IPIU 2019

Color Image Processing: From RGB to Hyperspectrum

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C. Hue preserving gamut mapping
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    A. White balance
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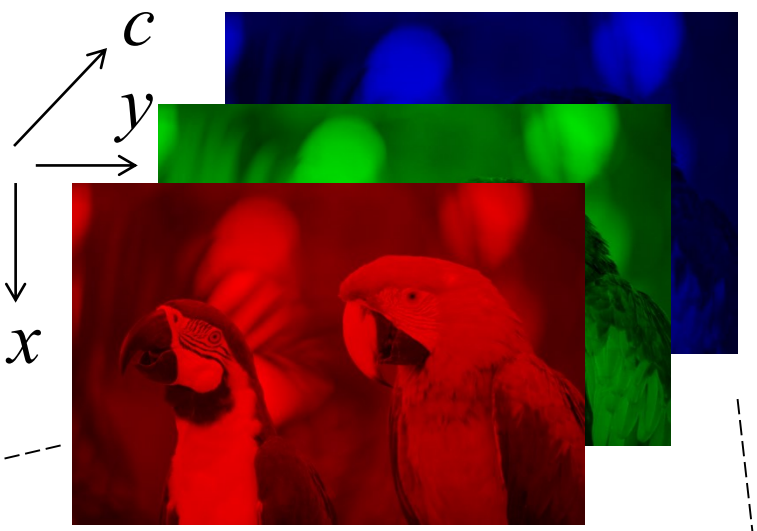
RGB Color image

Color image

=



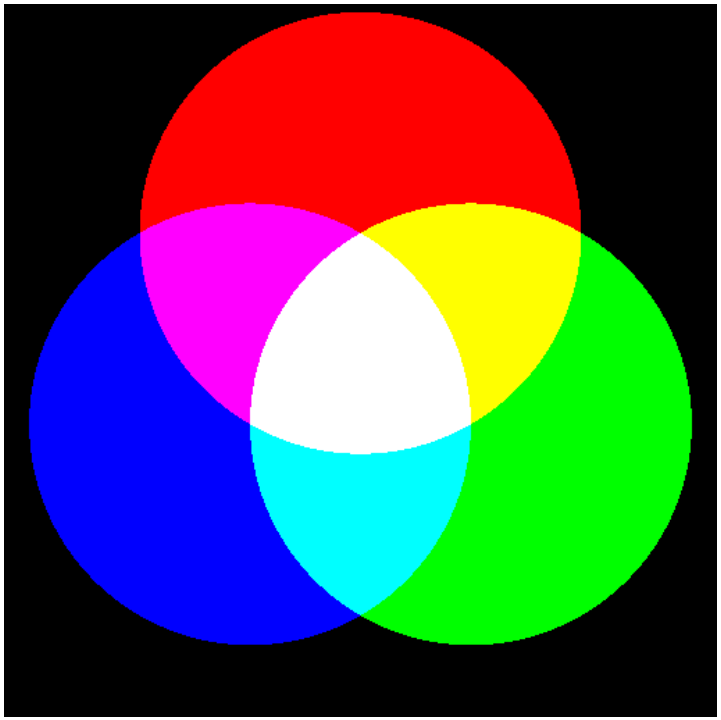
f(x,y,c)

f(x,y,1) Red

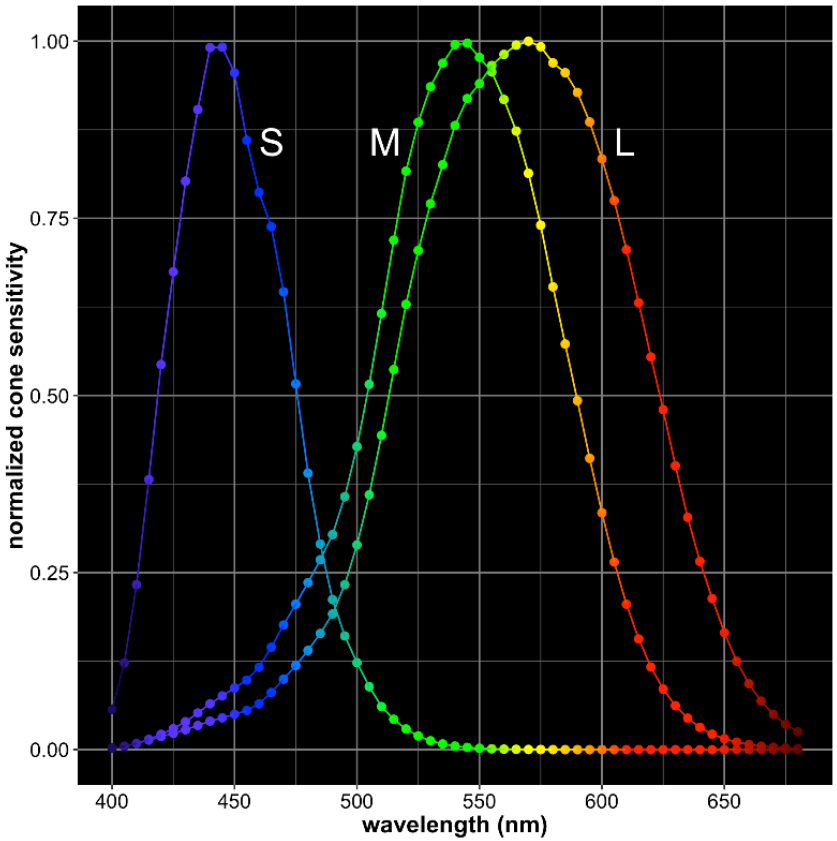
f(x,y,2) Green

f(x,y,3) Blue

Additive Primaries: RGB



Mixture of Light
Additive Primaries: RGB



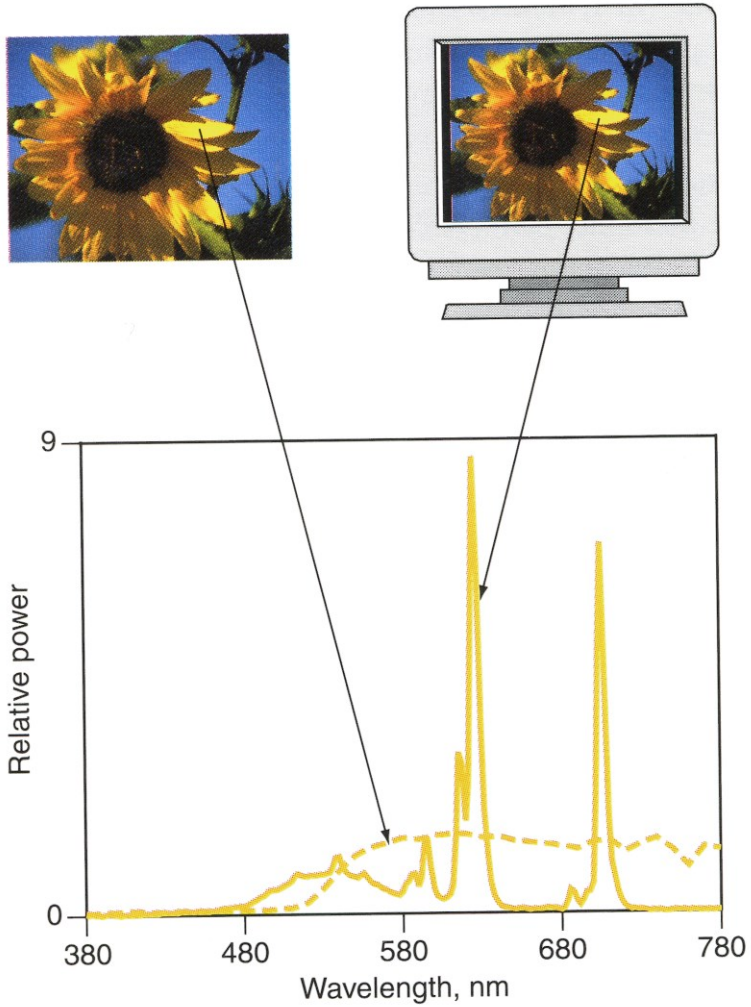
Near Infra red

Ultra Violet — Visible spectrum — Infra red

The spectral sensitivities of the middle- and long-wavelength-sensitive cones derived from measurements in observers of known genotype, Volume 40, Issue 13, 16 June 2000, Pages 1711–1737

https://commons.wikimedia.org/wiki/File:Normalized_Cone_Sensitivities.png

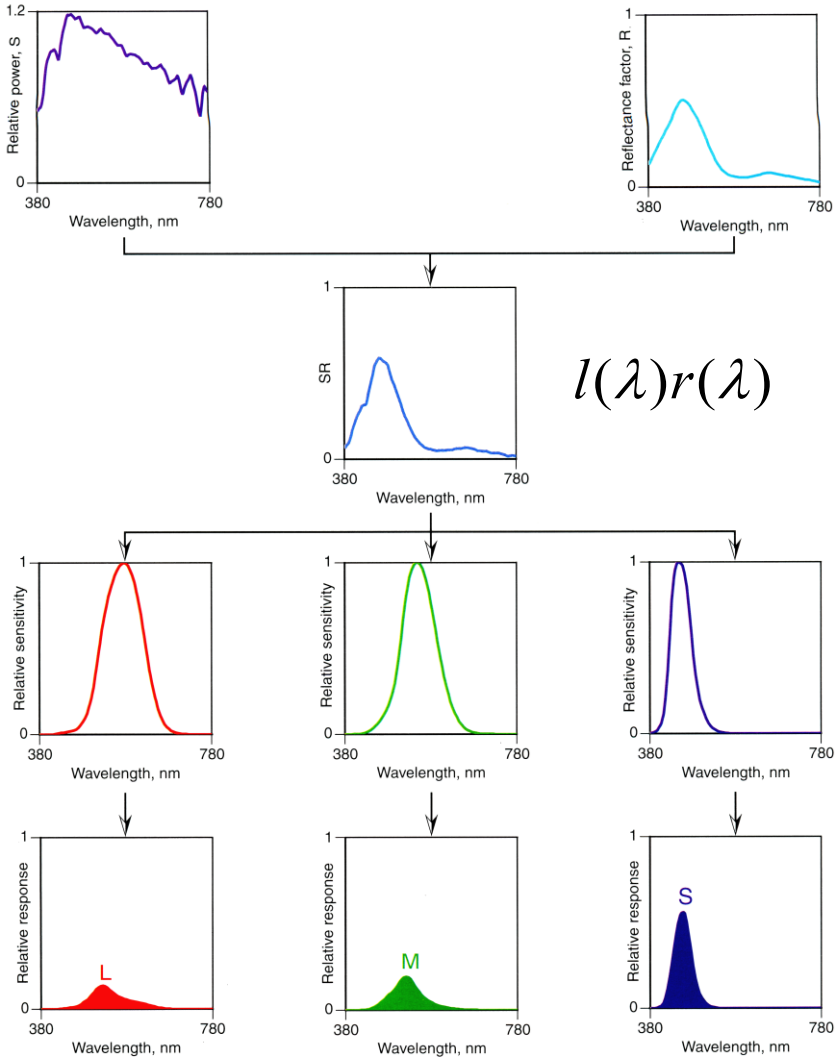
metamerism



[Berns 00]

Tristimulus value

illumination: $l(\lambda)$



reflectance: $r(\lambda)$

$l(\lambda)r(\lambda)$

Cone response:
$s_c(\lambda)$

integration
(area)

$$d_c = \int s_c(\lambda) l(\lambda) r(\lambda)\, d\lambda$$

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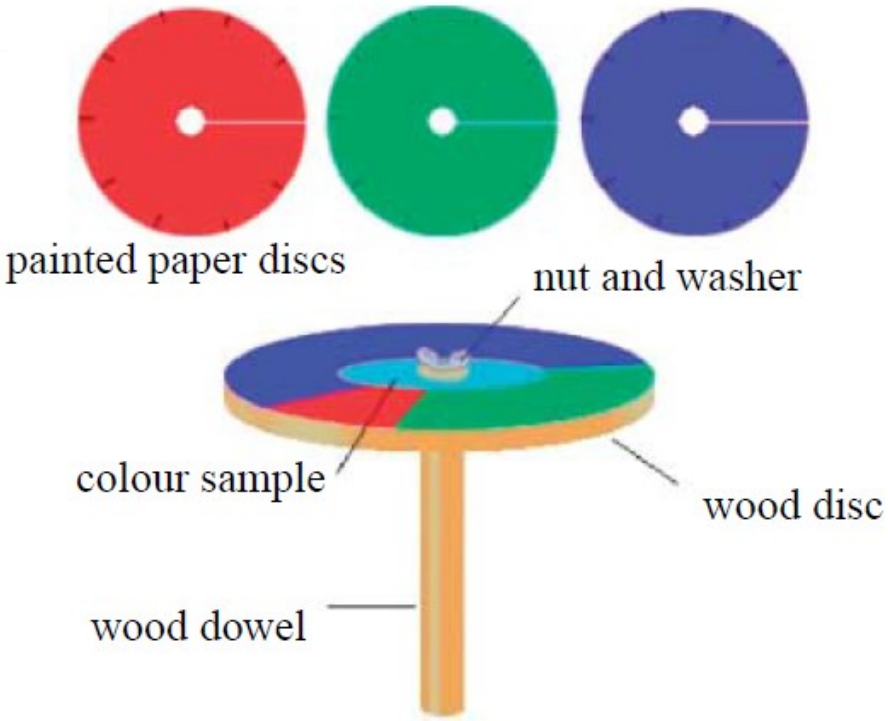
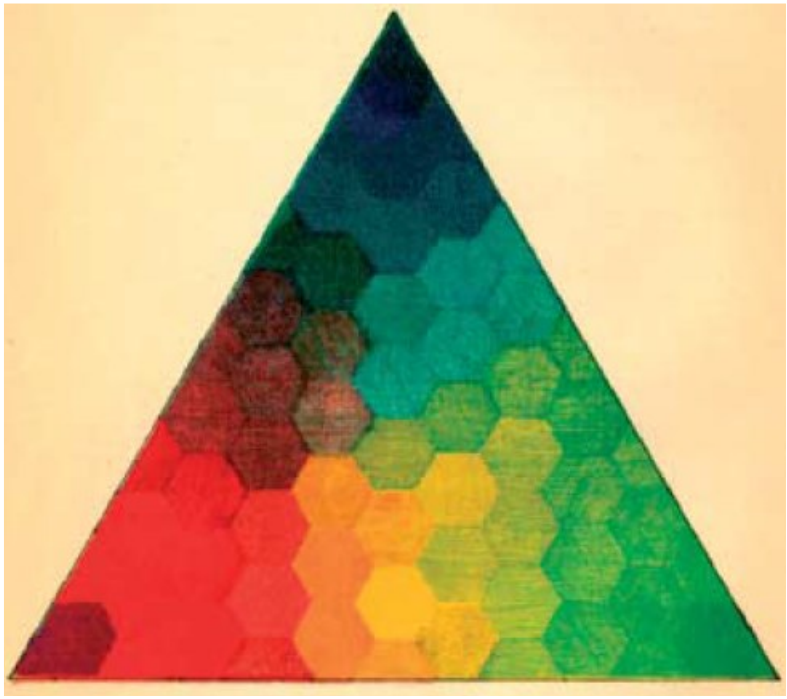
[Berns 00]

Quantitative theory of colour by James Clark Maxwell



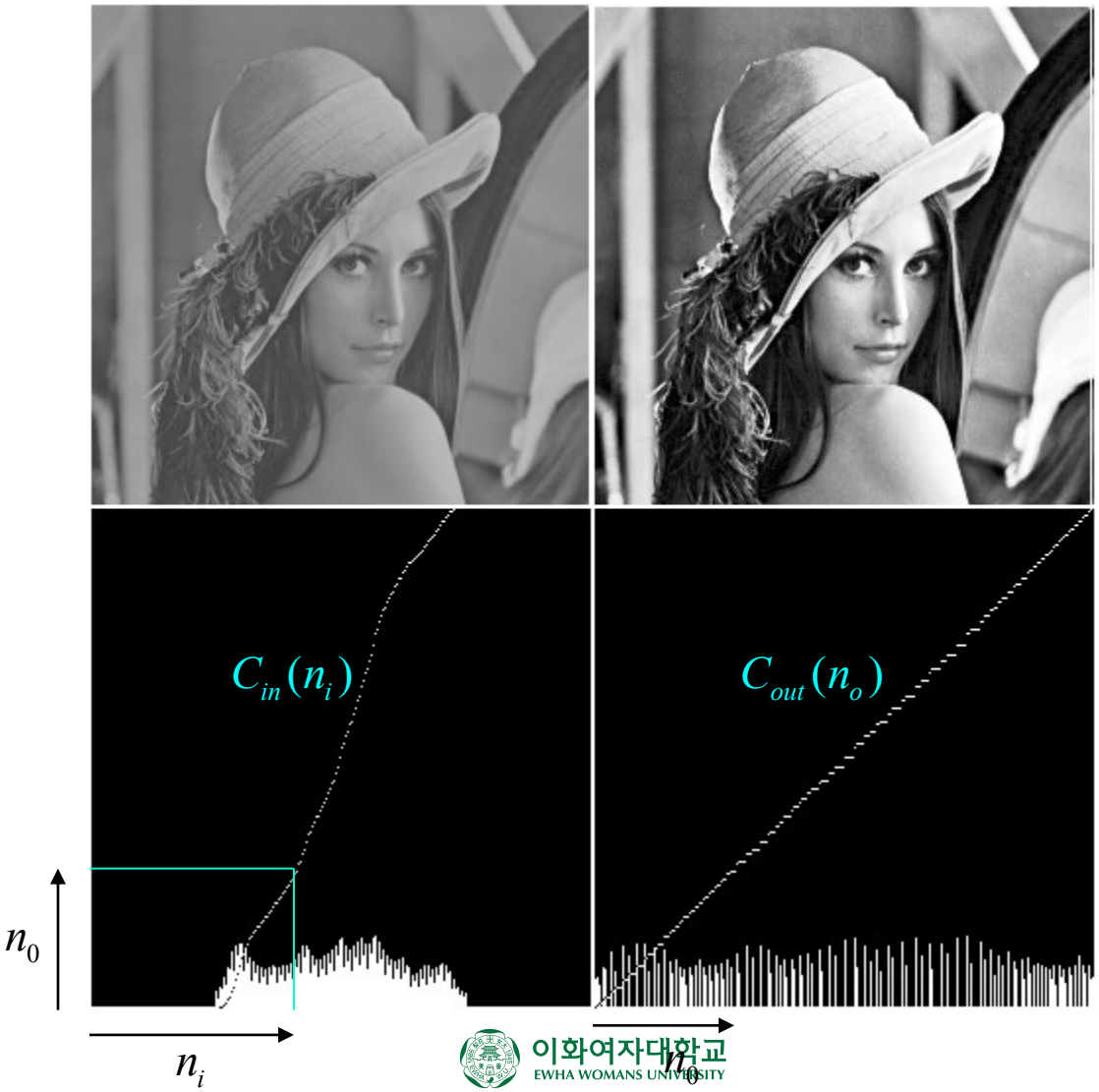
Three coloured disc for Maxwell's color mixing



Maxwell's original version of color triangle (Campbell & Garnett 1882)

[Longair 08]

Histogram Equalization – gray scale image



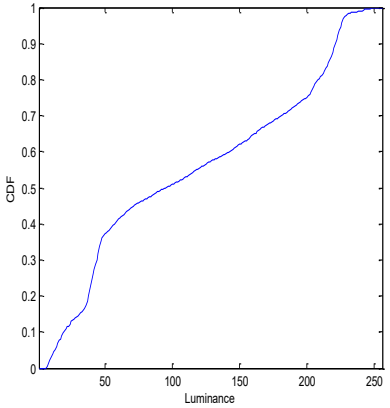
$$C_{out}(n_o) = (n_o + 1)/L$$
$$= C_{in}(n_i)$$

Histogram Equalization – Color image

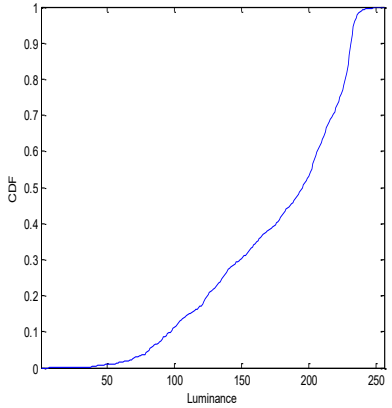
CDF

Input Image

Trahanias



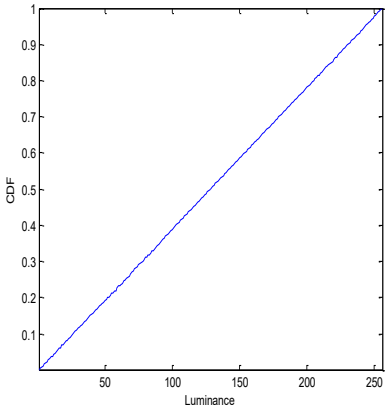
Input Image



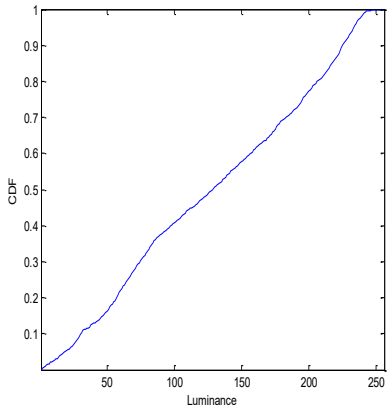
Trahanias

Iso Luminance Plane

Each RGB color channel



Iso Luminance Plane

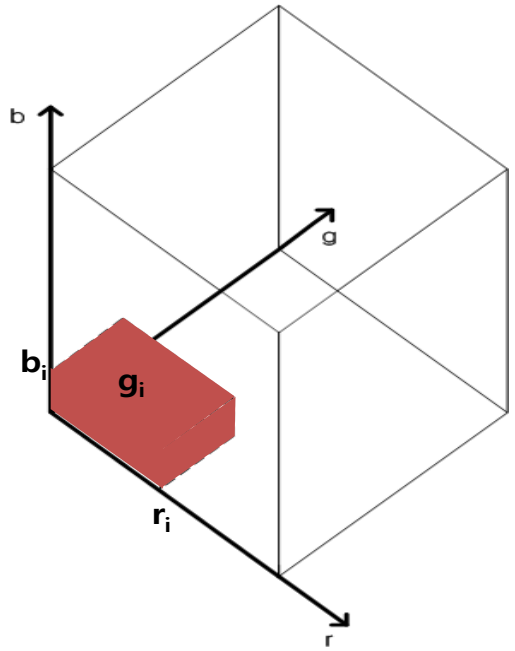


Each RGB color channel

[Trahanias 92] [Han 11]

The support region of input cdf (C_{in}) of each method

The Trahanias method



$$C_{in}(r_i,g_i,b_i) = prob\{(0 \le r \le r_i),(0 \le g \le g_i),(0 \le b \le b_i)\}$$

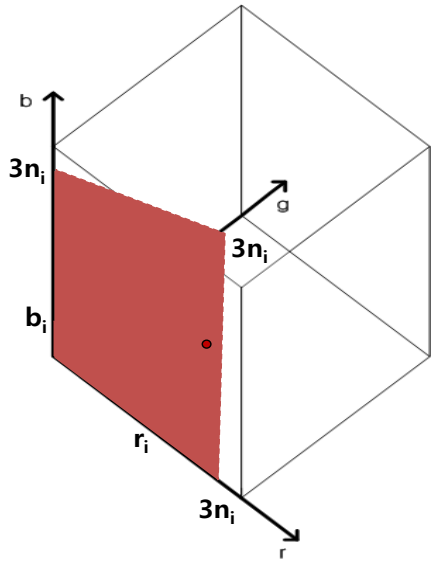
$$= \sum_{r=0}^{r_i}\sum_{g=0}^{g_i}\sum_{b=0}^{b_i} p(r,g,b);$$

$$C_{out}(r_o,g_o,b_o) = (r_o+1)(g_o+1)(b_o+1)/L^3 = C_{in}(r_i,g_i,b_i)$$

such that $r_o - r_i = g_o - g_i = b_o - b_i$

[Trahanias 92]

The iso-luminance-plane method

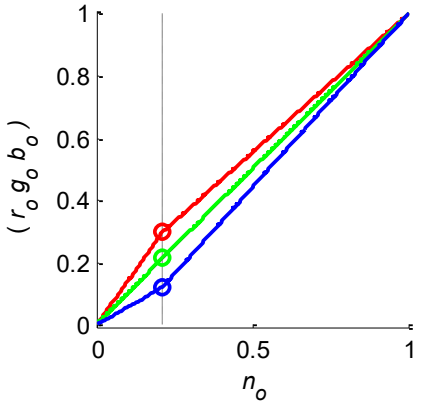


$$C_{in}(r_i,g_i,b_i) = prob\{r+g+b \le (r_i+g_i+b_i)\}$$

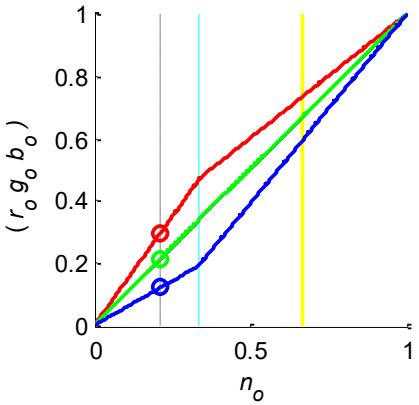
$$= \sum_{r+g+b \le (r_i+g_i+b_i)} p_{in}(r,g,b).$$

[Han 11]

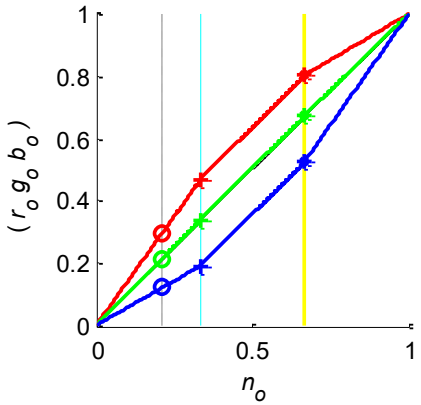
Hue preserving gamut mapping with high saturation



[Naik 03]



[Yang 13]



[Park 19]

Input Image

Color Constancy

- Human vision compensates for color of illumination.
- Computational color constancy requires estimation of illuminants, and then correct for illumination spectrum.

Macbeth Chart
under A light

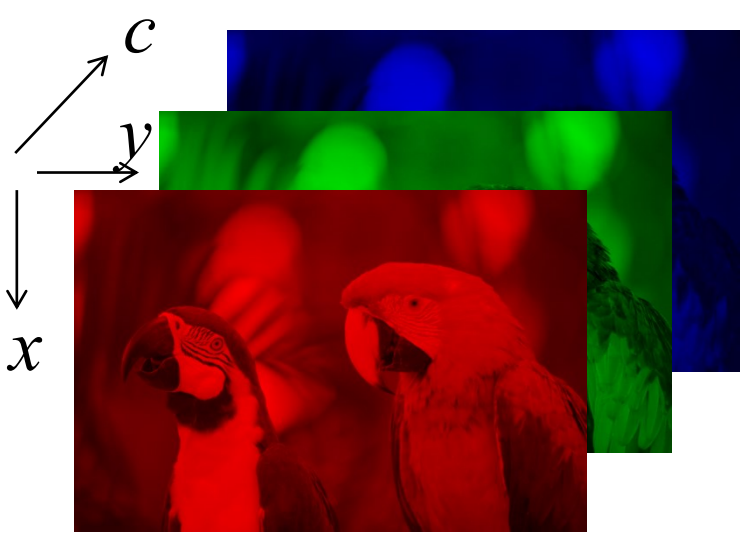
Macbeth Chart
under daylight

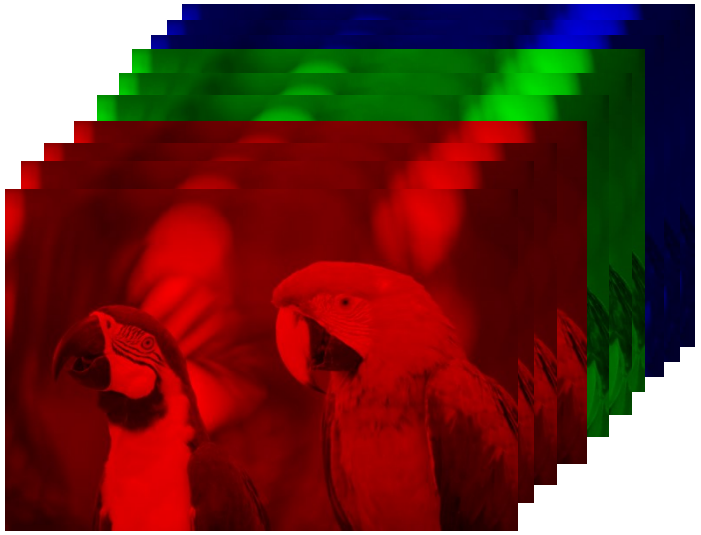
White balance

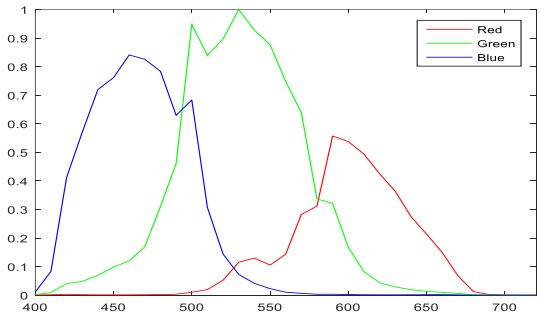
- White balance: adjust color gain to compensate for the illumination.
- Illumination estimation
  - Gray-world assumption
    - The spatial average reflectance is achromatic.
  - White-patch assumption
    - The maximum response (the brightest pixel) is caused by a white patch.
  - Gray-edge assumption
    - Spatial derivative of an image is achromatic.

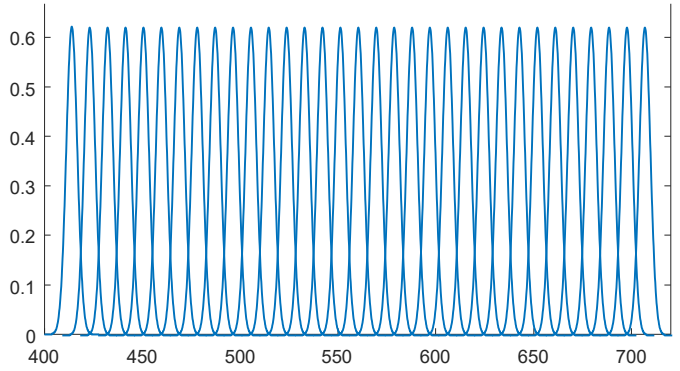
Hyperspectral Image

- RGB vs Hyperspectral Image









An RGB image and camera spectral sensitivity

Spectral sensitivity of a hyperspectral image

correlated

independent

HSI application

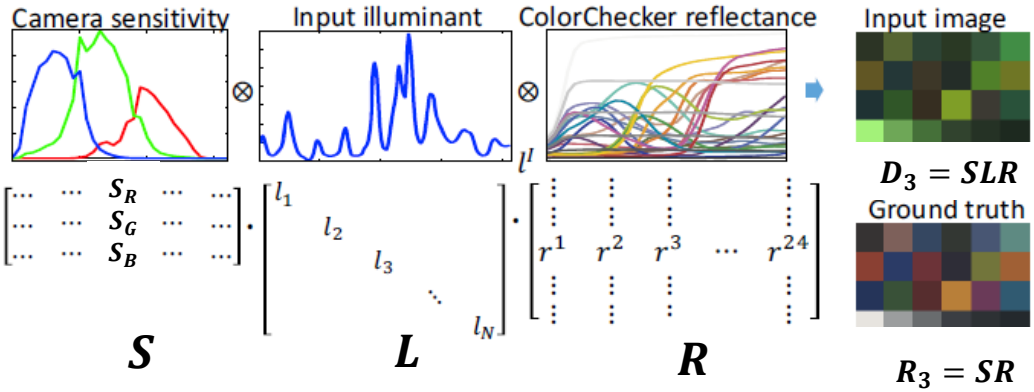
- Material recognition (unmixing)
- Environment monitoring: heavy metal, vegetation, planktonic species
- Object detection
- Relighting
- Food inspection
- Old document restoration

Color correction matrix in RGB space

A hyperspectral image is a multiplication of illumination and reflectance, under Lambertian model.

$$\mathbf{D}_{m\times n} = \mathbf{L}_{m\times m}\mathbf{R}_{m\times n}$$

$\mathbf{D}_{m\times n}$: hyperspectral image
$\mathbf{R}_{m\times n}$: reflectance
$\mathbf{L}_{m\times m}$: diagonal illumination
$\boldsymbol{m}$: the number of spectral channels,
$\boldsymbol{n}$: the number of pixels



An RGB image is a filtering of a hyperspectral image.

$$\mathbf{D_3} = \boldsymbol{S}\mathbf{D} = \mathbf{SLR}, \mathbf{R_3} = \mathbf{SR}$$

$\mathbf{D}_3$: RGB image obtained by a camera

$\mathbf{S}$: camera sensor sensitivity

$\mathbf{R}_3$: RGB reflectance

$$\mathbf{D_3} = \boldsymbol{SLR} \cong \mathbf{MR_3} = \mathbf{MSR}$$

$\mathbf{M}$: 3x3 illumination correction matrix

Illumination of an RGB image (**SLR**) can be obtained from RGB reflectance (**SR**) without error using a 3x3 correction matrix (**M**) if the rank of reflectance is not greater than 3.

$$\mathbf{SLR} = \mathbf{MSR}, \boldsymbol{if\ rank}(\mathbf{R}) \leq \mathbf{3}$$

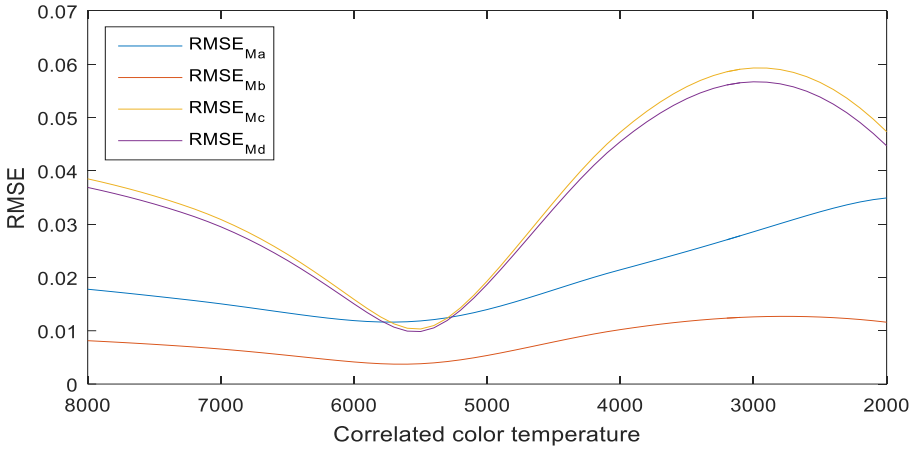
[Cheng 15]

Relation of CSS and illumination

- Illumination correction equation can be interpreted from a different perspective: CSS vector weighted by illumination is represented as a linear combination of the CSS.

$$\|\boldsymbol{SL} - \boldsymbol{MS}\|_{\boldsymbol{F}}^{\boldsymbol{2}} = \boldsymbol{0}$$

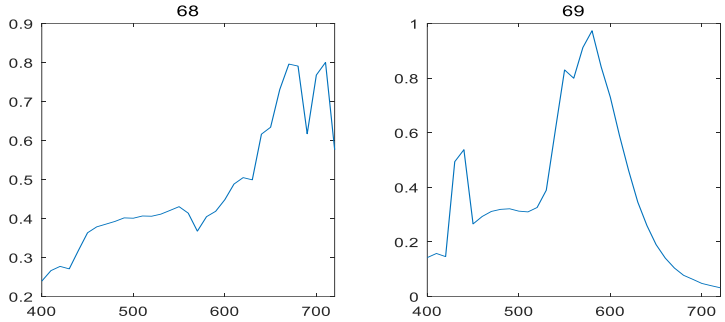
$$\begin{bmatrix} \boldsymbol{s_1^T} \odot \boldsymbol{l} \\ \boldsymbol{s_2^T} \odot \boldsymbol{l} \\ \boldsymbol{s_3^T} \odot \boldsymbol{l} \end{bmatrix} = \begin{bmatrix} \boldsymbol{m_{11}s_1^T + m_{12}s_2^T + m_{13}s_3^T} \\ \boldsymbol{m_{21}s_1^T + m_{22}s_2^T + m_{23}s_3^T} \\ \boldsymbol{m_{31}s_1^T + m_{32}s_2^T + m_{33}s_3^T} \end{bmatrix}$$



RMSE of color correction matrix for blackbody radiation

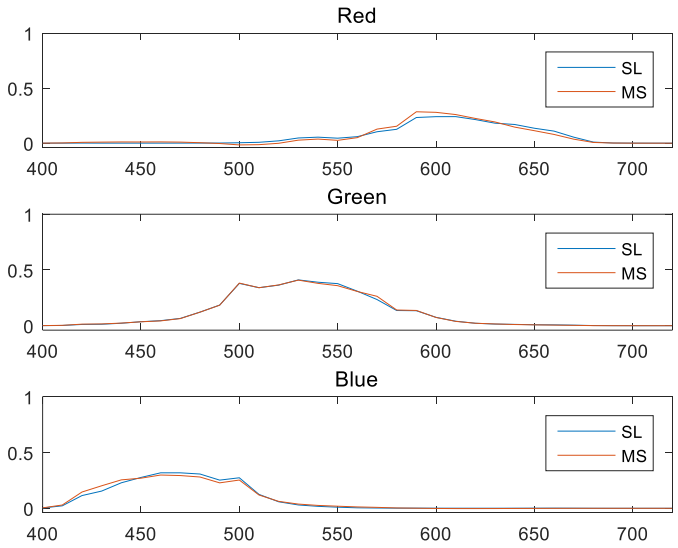
Plot of $\|\mathbf{SL} - \mathbf{MS}\|_{\boldsymbol{F}}^{\boldsymbol{2}}$ [Lee 19]

Relation of CSS and illumination

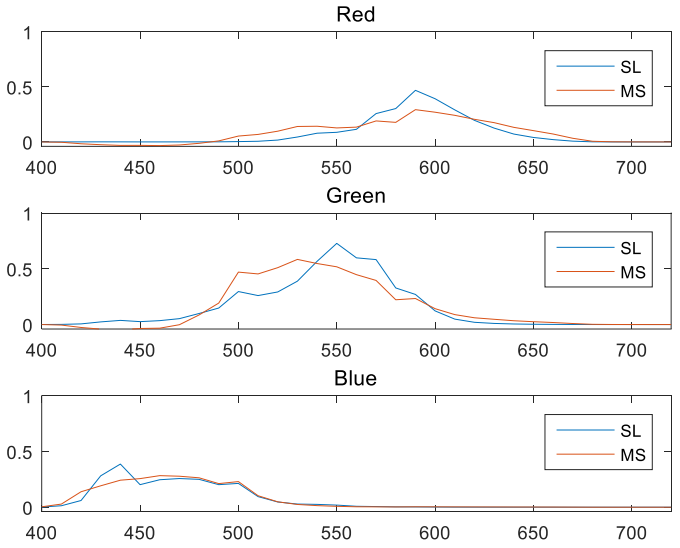


Illumination #	68	69
$RMSE_{M_b}$	0.0086	0.0382
CCT (K)	4279	4216

Two illuminants with similar CCT, but quite different color correction error.



Plot of SL and MB for illuminant 68



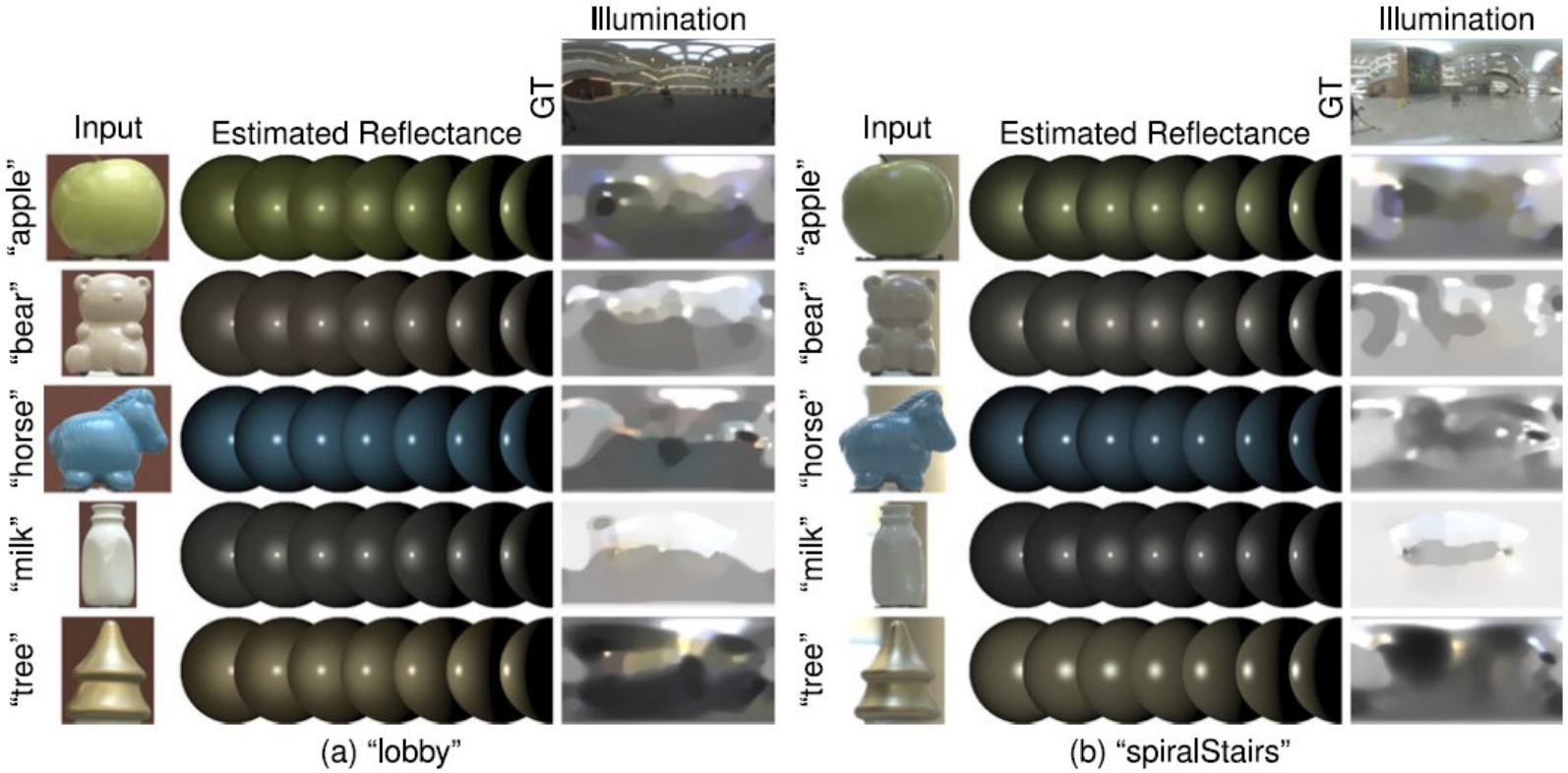
Plot of SL and MB for illuminant 69

[Lee 19]

Recovery of illumination and reflectance - RGB

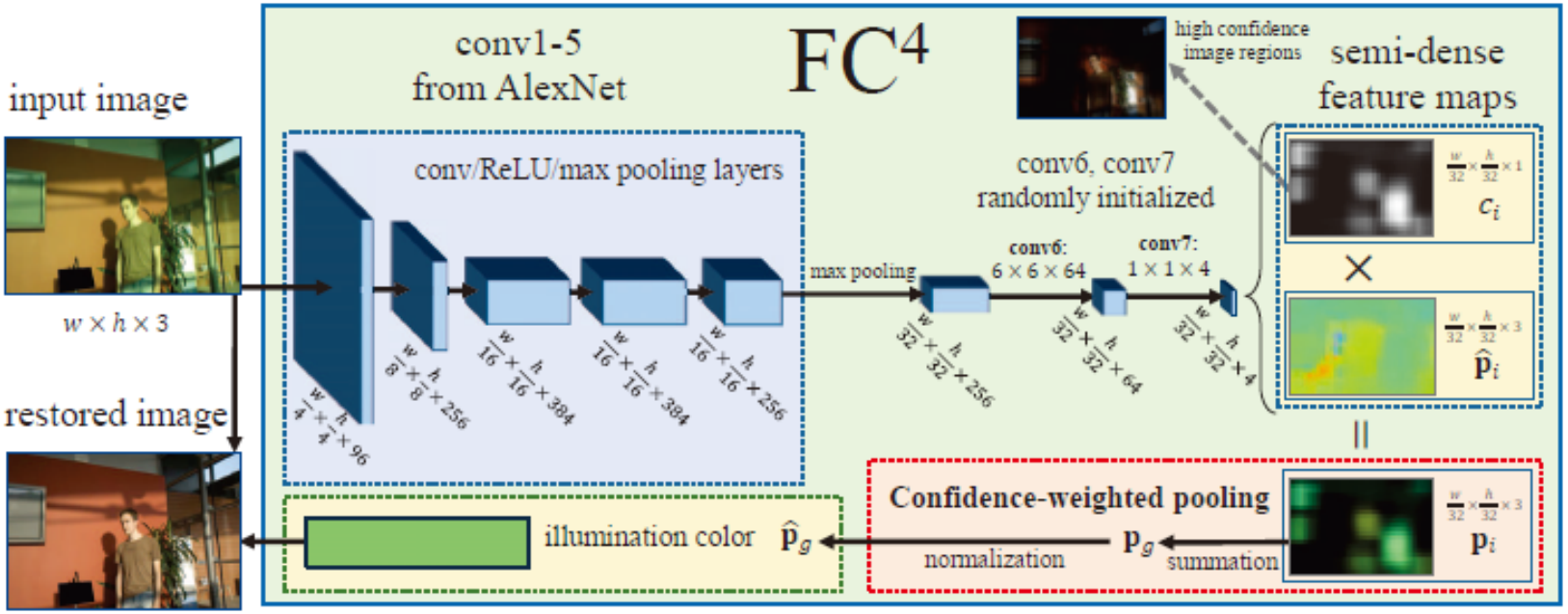
[Lombardi 16]

- Bayesian approach
  - Reflectance: mixture of Gaussians
  - Illumination: exponential distribution



Color Constancy (RGB) - CNN

[Hu 17]



Illumination estimation from HSI

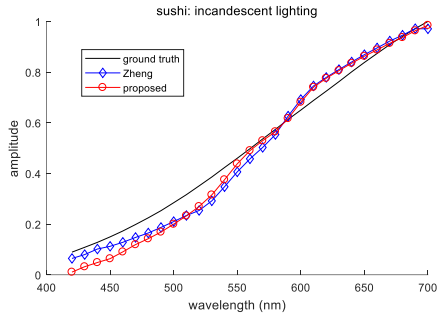
$$\mathbf{D}_{m\times n} = \mathbf{L}_{m\times m}\mathbf{R}_{m\times n}=\mathbf{L}_{m\times m}\mathbf{B}_{m\times k}\mathbf{C}_{k\times n}$$

$\mathbf{D}_{m\times n}$: hyperspectral image
$\mathbf{B}_{m\times k}$: reflectance basis vector
$\mathbf{C}_{k\times n}$: coefficients for reflectance

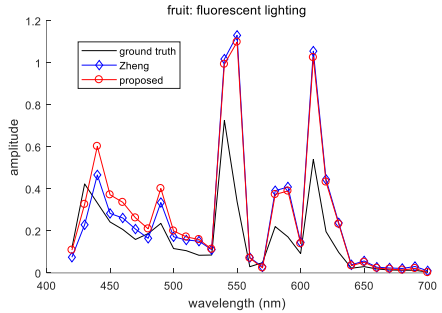
Natural reflectance can be modeled as a low dimensional subspace, typically five to seven.

[Maloney 86]

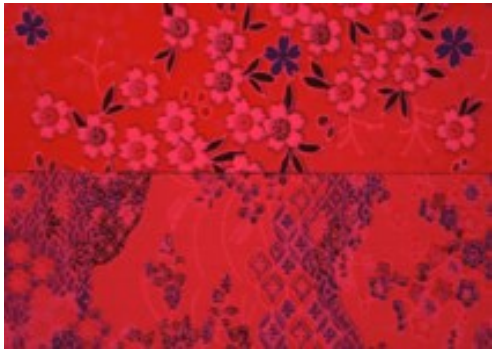
Illumination estimation from HSI

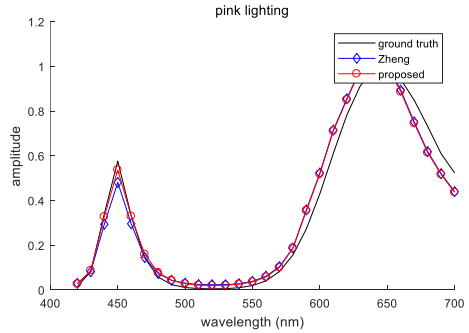


Sushi image under incandescent lighting and estimated illumination spectrum



Fruit image under fluorescent lighting and estimated illumination spectrum





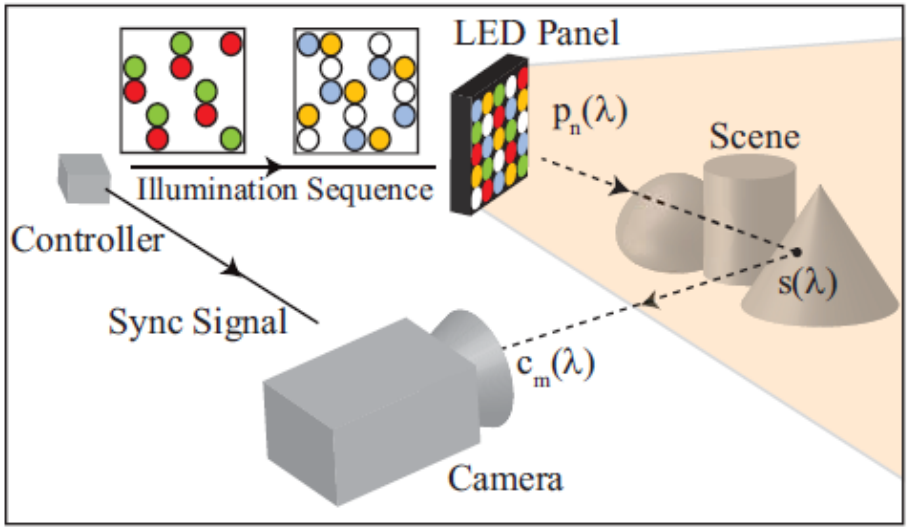
[Zheng 15]

[이지원 17]

Paper image under pink lighting and estimated illumination spectrum

HSI from multiplexed illumination

[Park 07]



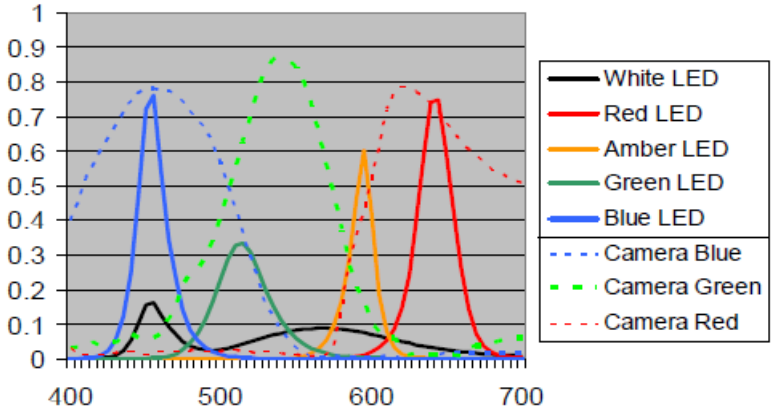
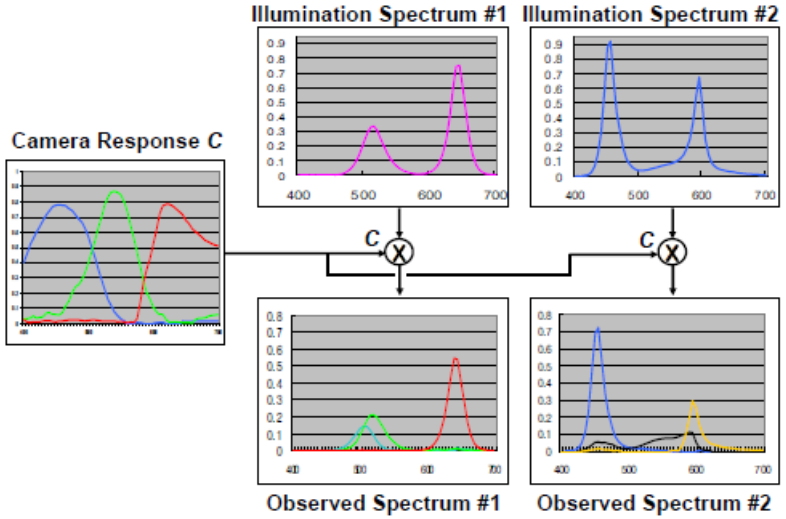
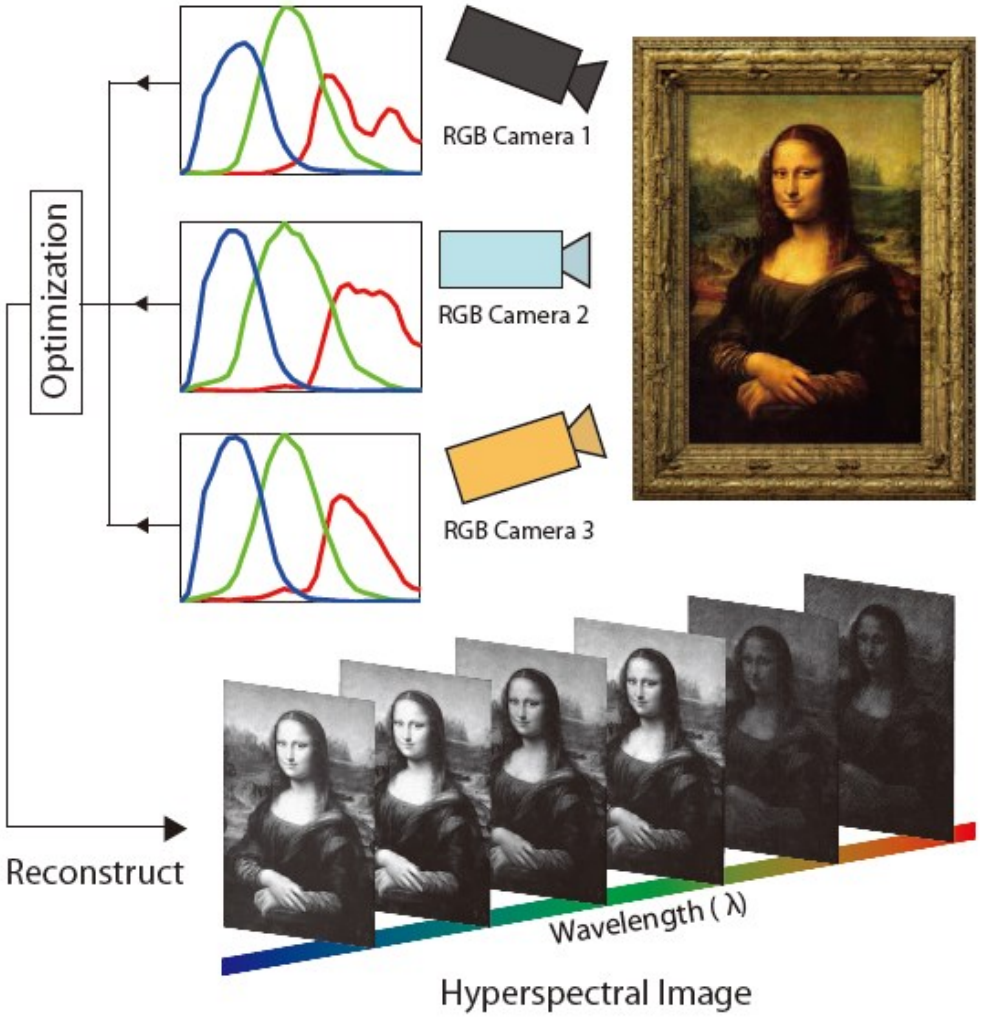


Figure 2. The spectra of the 5 types of LEDs (solid lines) and the spectral responses of the three color channels of the PointGrey Dragonfly Express camera (dashed lines) used in our system.



HSI from everyday digital cameras

[Oh 16]



HSI from filtered images

[심규동 18]

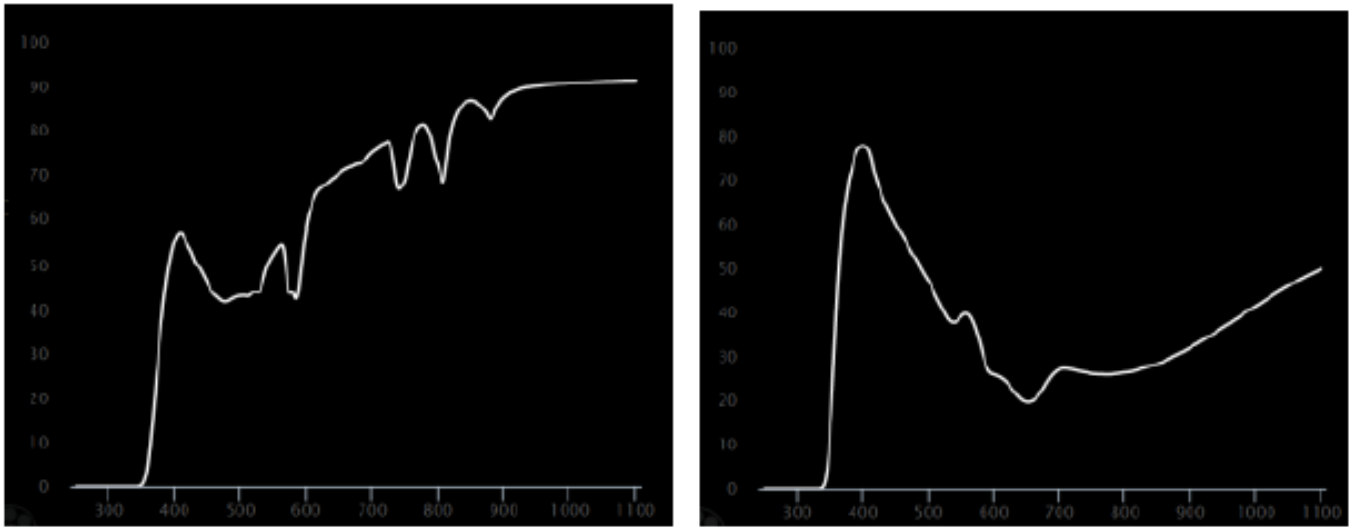
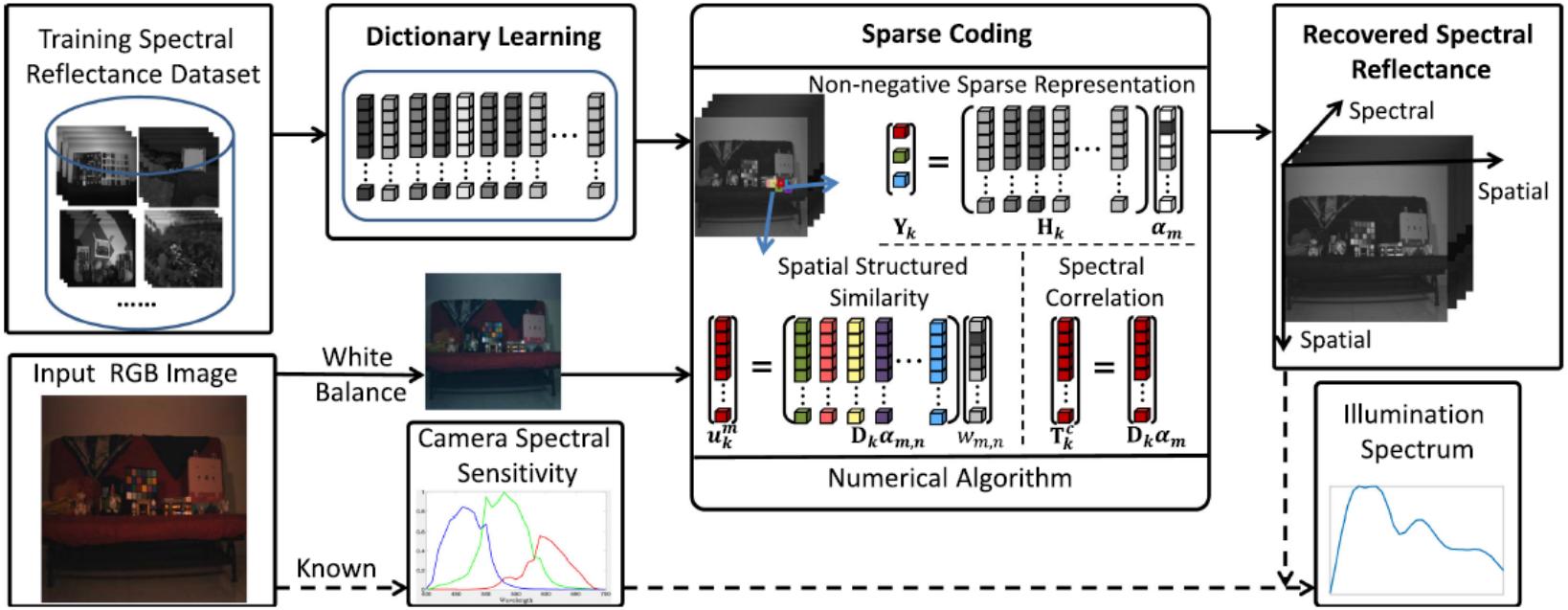


그림 1. 두 종류의 컬러필터 투광 특성. FL550(좌), LB080(우)

HSI reflectance from a RGB image [Fu 18]



- 1024 clusters
- number of samples per cluster is 400 or more
- Atoms in a dictionary is 20.

What's next?

- Non Lambertian reflectance
  - Specular components
  - Scattering (skin)
  - Translucent materials
  - Fluorescence
- More data acquisition
  - More than three channels
  - Use of NIR
  - Direct measurement of illumination

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