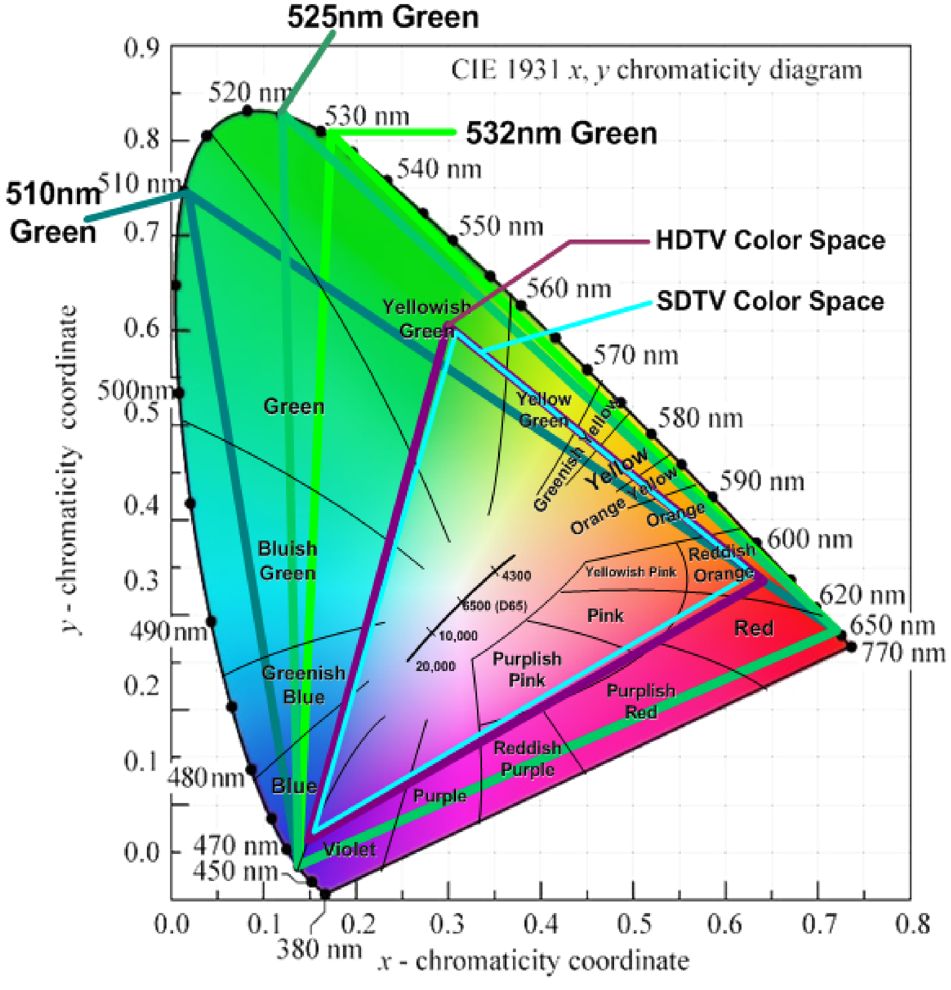


$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.490 & 0.310 & 0.200 \\ 0.177 & 0.813 & 0.011 \\ 0.000 & 0.010 & 0.990 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

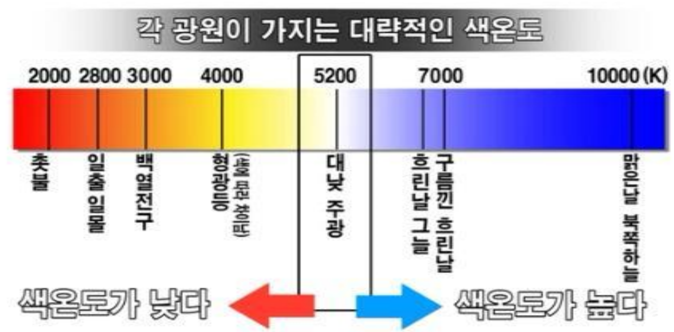
x=X/(X+Y+Z)
y=Y/(X+Y+Z)

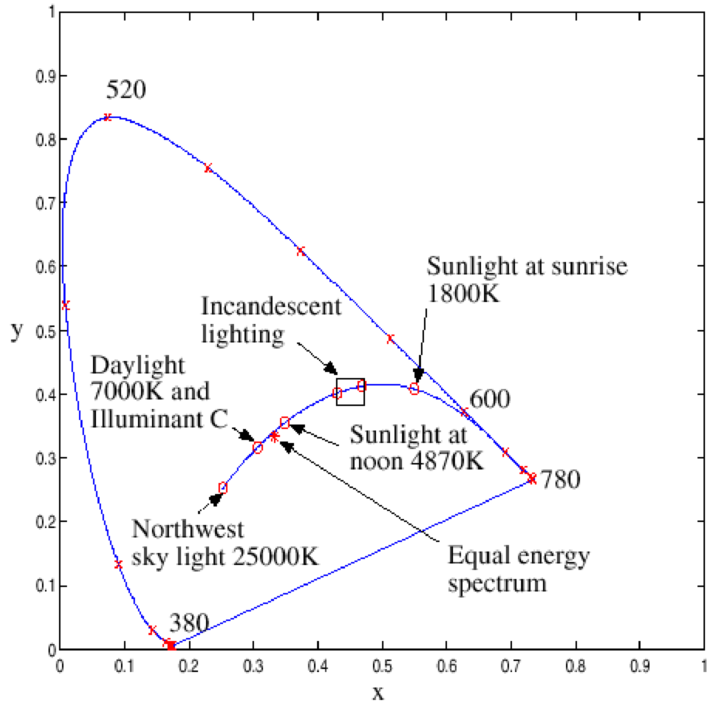
$$X = 0.490R + 0.310G + 0.200B$$
$$Y = 0.177R + 0.813G + 0.011B$$
$$Z = 0.000R + 0.010G + 0.990B$$

CIE XYZ Color Space (2)



x+y+z=1 plane

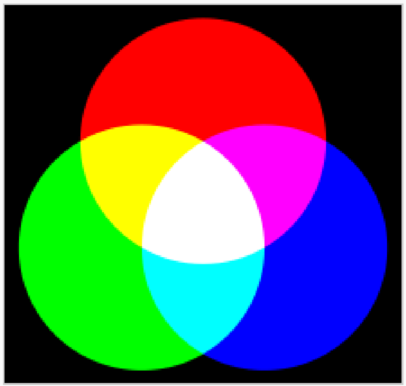




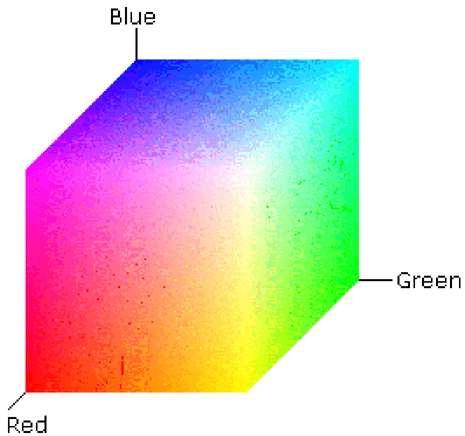
광원 색온도

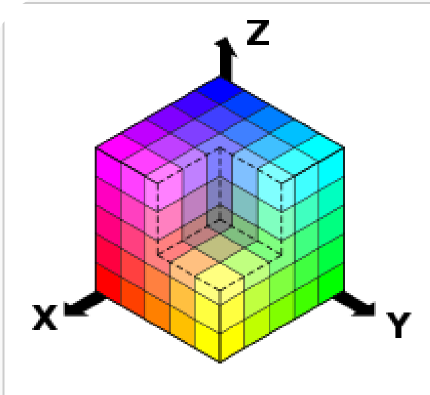
RGB Color Space

- 3 Primaries of colors
  - Red (645.2nm), Green (526.3nm), Blue (444.4nm)
- 3-D orthogonal rectangular coordinate
  - RGB cube
  - Actually neither independent nor orthogonal to each other
- The more is mixed, the brighter is.
  - Additive mixing
- Variations: sRGB, adobeRGB, …



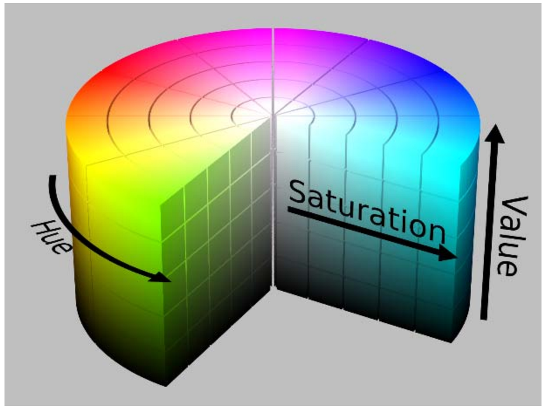
가산혼합의 원리



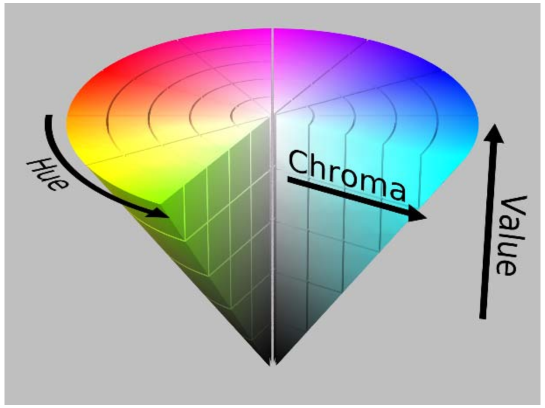


RGB의 큐브 모델

HSV Color Space (1)



Cylinder HSV



Cone HSV

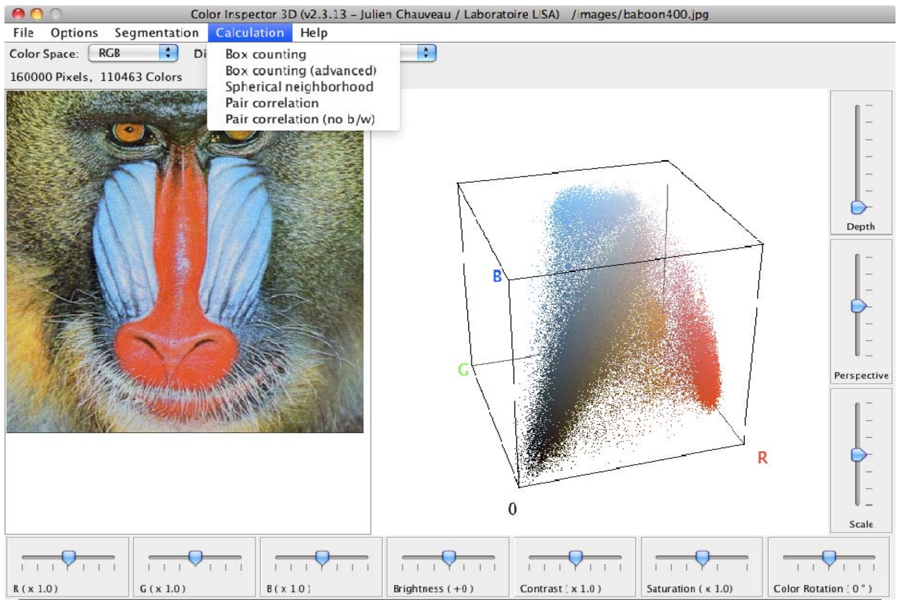
- Cylindrical representation of colors
  - Nonlinear color representation
  - Independent components: (H,S,V)
- Hue
  - Visible light spectrum
  - Red ~ violet mapping to 0°~360°
- Saturation
  - Purity of color
  - the radius of cylinder: 0(achromatic)~1(chromatic)
- Value (Intensity)
  - Luminance or brightness
  - the height of cylinder
- Cone Representation
  - Low values -> Hue components are not distinctive.

HSV Color Space (2)

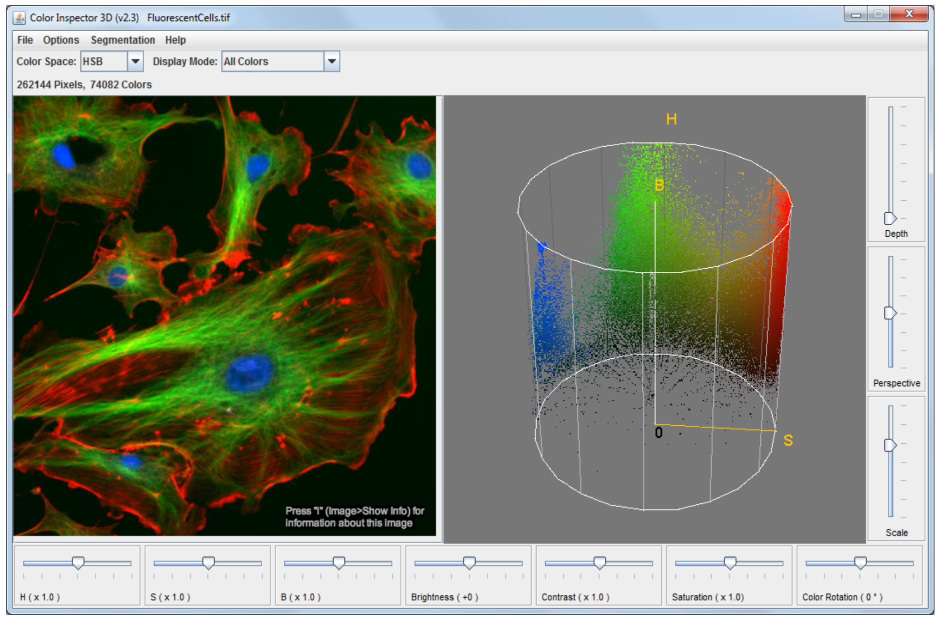
Transform of RGB to HSV

```
RGBtoHSV( float r, float g, float b, float *h, float *s, float *v )
{
        float min, max, delta;
        min = MIN( r, g, b );
        max = MAX( r, g, b );
        *v = max;                          // v
        delta = max - min;
        if( max != 0 )
                *s = delta / max;          // s
        else {
                // r = g = b = 0              // s = 0, v is undefined
                *s = 0;
                *h = -1;
                return;
        }
        if( r == max )
                *h = ( g - b ) / delta;          // between yellow & magenta
        else if( g == max )
                *h = 2 + ( b - r ) / delta;          // between cyan & yellow
        else
                *h = 4 + ( r - g ) / delta;      // between magenta & cyan
        *h *= 60;                          // degrees
        if( *h < 0 )
                *h += 360;
}
```

RGB and HSV



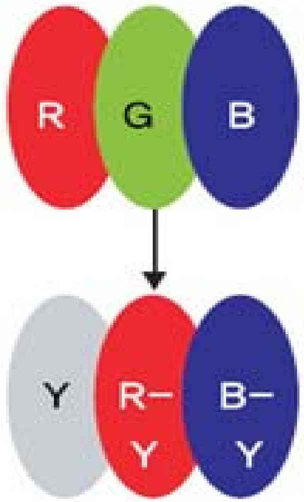
RGB 분포



HSV 분포

YUV Color Space (1)

- Rectangular representation of colors
  - Color TV signal transmission (composite color)
- Reducing the redundancy (correlation) among color components
  - Y: Luminance, brightness
  - U, V : Chrominance (color difference)
- Human visual system (HVS) is less sensitive to chrominance than luminance or RGB
  - Spectral reduction : 4:2:0 format encoding
  - Image and video compression: JPEG, MPEG
- Variations: YCbCr, YIQ (NTSC)



Correlation reduction

YUV Color Space (2)

RGB to YUV

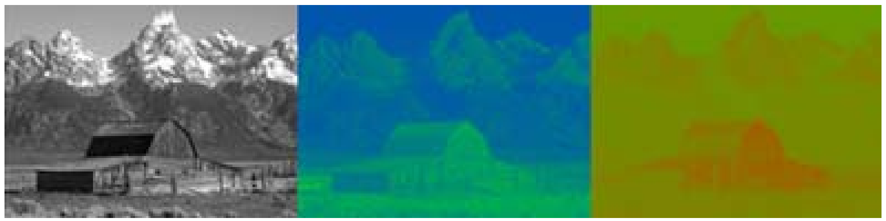
$$\begin{bmatrix} Y' \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.13983 \\ 1 & -0.39465 & -0.58060 \\ 1 & 2.03211 & 0 \end{bmatrix} \begin{bmatrix} Y' \\ U \\ V \end{bmatrix}$$

RGB to YCbCr

$$Y = 0.299 \times R + 0.587 \times G + 0.114 \times B + 0$$
$$C_b = -0.169 \times R - 0.331 \times G + 0.499 \times B + 128$$
$$C_r = 0.499 \times R - 0.418 \times G - 0.0813 \times B + 128$$

$$R = \text{clamp}(Y + 1.402 \times (Cr - 128))$$
$$G = \text{clamp}(Y - 0.344 \times (Cb - 128) - 0.714 \times (Cr - 128))$$
$$B = \text{clamp}(Y + 1.772 \times (Cb - 128))$$

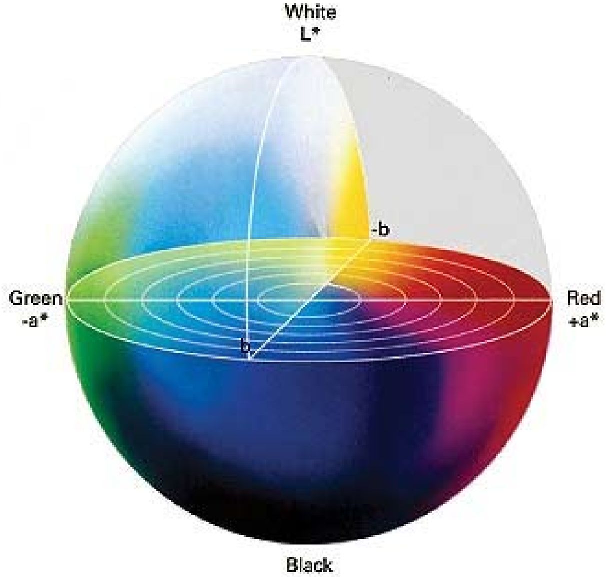


	R	G	B
Black	0	0	0
White	255	255	255
Yellow	255	255	0
Cyan	0	255	255
Green	0	255	0
Magenta	255	0	255
Red	255	0	0
Blue	0	0	255

Y	U	V
16	128	128
235	128	128
210	16	146
170	166	16
145	54	34
107	202	222
82	90	240
41	240	110

CIE 1976 Lab Color Space

- **Wider representable, more uniform in color space**
  - **L: luminance (0~100)**
  - **a: green ~ red (-1~+1)**
  - **b: blue ~ yellow (-1~+1)**
- **Non-linear transform**



$$
\begin{aligned}
L^\star &= 116 f(Y/Y_n) - 16 \\
a^\star &= 500\left[f(X/X_n) - f(Y/Y_n)\right] \\
b^\star &= 200\left[f(Y/Y_n) - f(Z/Z_n)\right]
\end{aligned}
$$

$$
f(t) = \begin{cases} t^{1/3} & \text{if } t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{4}{29} & \text{otherwise} \end{cases}
$$

$$
\begin{aligned}
Y &= Y_n f^{-1}\left(\tfrac{1}{116}\left(L^* + 16\right)\right) \\
X &= X_n f^{-1}\left(\tfrac{1}{116}\left(L^* + 16\right) + \tfrac{1}{500} a^*\right) \\
Z &= Z_n f^{-1}\left(\tfrac{1}{116}\left(L^* + 16\right) - \tfrac{1}{200} b^*\right)
\end{aligned}
$$

$$
f^{-1}(t) = \begin{cases} t^3 & \text{if } t > \frac{6}{29} \\ 3\left(\frac{6}{29}\right)^2\left(t - \frac{4}{29}\right) & \text{otherwise} \end{cases}
$$

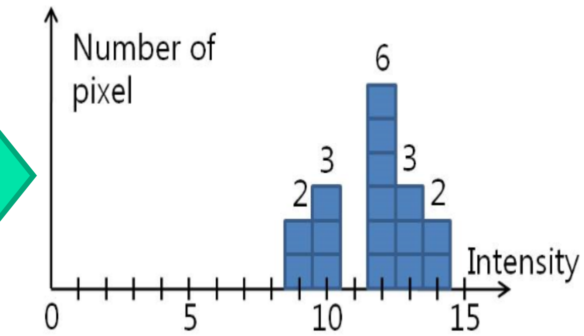
*X_n, Y_n, Z_n: normalized XYZ for standard white color

Histogram (1)

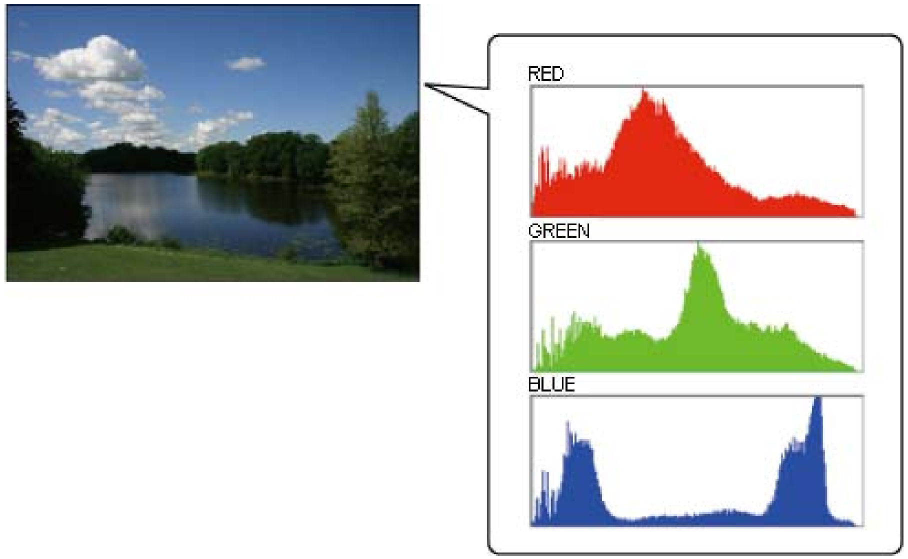
- Histogram: Number of pixels to have an intensity
  - Statistical information: probability function
  - Histogram bin: width of intensities or colors

<Histogram example>

9	13	12	10
12	10	13	12
14	12	12	9
10	13	14	12



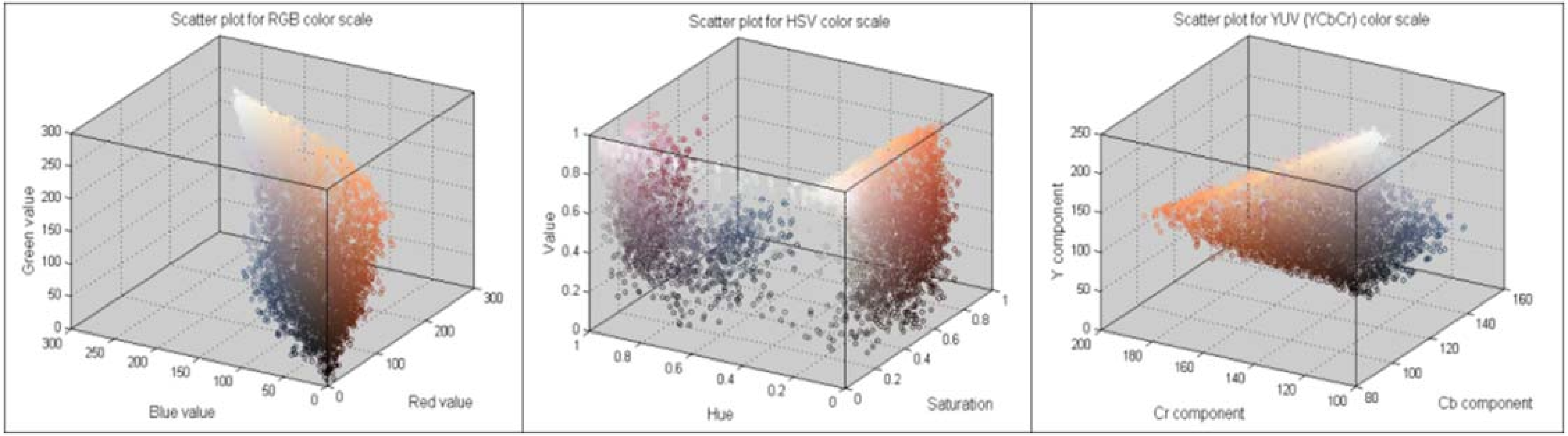
Gray-scale



RGB color

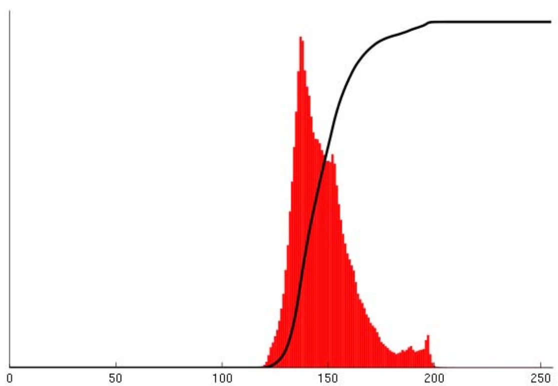
Histogram (2)

- Histogram of skin colors
  - Face/hand detection
  - RGB => HSV, YUV

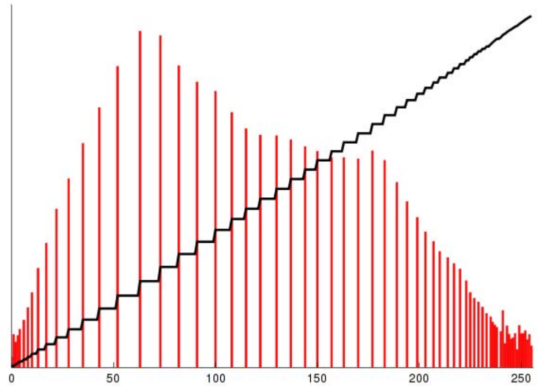


Histogram Equalization

- Automatic statistical and non-linear modification of intensity distribution



Intensity histogram (red) and cumulative histogram(black curve)



Equalized intensity histogram (red) and uniform cumulative histogram(black curve)