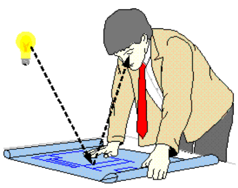
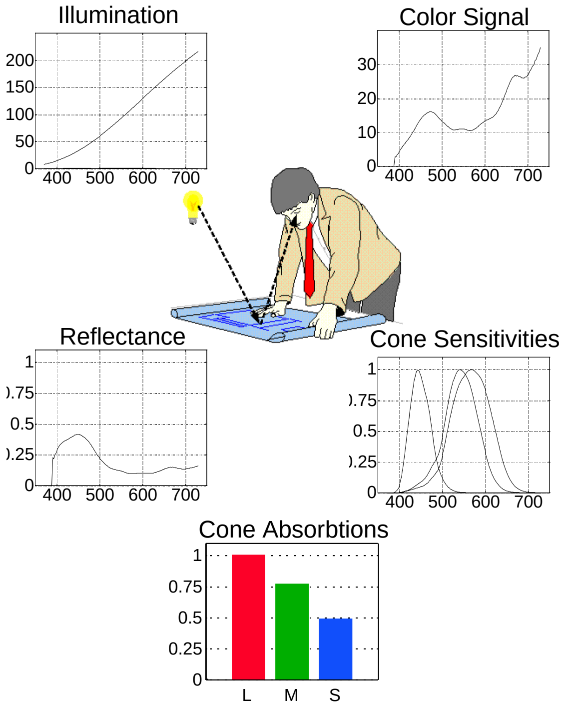
Lecture 6

Image Formation

Radiometric Units
Photometric Units
Image Formation Model
Illuminant Linear Approximations
Surface Linear Approximations



Spectral Image Formation



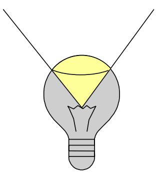
Radiometric Units

Radiant Flux – Joules/Sec = Watt

Light emitted from a source
(in all directions) .

Radiant Intensity (Density) –
Watt/sr (sr = steradian)

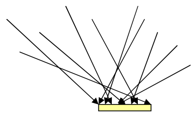
Light emitted from a source
per solid angle .



Radiometric Units

Irradiance – Watt/m^2

Light density incident on a plane
(from all directions).

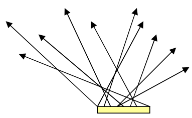


(How many photons reach a given surface
area in a given amount of time).

Radiance – Watt/m^2/sr

Power per unit solid angle per unit area.

(Radiance is independent of distance).



Radiance and Irradiance Units

Term	Defining Equation	Application	SI Unit
Radiant Flux	$F = \frac{\Delta Q}{\Delta t}$	Total quantity of light emitted from a point	watt
Radiant Intensity	$I = \frac{\Delta F}{\Delta \omega}$	Total quantity of light emitted from a point in a given solid angle	watt /sr
Irradiance	$E = \frac{\Delta F}{\Delta A_r}$	Light density incident on a plane	watt /m^2
Radiance	$L = \frac{\Delta I}{\Delta A_s \cos(\theta)}$	Light emitted or reflected from an extended source in a given direction	watt /sr/m^2

Q = energy (joules)
t = time (sec)
ω = solid angle (steradian)
A = area (meter^2)
θ = angle incident to plane

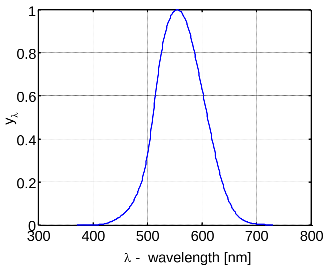
watt=joule/sec

http://www.calculator.org/properties/luminance.prop

Radiometry – Photometry

Source Radiance
Symbol: L
Units: W/(sr m^2)

Source Luminance
Symbol: L_v
Units: lm/(sr m^2)



Luminous Efficiency Function

Courtesy P. Catrysse

Radiometry – Photometry

$$X_v = K_m \int X_l(\lambda) V(\lambda) d\lambda$$

Photometric term

Radiometric term

$V(\lambda)$ is the Photopic Luminous Efficiency function (Y(λ)).

This equation represents a weighting, wavelength by wavelength of the radiant spectral term by the visual response at that wavelength. The constant K_m is a scaling factor = 683 lm/W.

Basic Unit in Photometry is the Lumen and the Candela

Monochromatic light 555nm with radiant intensity of 1 Watt = 683 Lumens.

Monochromatic light 555nm with radiant intensity of 1 Watt/sr = 683 Candela.

Radiometry – Photometry

$$X_v = K_m \int X_l(\lambda) V(\lambda) d\lambda$$

For *X*, we can pair the Radiometric and Photometric pairs:

QUANTITY	RADIOMETRIC	PHOTOMETRIC
power	Radiant Flux watt (W)	Luminous Flux lumen (lm)
power per unit solid angle	Radiant Intensity W/sr	Luminous Intensity lm/sr = candela (cd)
power per unit area	Irradiance W/m^2	Illuminance lm/m^2 = lux (lx)
power per area per solid angle	Radiance W/m^2/sr	Luminance lm/m^2/sr = cd/m^2 = nit

Luminance and Illuminance Units

Term	Defining Equation	Application	SI Unit
Luminous Flux	$F_v = K_m \int F_e(\lambda) V(\lambda) d\lambda$	Total quantity of light emitted from a point	lumen
Luminous Intensity	$I_v = \frac{\Delta F_v}{\Delta \omega}$	Total quantity of light emitted from a point in a given solid angle	candela (cd)
Illuminance	$E_v = \frac{\Delta L_v}{\Delta A_r}$	Light density incident on a plane	lumens/m^2 (lux)
Luminance	$L_v = \frac{\Delta I}{\Delta A_s \cos(\theta)}$	Light emitted or reflected from an extended source in a given direction	cd/m^2

Q = energy (joules)
t = time (sec)
ω = solid angle (steradian)
A = area (meter^2)
θ = angle incident to plane

watt=joule/sec

http://www.electro-optical.com/whitepapers/candela.htm

Photometry of Scenes: Illuminance

Typical illuminance produced by various sources
(lux = lm/m^2)

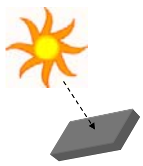
Direct sunlight	110,000
Open shade	11,000
Overcast/dark day	110 - 1,100
Twilight	1.1 - 11
Full moon	0.11
Starlight	0.0011
Dark night	0.00011

Courtesy P. Catrysse

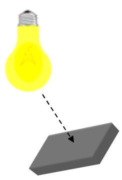
Photometry of Scenes: Luminance

Luminance of outside scenes (cd/m^2)

Sun	6x10^8
Visual saturation	49,000
Just below saturation	25,000
Outdoor building façade	10,000
Blue sky (morning)	4,600
Concrete sidewalk	
in sun	3,200
in shadow	570
in deep shadow	290



Luminance of interior scenes (cd/m^2)



Interior room (fluorescent lighting)	
floor/walls	90
in shadow	10
Interior room (no lighting)	
floor/walls	30
in shadow	5
in closet door	1

Photometry of Scenes: Luminance

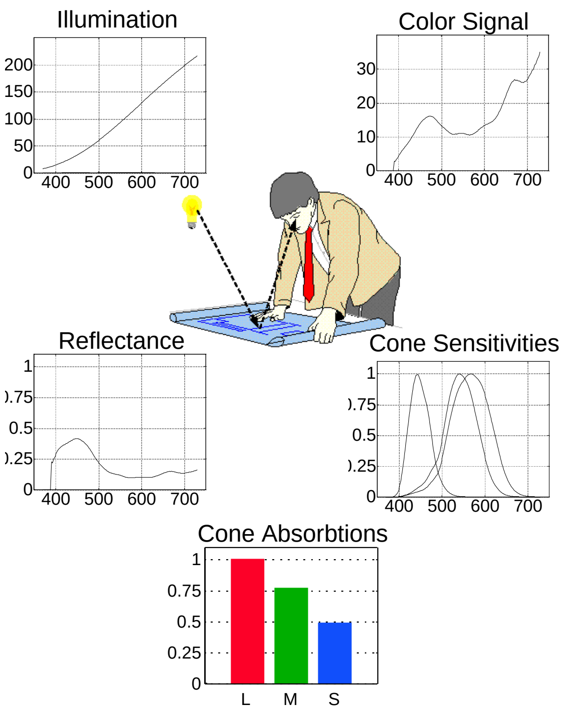
Intensity Ranges (orders of magnitude):

Natural Light – 12
Natural scene – 4

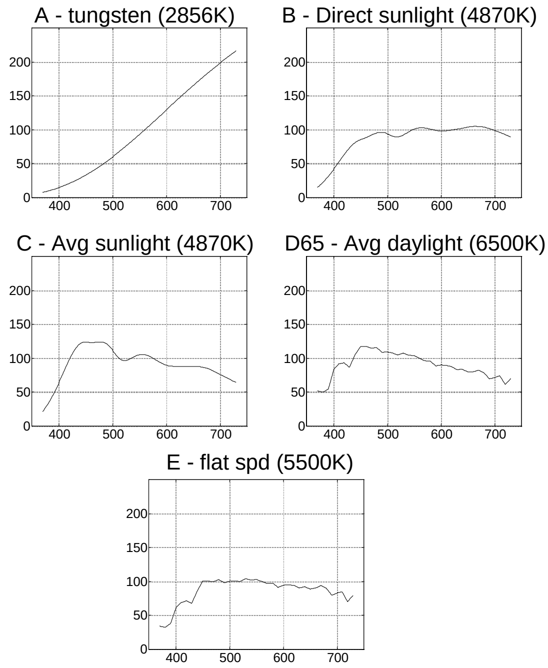
Human Visual System:
operating range – 14
Single view – 5

Technical devices (e.g. displays) :
Absolute Dynamic range – 2

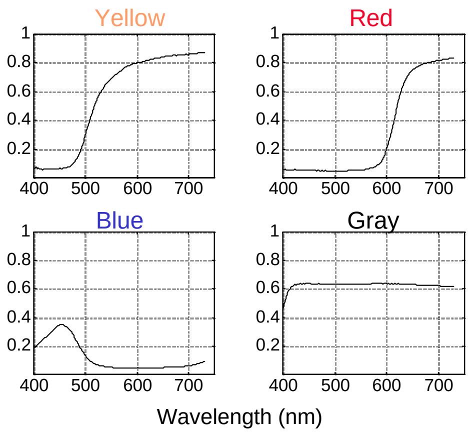
Spectral Image Formation



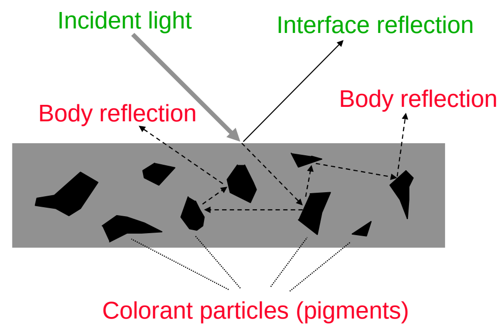
Illuminants (CIE standard illuminants)



Surface Reflectances

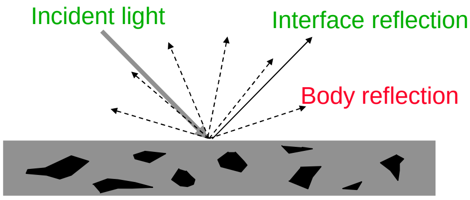


Dichromatic Reflection Model



(Shafer ‘85)

Reflection Model



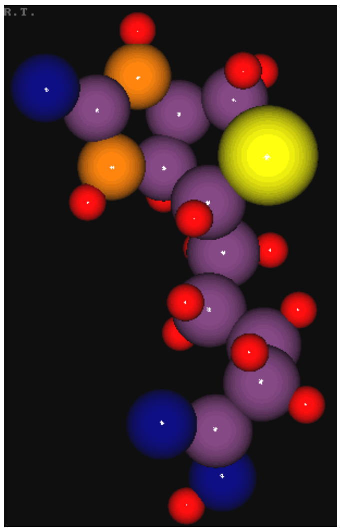
Interface reflection - mirror like reflection at the surface

Body reflection - reflected randomly between color particles. Reflection is equal in all directions

Types of Surfaces:

Specular surface = Interface reflection is non-zero - object appears glossy.

Lambertian surface (matte) = surface with no interface reflection, only body reflection.



Interface reflection - reflects all wavelengths equally and in the same direction, thus this reflection takes on the same color as the illuminant (and the same SPD).

Spectral Image Formation

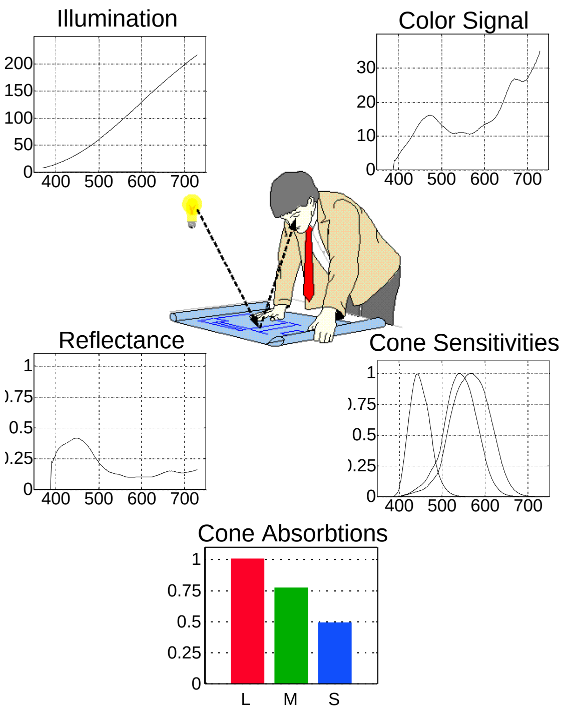


Image Formation Equation

Assuming **Lambertian** Surfaces

$e(\lambda)$ – Illuminant
$s(\lambda)$ – Surface reflectance
$l(\lambda), m(\lambda), s(\lambda)$ –Cone responsivities

Sensors Illuminant Surface

Output

$$L = \int l(\lambda)e(\lambda)s(\lambda)$$

$$M = \int m(\lambda)e(\lambda)s(\lambda)$$

$$S = \int s(\lambda)e(\lambda)s(\lambda)$$

Image Formation Equation

Assuming Lambertian Surfaces

$e(\lambda)$ – Illuminant
$s(\lambda)$ – Surface reflectance
$l(\lambda), m(\lambda), s(\lambda)$ –Cone responsivities

Sensors Illuminant Surface

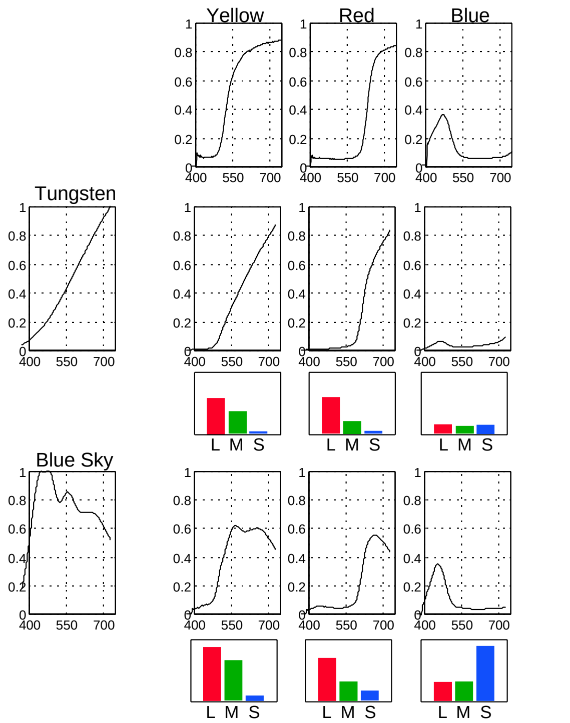
$$\begin{pmatrix}L\\M\\S\end{pmatrix} = \begin{pmatrix}\cdots & l(\lambda) & \cdots\\ \cdots & m(\lambda) & \cdots\\ \cdots & s(\lambda) & \cdots\end{pmatrix}\begin{pmatrix}\ddots & & 0\\ & e(\lambda) & \\ 0 & & \ddots\end{pmatrix}\begin{pmatrix}\vdots\\ s(\lambda)\\ \vdots\end{pmatrix}$$

Output

$$\mathbf{r}_{hvs} = \mathbf{R}_{hvs}^{t}\, diag(\mathrm{e})\mathbf{s}$$

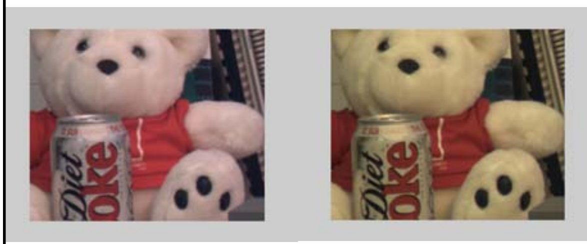
End this section!

Affects of Illumination

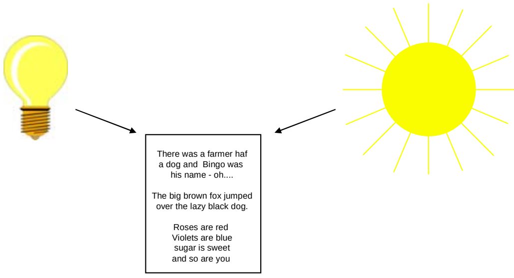


Affects of Illumination

Illuminant 1 Illuminant 2



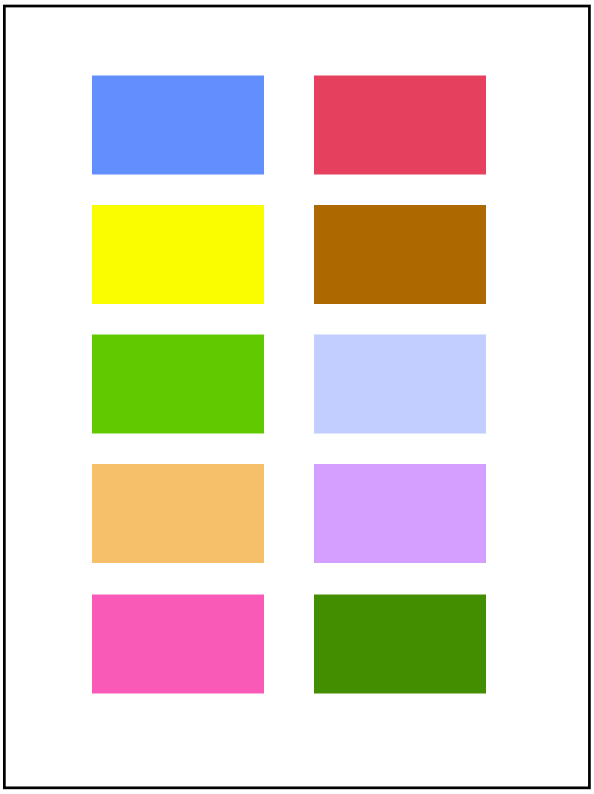
Color Constancy

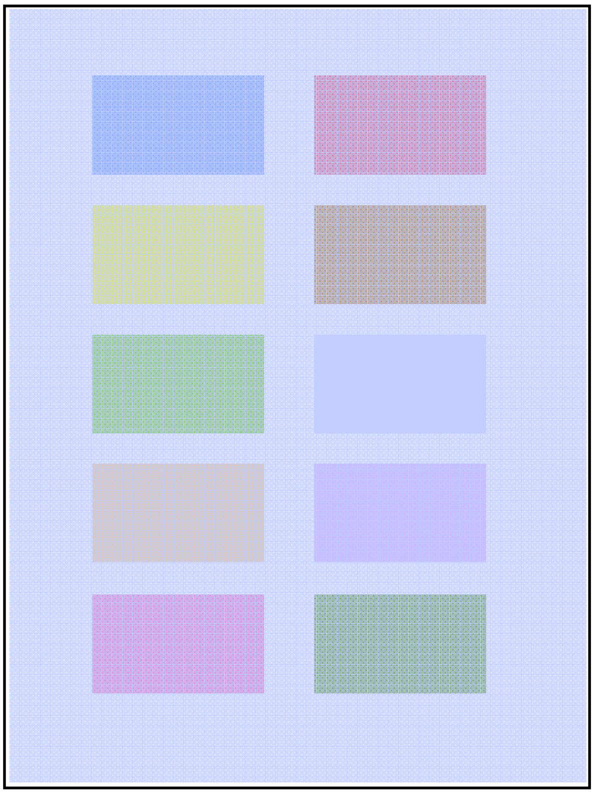


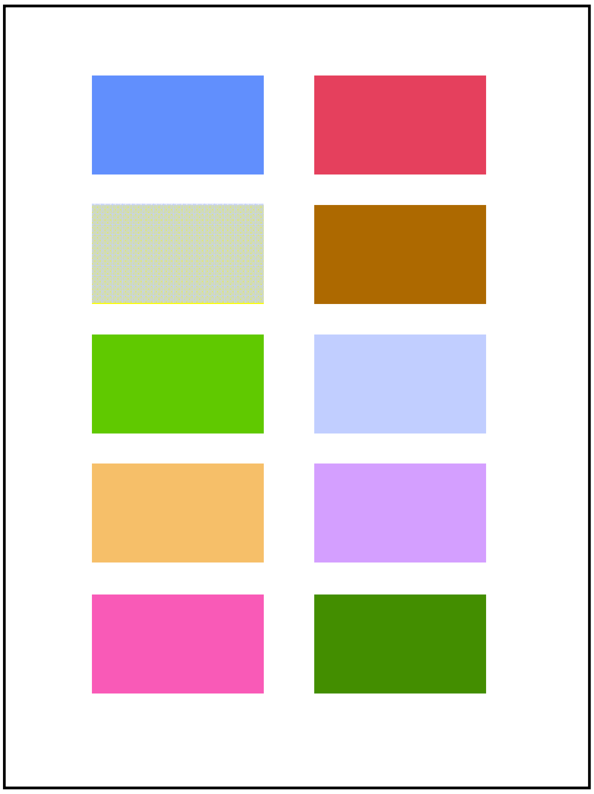
White paper - reflects 90%
Black ink - reflects 2%

Indoor: 100 units illumination
Outdoor: 10,000 units illumination.

Outdoors, black ink reflects more than white paper indoors yet the ink still looks black.



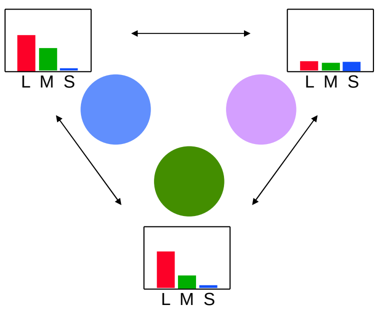




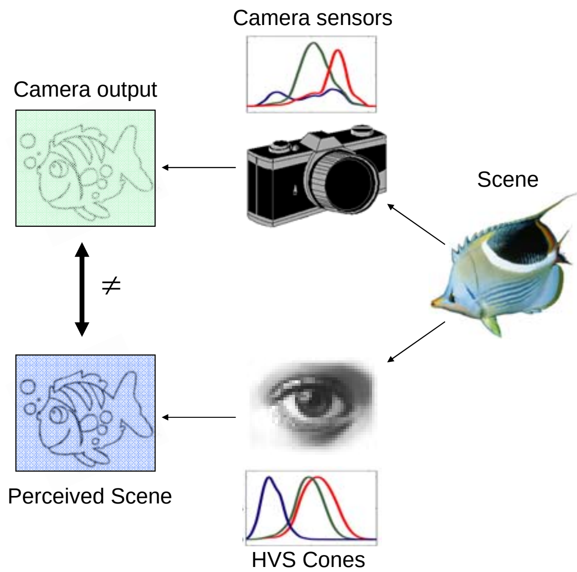
Color Constancy

Absolute level of cone responses does **not** define an object's color appearance.

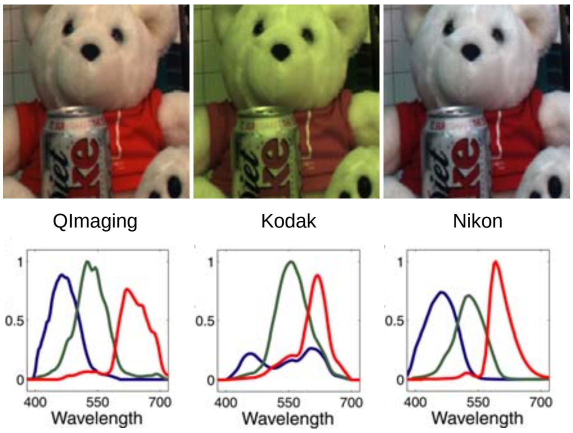
The level of sensor responses relative to responses to other objects in the scene defines the color appearance of an object..



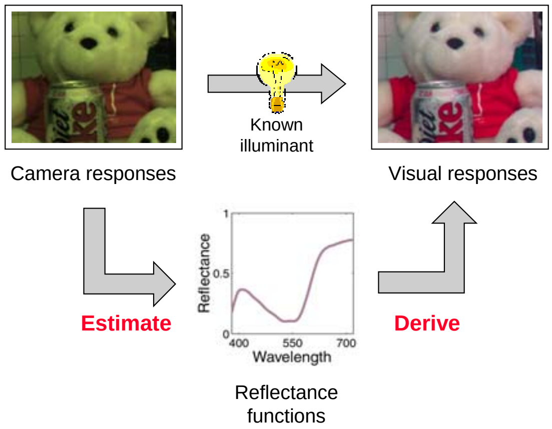
Camera vs Perceived



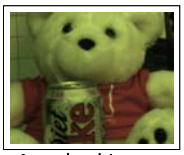
Additional Variations due to Camera Sensors



Color Correction



Color Correction



Assume camera sensors are known

Acquired Image

Estimate Reflectance → Derive new image from reflectances and standard illumination

Estimate Illuminance → Derive new image by transforming from estimated to standard illuminance

Corrected Image simulates surfaces viewed under standard (white) illumination

Corrected Image

Surface reflectance estimation

$e(\lambda)$ = illuminant
$s(\lambda)$ = surface reflectance

color signal $\boxed{c(\lambda) = e(\lambda) \cdot s(\lambda)}$

Problems:

1) There is no way to distinguish between the following illuminant-surface pairs:

$e'(\lambda) = e(\lambda) \cdot f(\lambda)$
$s'(\lambda) = s(\lambda) / f(\lambda)$
$c'(\lambda) = e'(\lambda) \cdot s'(\lambda) = [e(\lambda) \cdot f(\lambda)] \cdot [s(\lambda) / f(\lambda)] = c(\lambda)$

Surface reflectance estimation

2) Visual systems receives LMS cone absorption values (or sensor output values) and not SPDs, thus metameric pairs add to the confusion:

$$r_i = \sum_{\lambda} R_i(\lambda) \bullet C(\lambda)$$

($R_i(\lambda)$ = Spectral sensitivity of sensor i)

Metameric pair

$\boxed{c_1(\lambda) = e(\lambda) \bullet s_1(\lambda)}$ $\boxed{c_2(\lambda) = e(\lambda) \bullet s_2(\lambda)}$

$$\sum_{\lambda} R_i(\lambda) \bullet C_1(\lambda) \overset{=}{\longleftrightarrow} \sum_{\lambda} R_i(\lambda) \bullet C_2(\lambda)$$

Sensor response

Illuminant + Surface reflectance Estimation

Linear Models

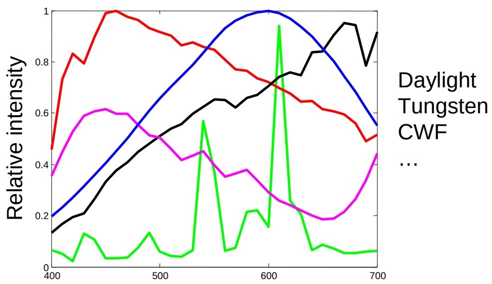
Judd et al '64
Cohen '64
Maloney '86
Marimont & Wandell '93

Assume: Likely Illuminants and Surfaces

Represent Illuminants and Surfaces using low dimensional linear representation

Linear Model - Illuminants

Likely Illuminants:



Judd, MacAdam & Wyszecki (1964)
Modeling of Daylight

Linear Model - Illuminants

Find a basis of SPDs

$e_1(\lambda)$ $e_2(\lambda)$ $e_3(\lambda)$ ….

such that a linear combination gives a good approximation for every illuminant.

Chose a linear model that minimizes:

$$\sum_{\lambda} [\, e(\lambda) - \sum_{i=1}^{n} \omega_i \, e_i(\lambda) \,]^2$$

For all illuminants $e(\lambda)$.

n = dimensions of the linear model (# of basis finctions)

Standard daylight Model

$$\boxed{e(\lambda) = \sum_{i=1}^{3} \omega_i \, e_i(\lambda)}$$

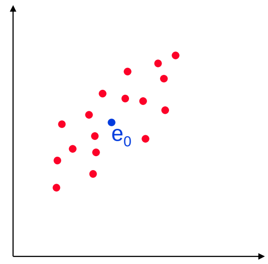
Matrix representation:

$$\begin{bmatrix} | \\ e \\ | \end{bmatrix} = \begin{bmatrix} | & | & | \\ e_1 & e_2 & e_3 \\ | & | & | \end{bmatrix} \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \end{bmatrix}$$

$$\boxed{\mathbf{e} = \mathbf{B}_e \, \omega}$$

Principle Component Analysis (PCA)

Data Set p_i

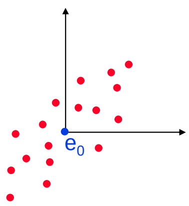


$e_0 = \text{mean}(p_i)$

Minimizes $\sum_i (p_i - e_0)^2$

Principle Component Analysis (PCA)

Data Set $\tilde{p}_i$

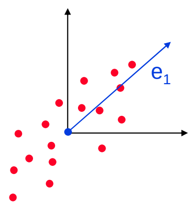


$\tilde{p}_i$ - Mean zero data set

$e_1 = ?$

Principle Component Analysis (PCA)

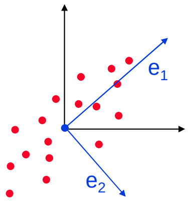
Data Set $\tilde{p}_i$



Minimizes $\sum_i (p_i - e_0 - w_1 e_1)^2$

Principle Component Analysis (PCA)

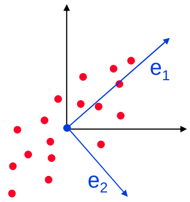
Data Set $\tilde{p}_i$



Minimizes $\sum_i (p_i - e_0 - w_1 e_1 - w_2 e_2)^2$

Principle Component Analysis (PCA)

Data Set $\tilde{p}_i$



Finding $e_i(\lambda)$:

Create covariance matrix $\quad \mathbf{C} = p_i \, p_i^t$

Diagonalize using Singular Value Decomposition (SVD) :

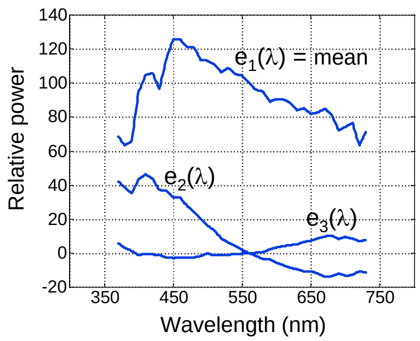
$$\mathbf{C} = \mathbf{UDV}^t$$

Where **D** is a diagonal matrix of eigen values
and **U,V** are matrices of eigenVectors.

$$\mathbf{U} = \mathbf{V} = [\; e_1(\lambda) \;\; e_2(\lambda) \;\; e_3(\lambda) \;\; \ldots.]$$

Standard daylight Model

$$\boxed{e(\lambda) = \sum_{i=1}^{3} \omega_i \, e_i(\lambda)}$$



Simple Illuminant Estimation

e(l) = illuminant to be estimated

3 color sensors: $R_1(\lambda)$ $R_2(\lambda)$ $R_3(\lambda)$

$\mathbf{B_e} = [\; e_1(\lambda) \;\; e_2(\lambda) \;\; e_3(\lambda)]$ matrix of illuminant basis

Given the sensor responses:

$$r_i = \sum_i R_i(\lambda)\, e(\lambda) \qquad i = 1,2,3$$

In matrix representation:

$$\begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix} = \begin{bmatrix} \text{—— } R_1 \text{ ——} \\ \text{—— } R_2 \text{ ——} \\ \text{—— } R_3 \text{ ——} \end{bmatrix} \begin{bmatrix} | \\ e \\ | \end{bmatrix}$$

$$\mathbf{r} = \mathbf{R}\,\mathbf{e}$$

$\mathbf{r} = \mathbf{R}(\mathbf{B_e}\omega) = (\mathbf{RB_e})\,\omega \qquad \mathbf{RB_e}$ = matrix 3x3

estimate ω : $\quad \omega = (\mathbf{RB_e})^{-1}\mathbf{r}$

estimate **e** : $\quad \boxed{\mathbf{e} = \mathbf{B_e}\,\omega}$

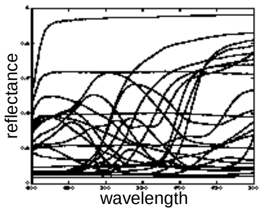
Linear model for Surface Reflectance

Linear models for special sets:
inks, geological materials, etc

Surface reflectances are relatively smooth,
so linear models can be used to approximate.

Example:

Macbeth Color Checker



Linear model for Surface Reflectance

Chose a linear model, i.e. basis functions s_i,
to minimize:

$$\sum_{\lambda} [\, s(\lambda) - \sum_{i=1}^{n} \sigma_i \, s_i(\lambda) \,]^2$$

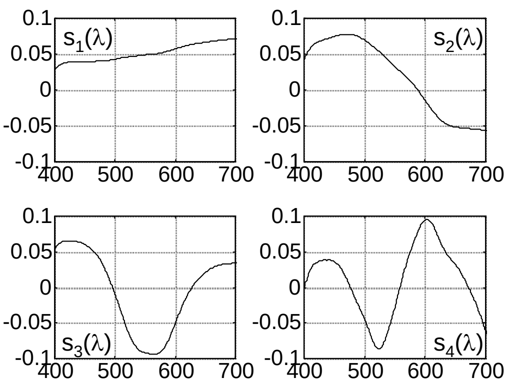
Where **s** is the surface reflectance function
σ_i = surface coefficients
n = dimension of linear model (# of basis functions)

$$\begin{bmatrix} \\ s \\ \\ \end{bmatrix} = \begin{bmatrix} \\ s_1 & s_2 & \cdots & s_n \\ \\ \end{bmatrix} \begin{bmatrix} \sigma_1 \\ \vdots \\ \sigma_v \end{bmatrix}$$

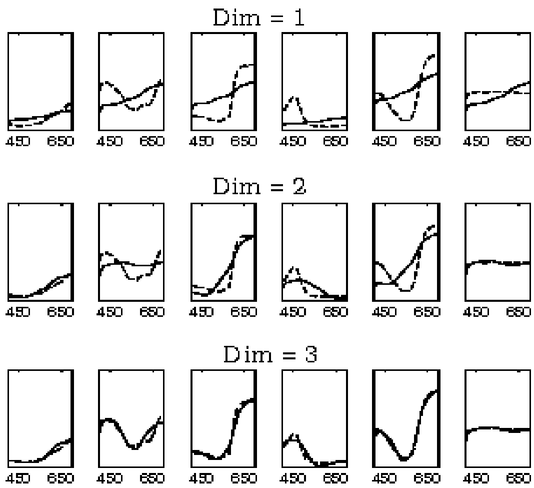
Matrix notation: $\boxed{\mathbf{s} = \mathbf{B_s}\,\sigma}$

Example: Linear model for Macbeth color checker

A minimum of 3 basis functions are needed.



Approximating surface reflectance using a linear model

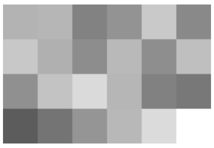


Using 1,2,3 basis functions (top to bottom)

Approximating surface reflectance using a linear model

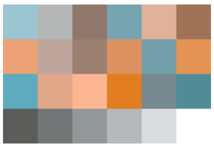
Macbeth Chart

n=1



n=4

n=2



n=5

n=3

n=6

Surface and Illumination Estimation of a Scene

Simplifying Assumptions:

1) Likelihood of surfaces and illuminants are given (for example using linear models).
2) Illuminant does not change rapidly over the scene.
3) Sensor sensitivities are known.

Problem: assuming a 3D linear model for surface reflection and for illuminants, find 3 surface reflection coefficients for each of the p points in the scene.

Case 1: Illuminant is known

If the illuminant **e** is given, then there are 3p measurements and 3p unknowns.
For every point :

$$r_1 = \sum_\lambda R_1(\lambda)e(\lambda)\, s(\lambda) = \sum_\lambda R_1(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

$$r_2 = \sum_\lambda R_2(\lambda)e(\lambda)\, s(\lambda) = \sum_\lambda R_2(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

$$r_3 = \sum_\lambda R_3(\lambda)e(\lambda)\, s(\lambda) = \sum_\lambda R_3(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

Surface and Illumination Estimation of a Scene

$$r_1 = \sum_\lambda R_1(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

$$r_2 = \sum_\lambda R_2(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

$$r_3 = \sum_\lambda R_3(\lambda)e(\lambda) \sum_{j=1}^{3}\sigma_j s_j(\lambda)$$

As a matrix equation:

$$\mathbf{r} = \Lambda_{\mathbf{e}}\, \sigma$$

where the (i,j) entry of matrix $\Lambda_{\mathbf{e}}$ is

$$\sum_\lambda R_i(\lambda)e(\lambda)s_j(\lambda)$$

Solving for σ :

if n=3 then $\sigma = \Lambda_{\mathbf{e}}^{-1}\mathbf{r}$

if n>3 then $\sigma = \Lambda_{\mathbf{e}}^{*}\mathbf{r}$ ($\Lambda_{\mathbf{e}}^{*}$ is the pseudo-inverse)

$\Lambda_{\mathbf{e}}$ is the surface matrix for illumination **e**.

Case 2: Illuminant is unknown, 1 surface is known

if illuminant is unknown: p points in scene
3p sensor responses are given
3p + 3 unknowns

Assume surface $s(\lambda)$ is known.

$$r_1 = \sum_\lambda R_1(\lambda)\, e(\lambda)\, s(\lambda) = \sum_\lambda R_1(\lambda) \sum_{j=1}^{3}\omega_j e_j(\lambda)\, s(\lambda)$$

$$r_2 = \sum_\lambda R_2(\lambda)\, e(\lambda)\, s(\lambda) = \sum_\lambda R_2(\lambda) \sum_{j=1}^{3}\omega_j e_j(\lambda)\, s(\lambda)$$

$$r_3 = \sum_\lambda R_3(\lambda)\, e(\lambda)\, s(\lambda) = \sum_\lambda R_3(\lambda) \sum_{j=1}^{3}\omega_j e_j(\lambda)\, s(\lambda)$$

As a matrix equation:

$$\mathbf{r} = \Lambda_{\mathbf{s}}\, \omega$$

where the (i,j) entry of matrix $\Lambda_{\mathbf{s}}$ is

$$\sum_\lambda R_i(\lambda)e_j(\lambda)s(\lambda)$$

Compute $\Lambda_{\mathbf{s}}$ for the known $s(\lambda)$, then solve for ω:

$$\omega = \Lambda_{\mathbf{s}}^{-1}\mathbf{r}$$

Calculate the illuminant: $e(\lambda) = \sum_{i=1}^{3}\omega_i\, e_i(\lambda)$

Proceed as in Case 1.

Case 3:
Illuminant is unknown, no surface is known

Some assumption must be made to solve for illuminants and surfaces.

Option 1: Gray world assumption – average of all surface in scene is gray. (Buchsbaum ‘80, Land ‘86)

Using linearity: if $\mathbf{s_1}$ under e produces response $\mathbf{r_1}$
and $\mathbf{s_2}$ under e produces response $\mathbf{r_2}$
then $\mathbf{s_1}+\mathbf{s_2}$ under e produces response $\mathbf{r_1}+\mathbf{r_2}$

Thus, under gray world assumption,
if $\sum_{i=1}^{p} \mathbf{s}_i$ averages to gray
then $\sum_{i=1}^{p} \mathbf{r}_i$ is the response to a gray surface.

Calculate Λ_s for gray surface (flat SPD), then :

$$\sum_{i=1}^{p} \mathbf{r_i} = \Lambda_s \omega \qquad \text{As in Case 2}$$

Calculate ω : $\omega = \Lambda_s^{-1} \sum_{i=1}^{p} \mathbf{r_i}$

Calculate illuminant: $e(\lambda) = \sum_{i=1}^{3} \omega_i \, e_i(\lambda)$

and calculate all reflectances as in Case 1.

Option 2: Uniform perfect reflector – brightest surface in scene has a flat SPD. (McCann et al ‘77)

Calculate brightness of every surface (RGB -> Y)
Find surface (pixel) r_{bright} of maximum brightness.

Calculate Λ_s for brightest surface (flat SPD), then :

$$\mathbf{r_{bright}} = \Lambda_s \, \omega \qquad \text{As in Case 2}$$

Calculate ω : $\omega = \Lambda_s^{-1} \mathbf{r}$

Calculate illuminant: $e(\lambda) = \sum_{i=1}^{3} \omega_i \, e_i(\lambda)$

and calculate all reflectances as in Case 1.

Option 3: Variations on Gray world assumption
Average of all surface in scene is not exactly gray.
The more colors in scene and larger std - the more likely to average to gray.

(Lee ‘01, Lam ‘04)

Additional Methods for Illuminant estimation

Intersection of convex sets of possible illuminants
(Forsyth ‘92)

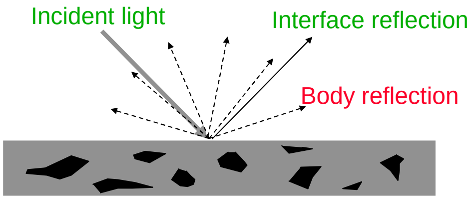
Illuminant estimation using additional sensors
(Wandell ‘87)

Illuminant estimation using several illuminants
(D’Zmura & Iverson ‘93)

Illumination from specularities -
(D’Zmura & Lennie ‘86, Lee ‘86,
Tominaga & Wandell ‘89 ‘90)

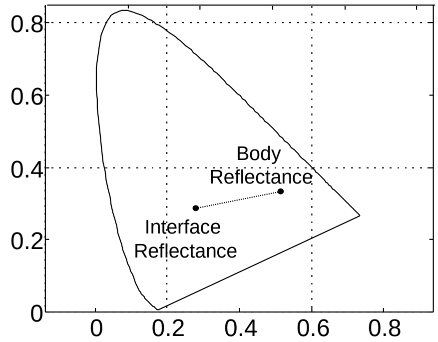
Object-based illumination classification
(Hel-Or & Wandell ‘02)

Illumination from Specularities

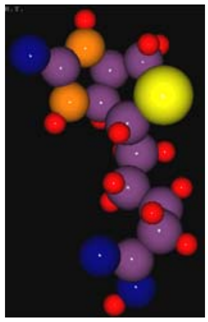


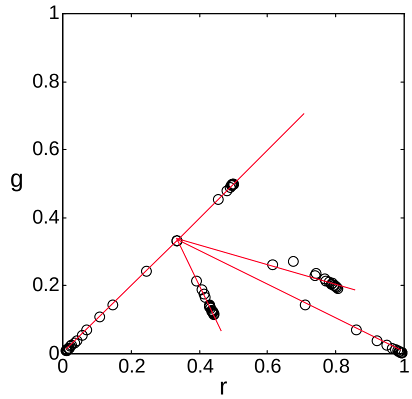
Dichromatic Surface Model

Color signal at any location is a linear combination of Interface reflectance and Body reflectance.

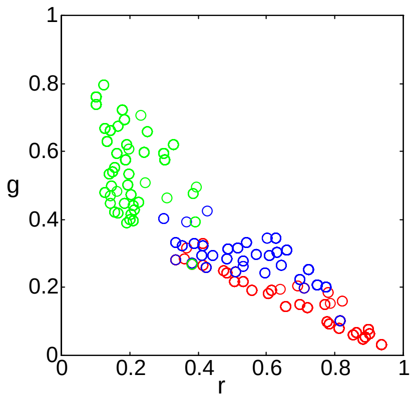


Illumination from Specularities

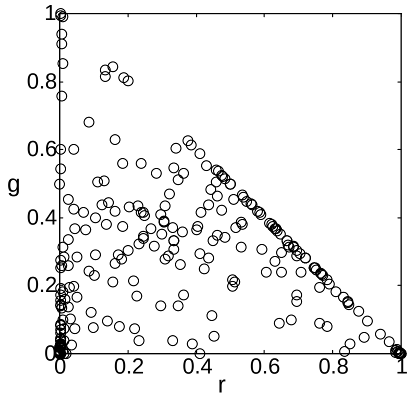




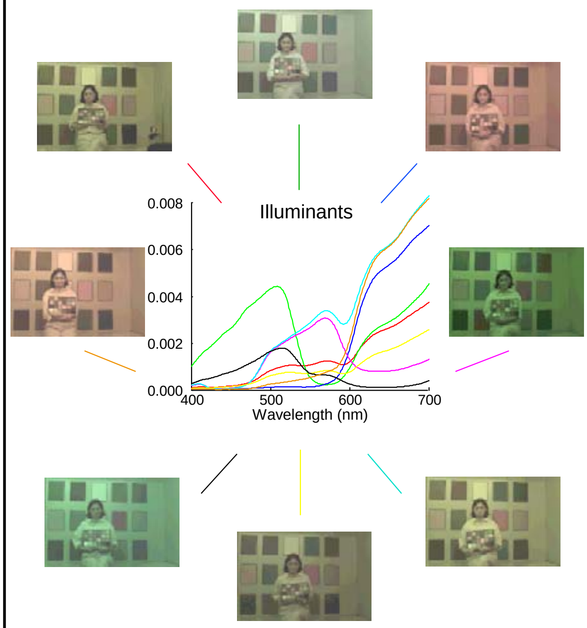
Illumination from Specularities



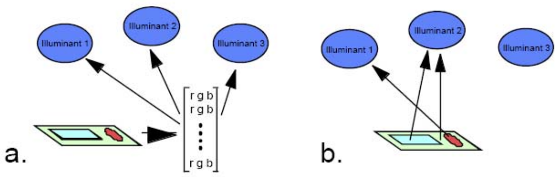
Illumination from Specularities



Object Based Illumination Classification



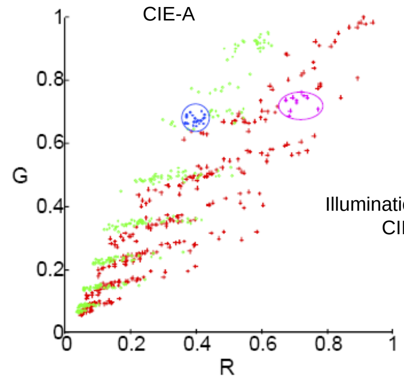
Object Based Illumination Classification



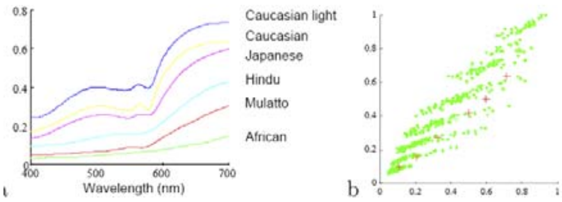
Classic approach

Content Based approach

RG(B) values of diff surfaces under 2 illuminants



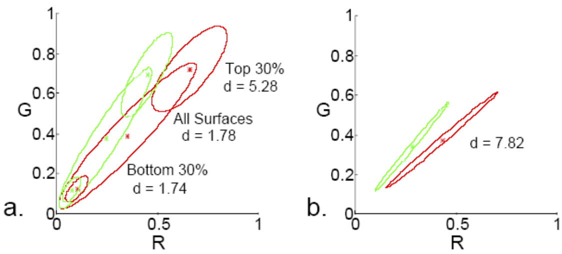
Object Based Illumination Classification



SPD of Human Skin

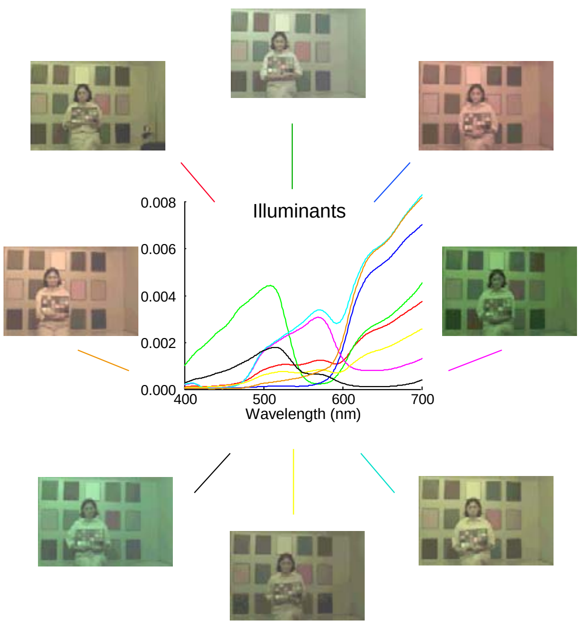
Munsell Surfaces o
Skin Surfaces +

Mahanalobis Distances

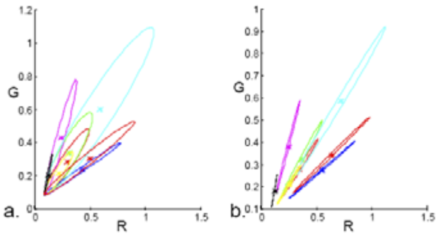


Clusters under 2 Illuminants:
Munsell Surfaces vs Skin Surfaces

Object Based Illumination Classification



Object Based Illumination Classification



Illumination Classification

Clusters under 8 Illuminants:
Munsell Surfaces vs Skin Surfaces

Illumination Correction

Change image acquired under one illumination, to appear as if taken under a different illumination.

- color correction for images
- normalization of images
- computer graphics - computer generated images.

Using linear models: $r_i = \sum_\lambda R_i(\lambda)e(\lambda)s(\lambda)$

using $s(\lambda) = \sum_{i=1}^{3} s_i(\lambda)\sigma_i$ we have: $\boxed{\mathbf{r} = \Lambda_\mathbf{e}\,\sigma}$

where (i,j) entry of $\Lambda_\mathbf{e}$ is $\sum_\lambda R_i(\lambda)e(\lambda)s_j(\lambda)$

Same surface under two illuminants:

$$\mathbf{r} = \Lambda_\mathbf{e}\sigma$$
$$\mathbf{r}' = \Lambda'_\mathbf{e}\sigma$$

$$\mathbf{r} = \Lambda_\mathbf{e}(\Lambda'_\mathbf{e})^{-1}\mathbf{r}'$$

ie a linear transformation of sensor responses.

Illumination Correction

Examples:

Tungsten $\longrightarrow$ Blue Sky

$$\mathbf{r} = \begin{bmatrix} 0.8119 & 0.2271 & 0.0550 \\ -0.0803 & 1.1344 & 0.1282 \\ 0.0429 & -0.0755 & 1.8091 \end{bmatrix} \mathbf{r'}$$

Notice diagonal elements are dominant.

$$\begin{bmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_3 \end{bmatrix}$$

Compensation for illuminants using pure diagonal transformation = scaling of sensor responses = **Von Kries Coefficient Law**

Illumination Correction

Given two images, find the illuminant transformation M between them.

Assume r_i and r'_i are sensor outputs in the two images corresponding to same surface reflectance.

$$r_i = M\, r'_i$$

Build sensor response matrixes:

$$\begin{bmatrix} | & | & & | \\ r_1 & r_2 & \cdots & r_n \\ | & | & & | \end{bmatrix} = M \begin{bmatrix} | & | & & | \\ r'_1 & r'_2 & \cdots & r'_n \\ | & | & & | \end{bmatrix}$$

Solve

$$M = \begin{bmatrix} | & | & & | \\ r_1 & r_2 & \cdots & r_n \\ | & | & & | \end{bmatrix} \begin{bmatrix} | & | & & | \\ r'_1 & r'_2 & \cdots & r'_n \\ | & | & & | \end{bmatrix}^*$$

Illumination Correction

White Balance

RGB = (215,253,178)

Apply transformation:

$$\begin{bmatrix} 253/215 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 253/178 \end{bmatrix}$$

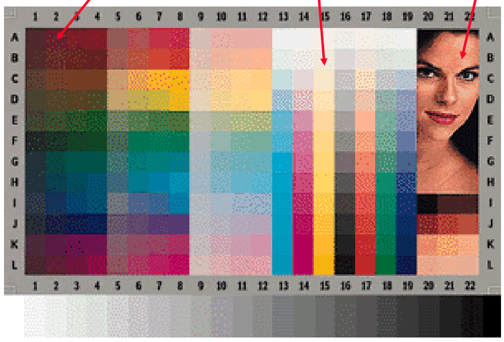
RGB = (253,253,253)

ANSI IT8.7 (Kodak-Q60)

Standard CIELAB

Printing primaries

Vendor area



- Columns 1-3, 5-7 and 9-11 have 108 standardized CIELAB values
- Accuracy to 10 ΔE_{ab}
- Produced by Kodak, Agfa, others

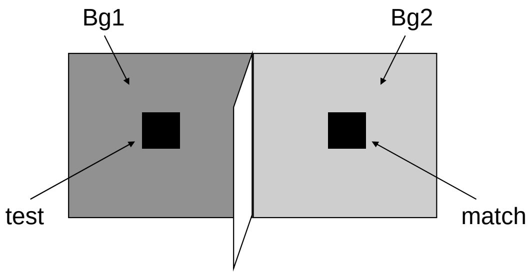
ftp://ftp.kodak.com/gastds/Q60DATA/TECHINFO.PDF

Altona TestSuite1.2a

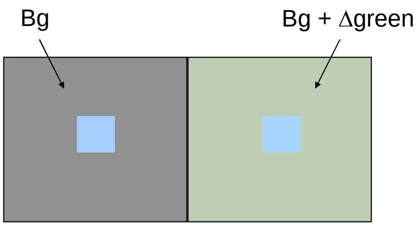
ftp://ftp.kodak.com/gastds/Q60DATA/TECHINFO.PDF

Color Constancy is not Complete

Asymmetric Color Matching Experiment

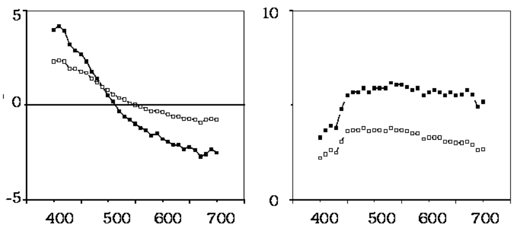


Memory match or Dichoptic match



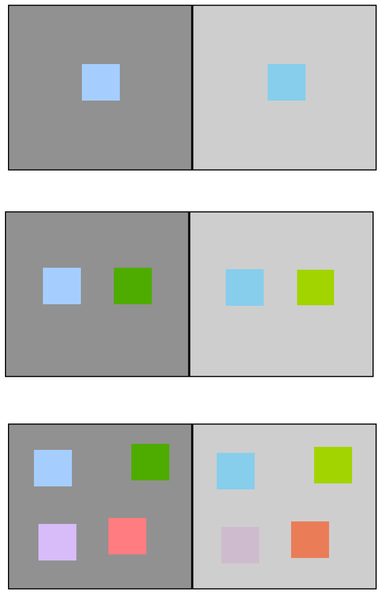
To make match patch appear equal to test, more green must be added.
Color Constancy says added green must equal Δgreen (as if adding illuminant to patch).

In practice:
compensation for illuminant is **not** complete.



Helson '38, Judd '40, Brainard & Wandell '91

When does color constancy "kick in" ?



Around 3-4 Surfaces (?)