Computer Vision 1

THEO GEVERS

MASTER AI

UNIVERSITY OF AMSTERDAM

Lectures/Theory

- 06-02-2018, 17:00-19:00, C0.05, **Introduction** (*Szeliski 1*)
- 13-02-2018, 17:00-19:00, C0.05, **Image Formation** (*Szeliski: 2.1.1 + 2.1.2 + 2.2 + 2.3.2 + 2.3.3*)
- 20-02-2018, 17:00-19:00, C0.05, **Color and Image Processing** (*Szeliski: 3.1 + 3.2 + 3.3*)
- 27-02-2018, 17:00-19:00, C0.05, **Feature Detection, Motion and Classification** (*Szeliski: 4, 8.1.1 + 8.1.3 + 8.2.1 + 8.4; Bengio: 4 + 5.1 + 5.2 + 5.3 + 5.7 + 5.8 + 5.9*)
- 06-03-2018, 17:00-19:00, C0.05, **Object Recognition: BoW and ConvNets** (*Szeliski: 5.1.1 + 5.1.4 + 5.1.5 + 5.2 + 5.3 + 5.4, 6.1 + 6.3, 14.1 + 14.2.1 + 14.3 + 14.4.1; Bengio: 7.2 + 7.4 + 9.1 + 9.2 + 9.3*)
- 13-03-2018, 17:00-19:00, C0.05, **Deep Learning, Stereo and 3D Reconstruction** (*Szeliski: 11.1 + 11.2 + 11.3 + 11.4, 12.1 + 12.2: Bengio: 12.1 + 12.2*)
- 20-03-2018, 17:00-19:00, C0.05, **Applications** (*Szeliski: 12.6.2 + 12.6.3 + 12.2.4)*
- 26-03-2018, Monday, 9:00-12:00, **Written Exam**

Today's class: Image Formation

1. Projective Geometry and Camera Models

2. Light and Color Models

3. Reflection Models

Including slides from Derek Hoiem, Alexei Efros, Steve Seitz, and David Forsyth, James Hays, Jinxiang Chai

Image formation

- There are two parts to the image formation process:
  - The **geometry of image formation**, which determines where in the image plane the projection of a point in the scene will be located.
  - The **physics of light**, which determines the brightness of a point in the image plane as a function of illumination and surface properties.

Pinhole Camera

- Abstract camera model - box with a small hole in it
- The simplest device to form an image of a 3D scene on a 2D surface.
- Rays of light pass through a "pinhole" and form an inverted image of the object on the image plane.
- Pinhole cameras work in practice

f = focal length

c = center of the camera

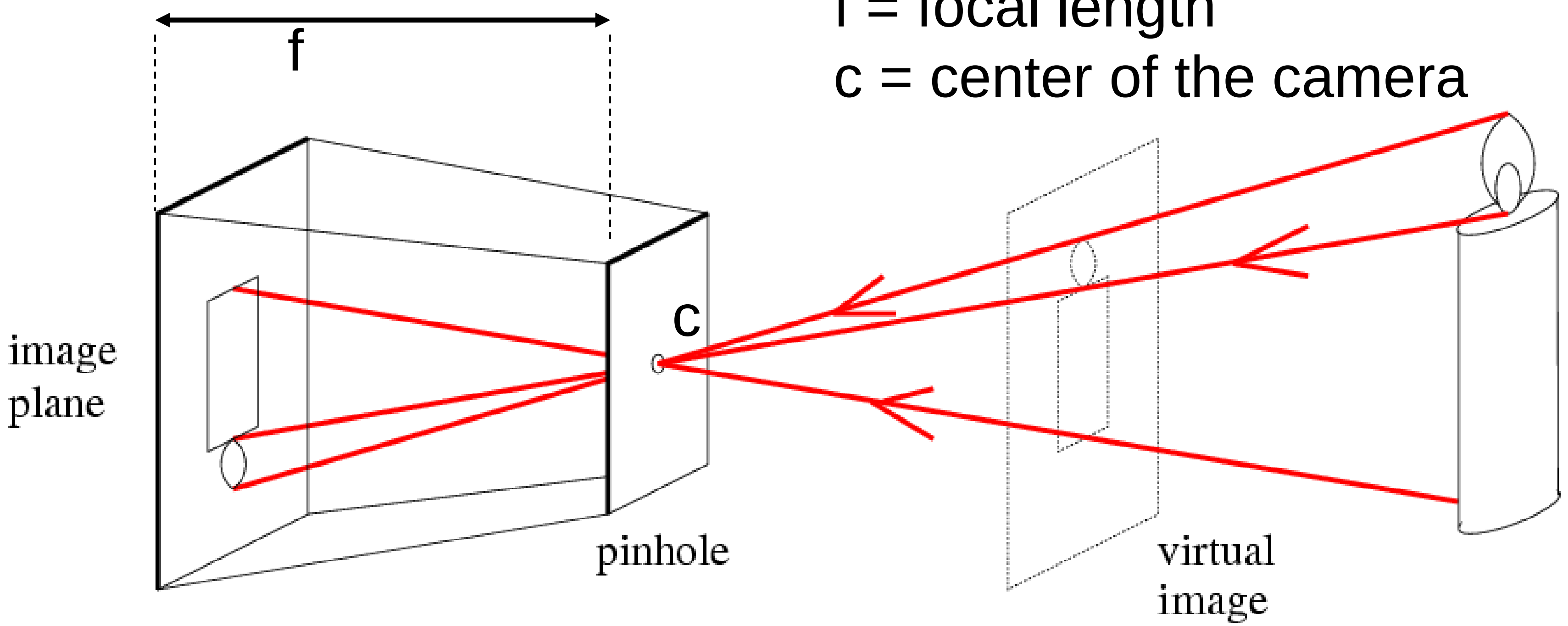
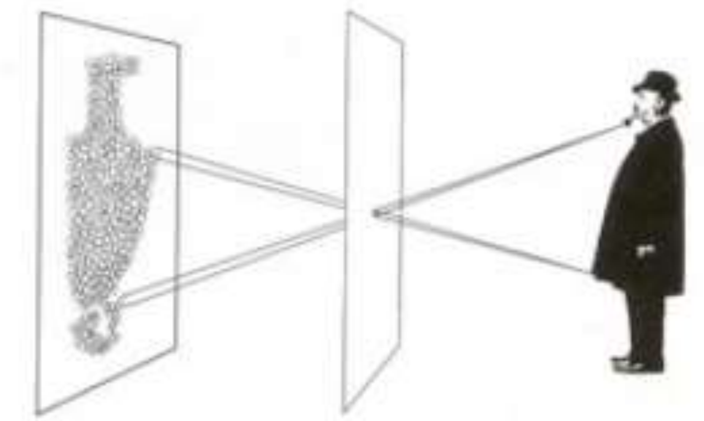


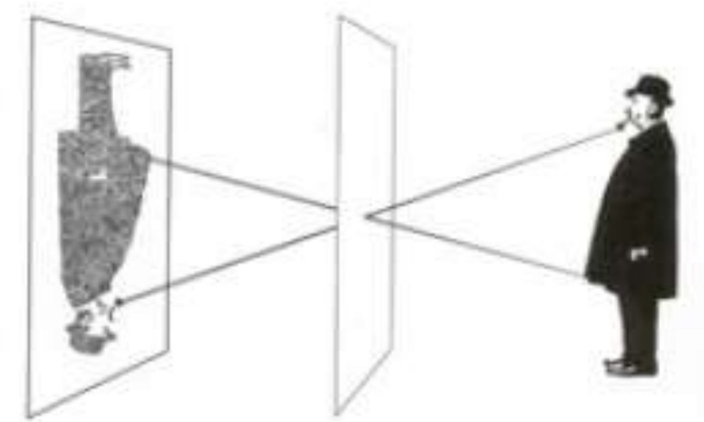
Figure from Forsyth

Effect of Aperture Size

- Large aperture: light from the source spreads across the image (i.e., not properly focused), making it blurry!



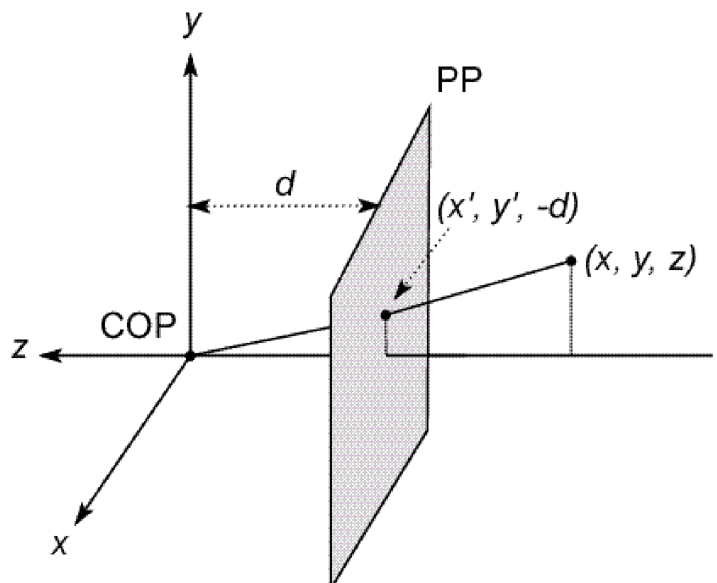
- Small aperture: reduces blurring but (i) it limits the amount of light entering the camera and (ii) causes light diffraction.



Modeling Projection: 3D->2D

The coordinate system

- We will use the pin-hole model as an approximation
- Put the optical center (**C**enter **O**f **P**rojection) at the origin
- Put the image plane (**P**rojection **P**lane) *in front* of the COP
- The camera looks down the *negative* z axis



Slide from Jinxiang Chai

Modeling Projection: 3D->2D

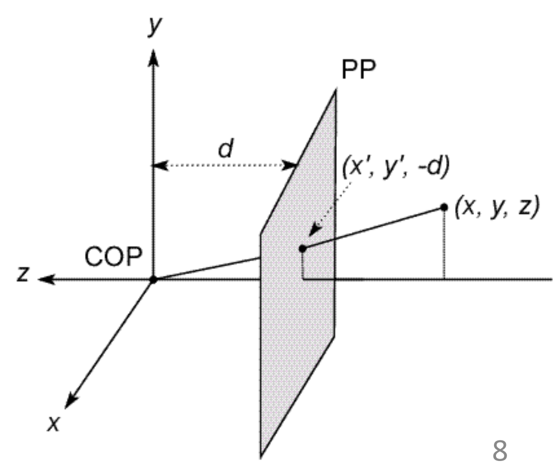
Projection equations

- Compute intersection with PP of ray from (x,y,z) to COP
- Derived using similar triangles

$$(x, y, z) \rightarrow (-d\frac{x}{z},\ -d\frac{y}{z},\ -d)$$

- We get the projection by throwing out the last coordinate:

$$(x, y, z) \rightarrow (-d\frac{x}{z},\ -d\frac{y}{z})$$



Slide from Jinxiang Chai

Perspective Projection

Projection is a matrix multiply using homogeneous coordinates:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1/d & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ -z/d \end{bmatrix} \Rightarrow (-d\frac{x}{z}, \ -d\frac{y}{z})$$

divide by third coordinate

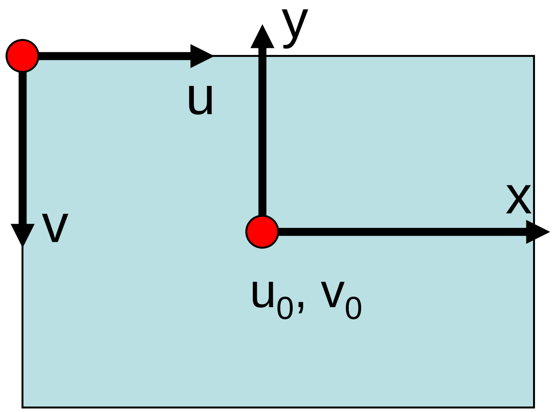
- This is known as **perspective projection**
  - The matrix is the **projection matrix**
  - Can also formulate as a 4x4

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & -1/d & 0 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \\ -z/d \end{bmatrix} \Rightarrow (-d\frac{x}{z}, \ -d\frac{y}{z})$$

divide by fourth coordinate

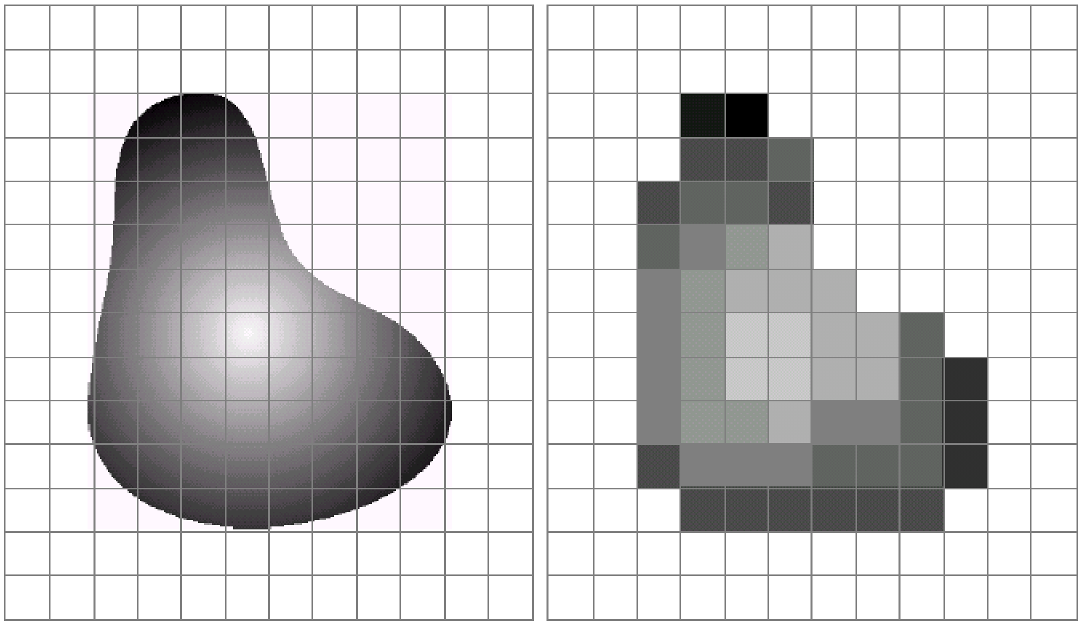
Viewport Transformation

From projection coordinate to image coordinate



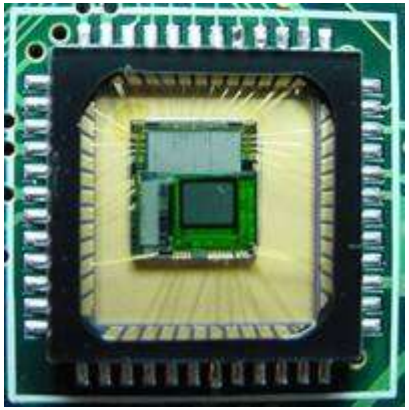
$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \Leftrightarrow \begin{bmatrix} s_x & 0 & u_0 \\ 0 & -s_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{pmatrix} x \\ y \\ 1 \end{pmatrix}$$

Sensor Array



a b

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



CMOS sensor

Putting It Together

From world coordinate to image coordinate

Viewport projection | Perspective projection | View transformation

$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \Leftrightarrow \begin{bmatrix} s_x & 0 & u_0 \\ 0 & -s_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1/d & 0 \end{bmatrix} \begin{bmatrix} \mathbf{R} & \mathbf{T} \\ \mathbf{0}_3^{\mathbf{T}} & 1 \end{bmatrix} \begin{bmatrix} X_S \\ Y_S \\ Z_S \\ 1 \end{bmatrix}$$

Image resolution, aspect ratio | Focal length | The relative position & orientation between camera and objects

Camera Parameters

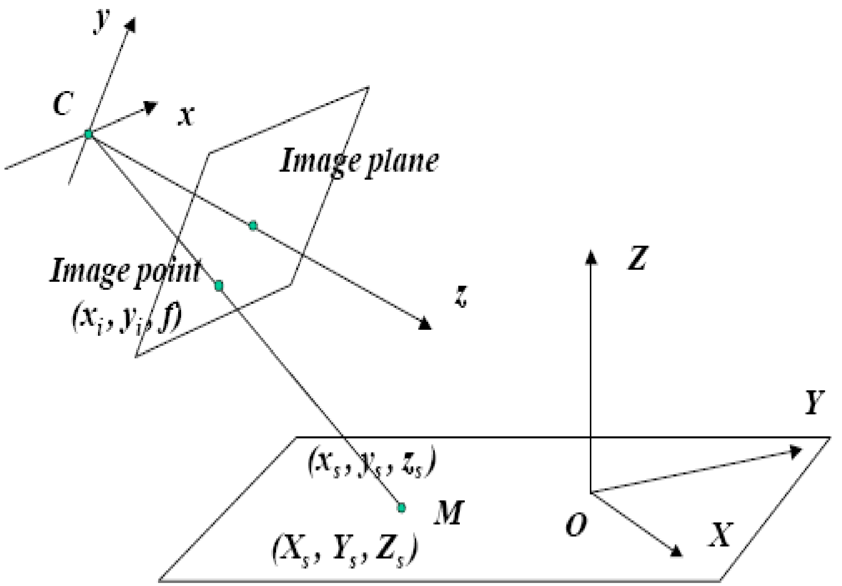
$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \Leftrightarrow \boxed{\begin{bmatrix} s_x & 0 & u_0 \\ 0 & -s_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1/d & 0 \end{bmatrix}} \boxed{\begin{bmatrix} \mathbf{R} & \mathbf{T} \\ \mathbf{0}_3^{\mathrm{T}} & 1 \end{bmatrix}} \begin{bmatrix} X_S \\ Y_S \\ Z_S \\ 1 \end{bmatrix}$$

Intrinsic camera parameters

extrinsic camera parameters

View Transformation

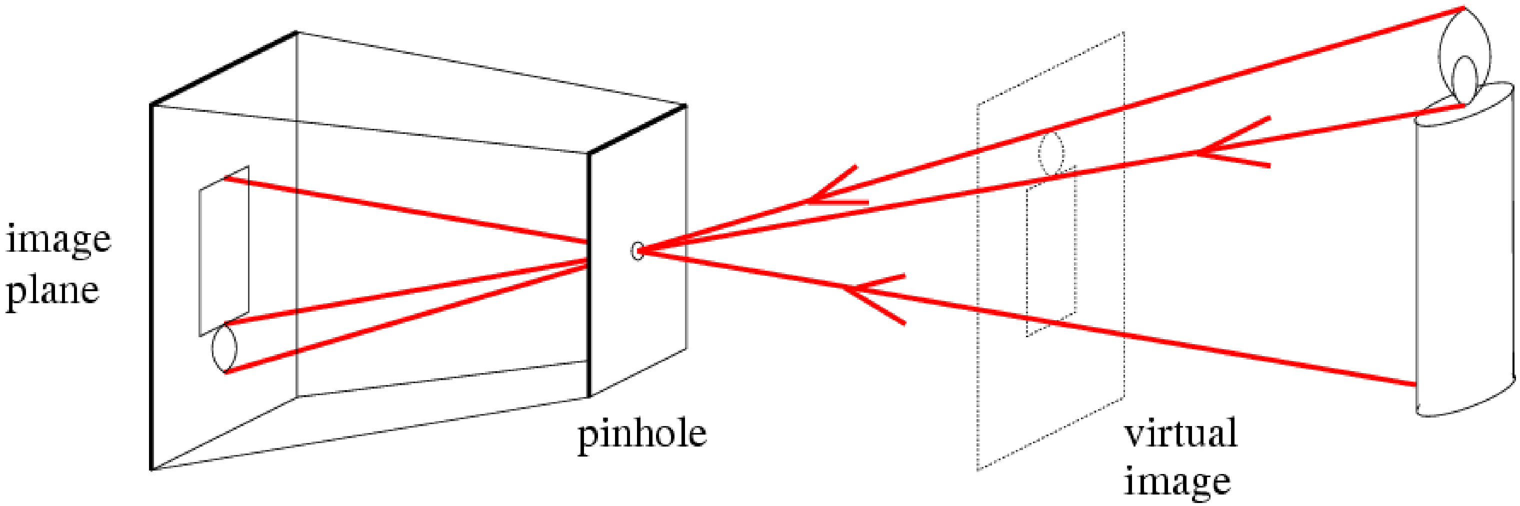
From world coordinate to camera coordinate



$$\begin{bmatrix} x_S \\ y_S \\ z_S \\ 1 \end{bmatrix} = \begin{bmatrix} \mathbf{R} & \mathbf{T} \\ \mathbf{0}_3^{\mathrm{T}} & 1 \end{bmatrix} \begin{bmatrix} X_S \\ Y_S \\ Z_S \\ 1 \end{bmatrix}$$

Things to Remember

- Pinhole camera model and camera matrix



$$\begin{pmatrix} u \\ v \\ 1 \end{pmatrix} \Leftrightarrow \begin{bmatrix} s_x & 0 & u_0 \\ 0 & -s_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1/d & 0 \end{bmatrix} \begin{bmatrix} x_S \\ y_S \\ z_S \\ 1 \end{bmatrix}$$

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Camera Models

2. Light and Color Models (Reading 2.3, paper on color models)

3. Reflection Models

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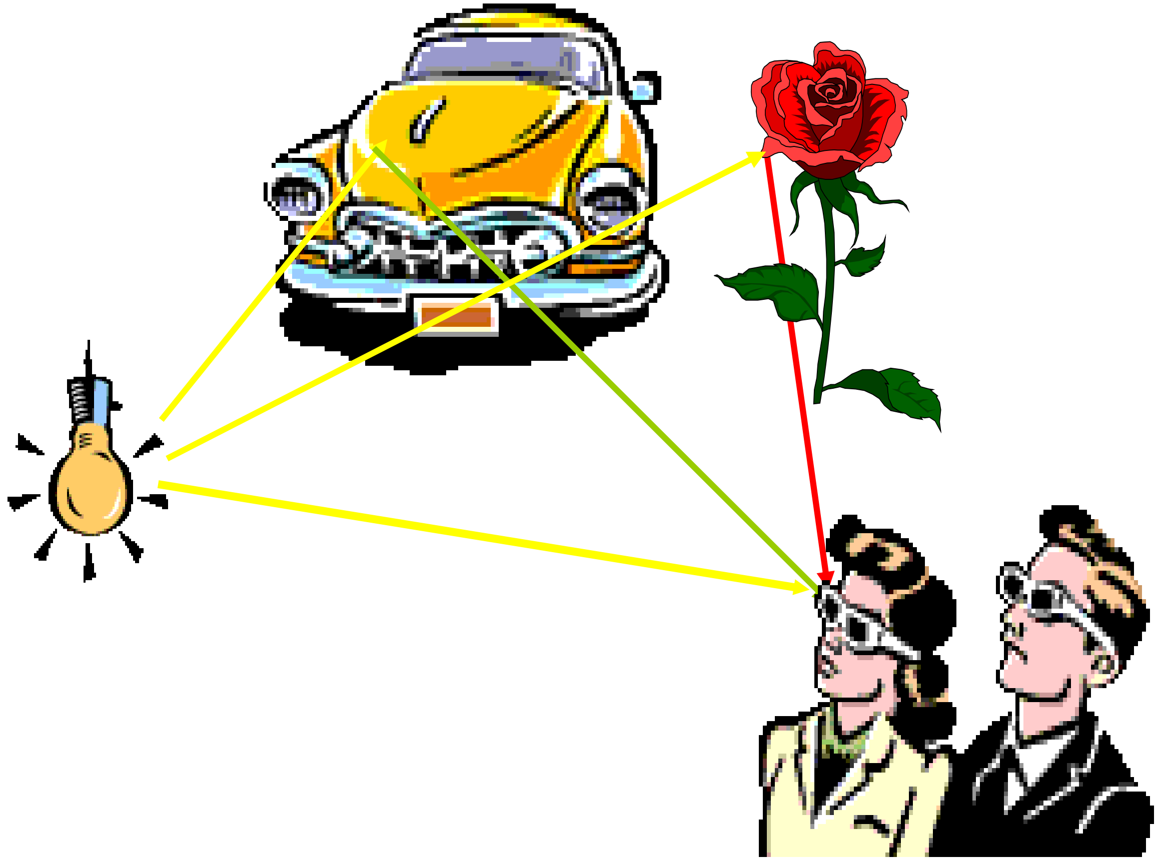
What makes an image?
the triplet light-objects-observer

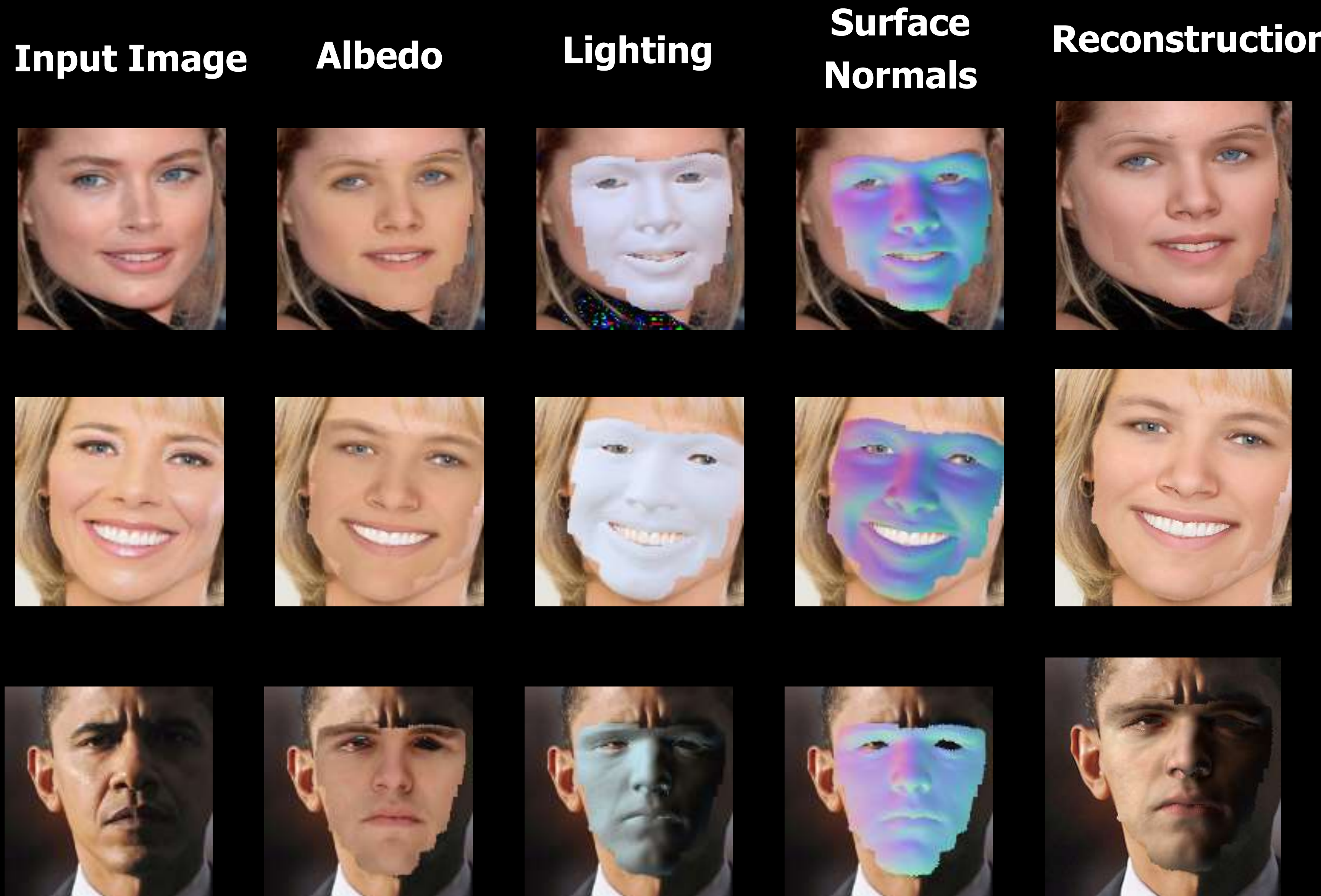
Light source

Object(s)

Sensor



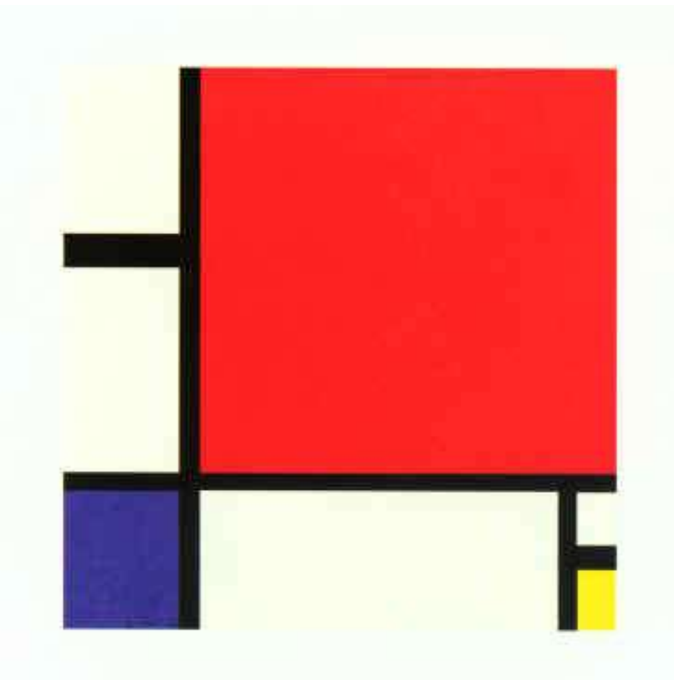
Diffuse Reflection



The science of Light and Colour

Fundamentals of colour science

Hall of fame



Mondrian

Pythagoras: undulation theory

Aristoteles: curpus theory

Newton 1665 “Opticks”

Planck, Einstein and Bohr “Quantum mechanics”

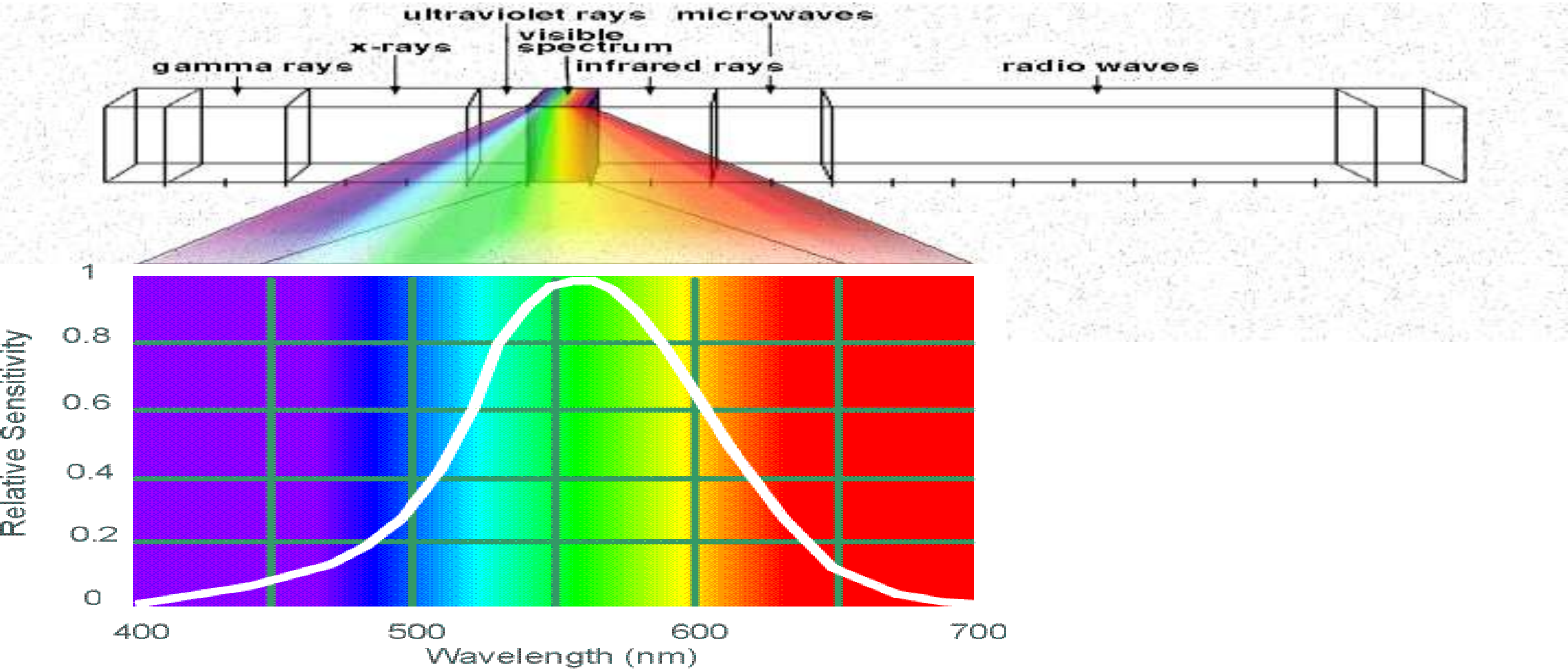
Goethe 1840 “Farbenlehre”

Munsell 1905 “A Colour Notation”

Descartes, Schopenhauer,

Hegel, Wittgenstein…and many others

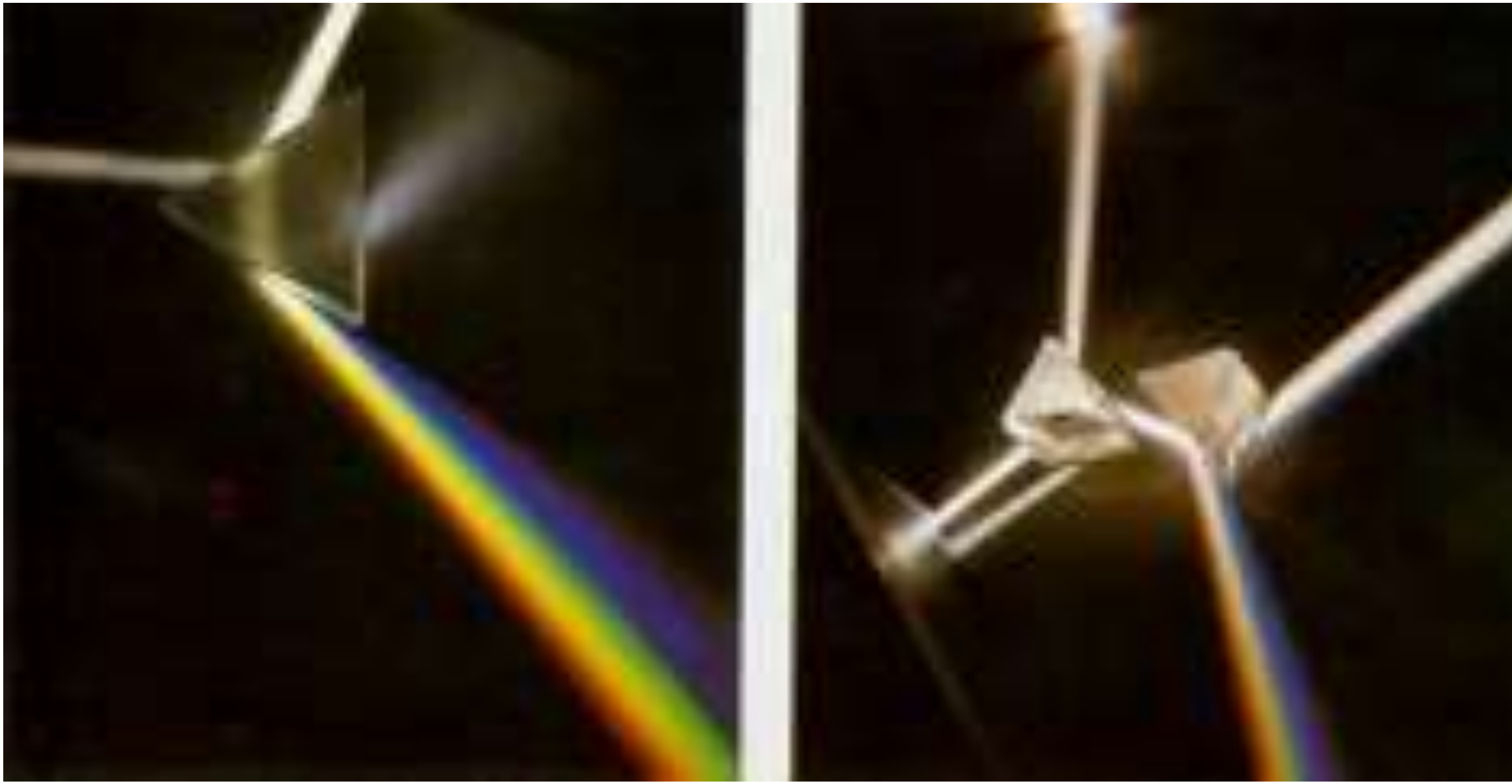
Electromagnetic Spectrum



Human Luminance Sensitivity Function

http://www.yorku.ca/eye/photopik.htm

Electromagnetic Spectrum

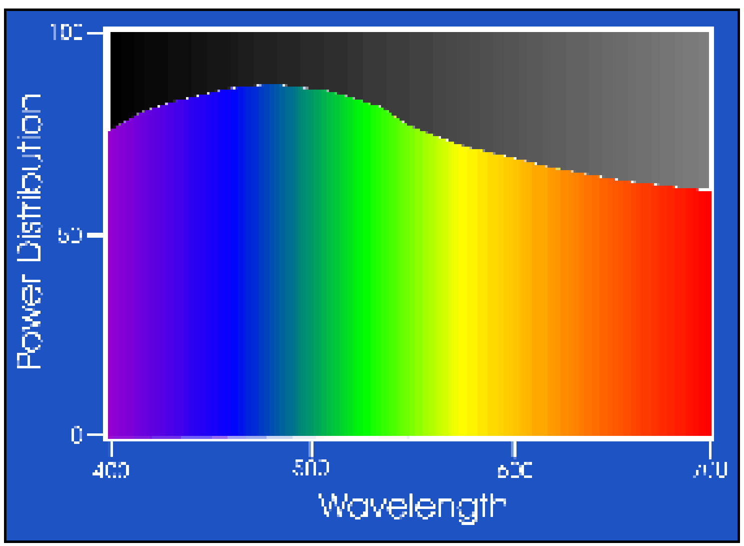


Spectral Power Distribution

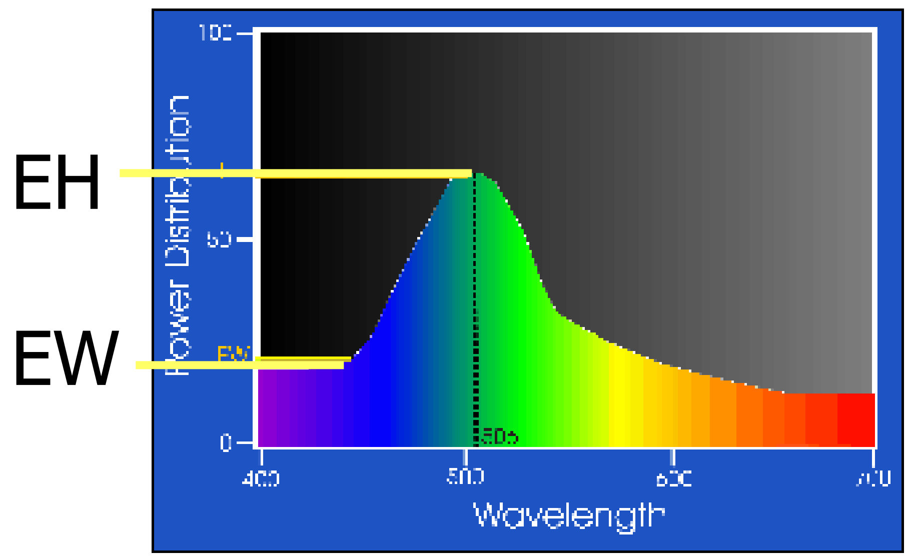
Hue: dominant wavelength of the SPD: EH

Saturation: purity of the colour: EH-EW

Intensity: brightness of the colour: EW



White light



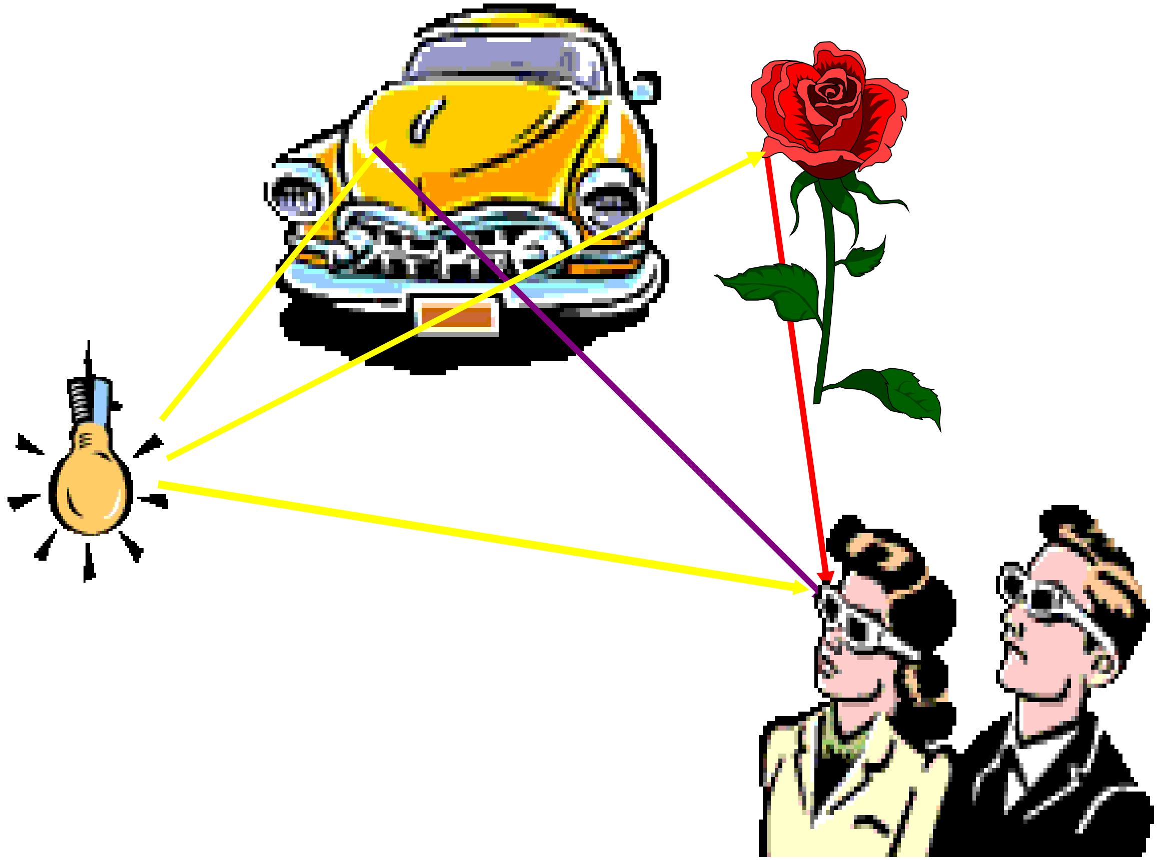
Green light

What makes an image?
the triplet light-objects-observer

Light source

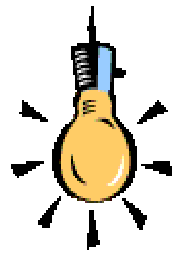
Object(s)

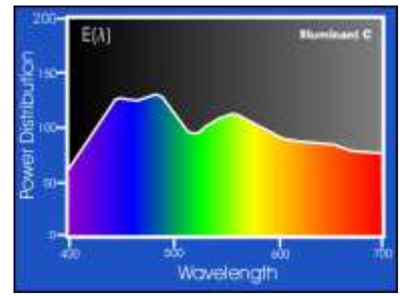
Sensor



What makes an image?
the triplet light-objects-observer

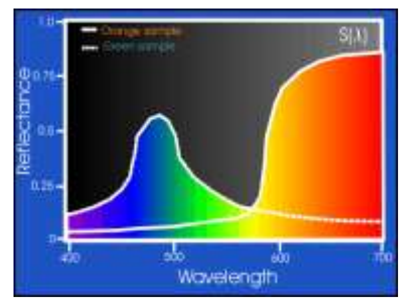
Light source





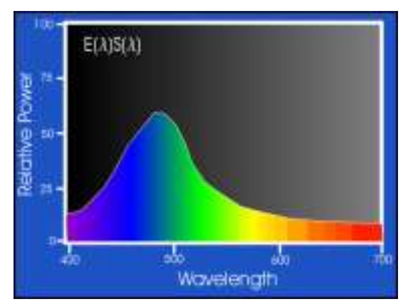
$e(\lambda)$

Object



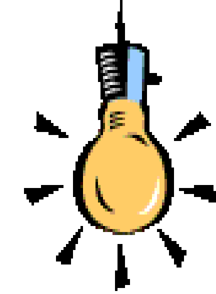
$\rho(\lambda)$

Sensor



$e(\lambda)\rho(\lambda)$

Light sources and illuminants



Light sources:

sun, candle,

fluorescent lamp,

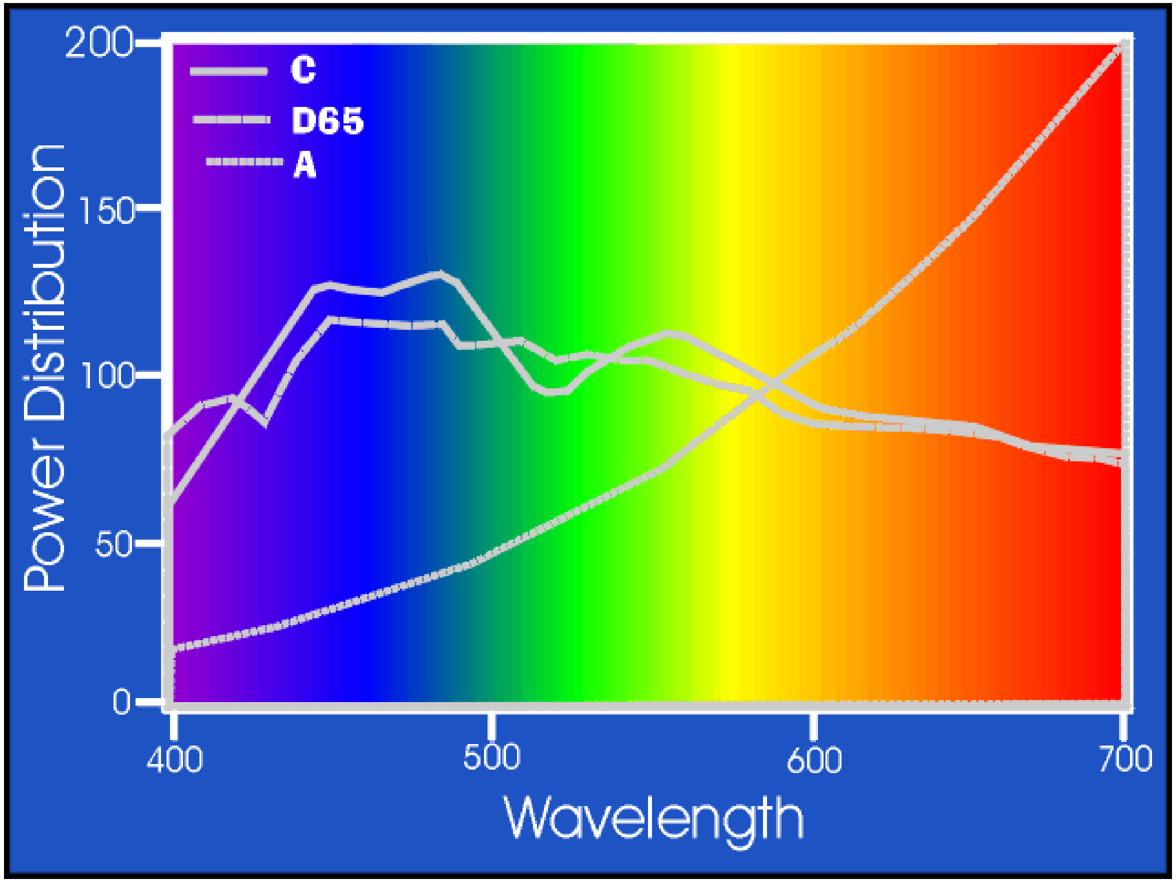
incandescent lamp

Illuminants:

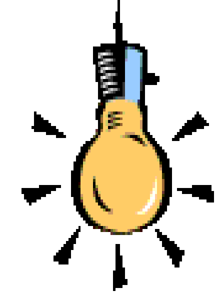
illuminant A

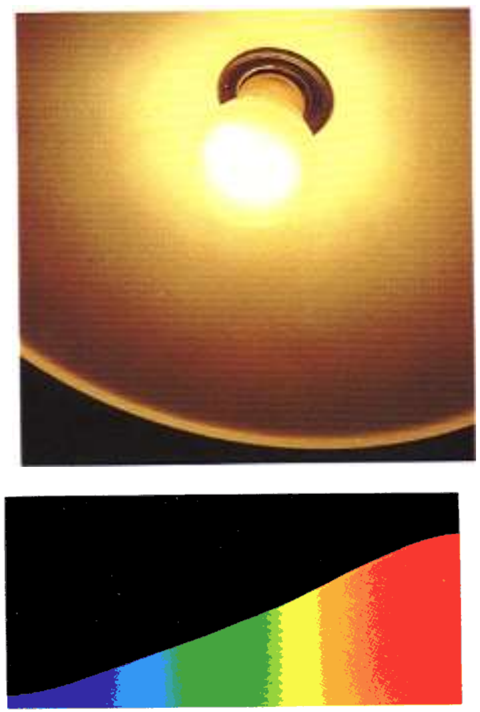
illuminant D65

illuminant C

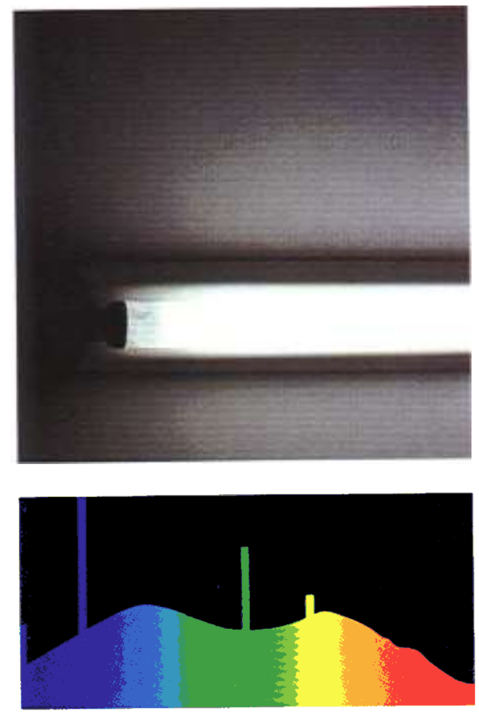


Light sources and illuminants





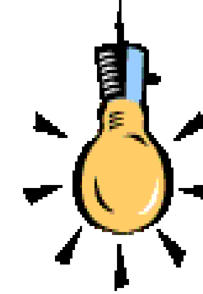
Incandescent lamp

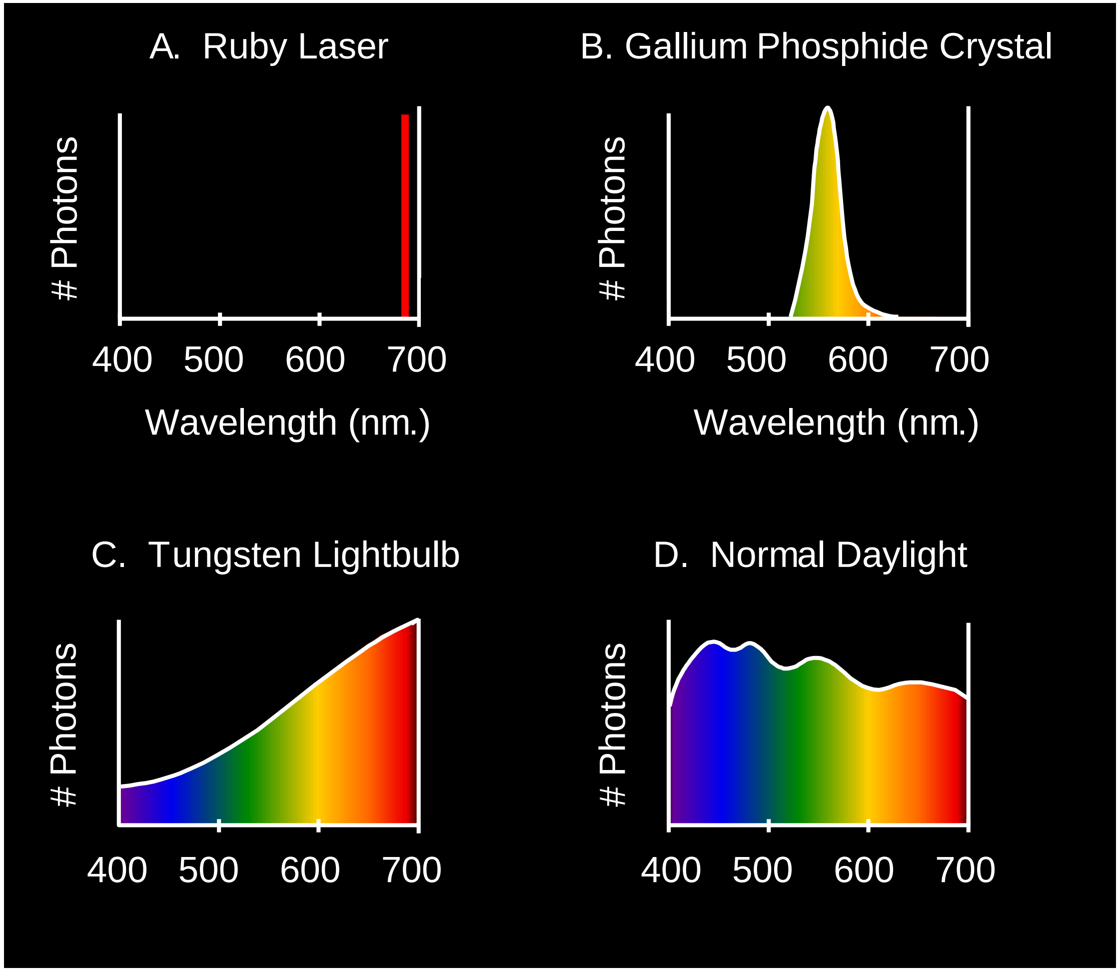


Fluorescent lamp

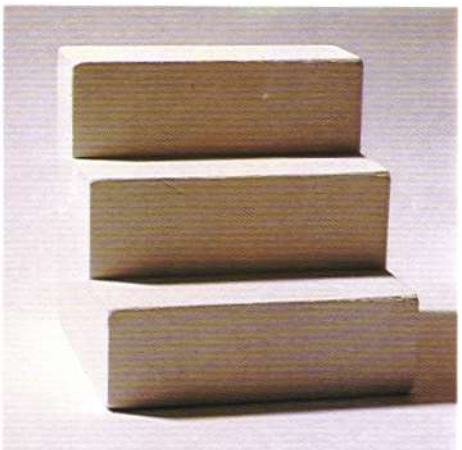
The Physics of Light

Some examples of the spectra of light sources

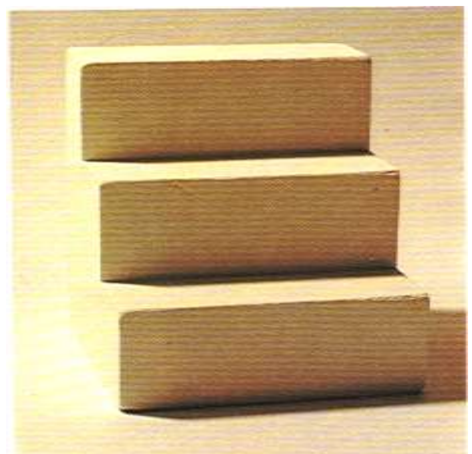




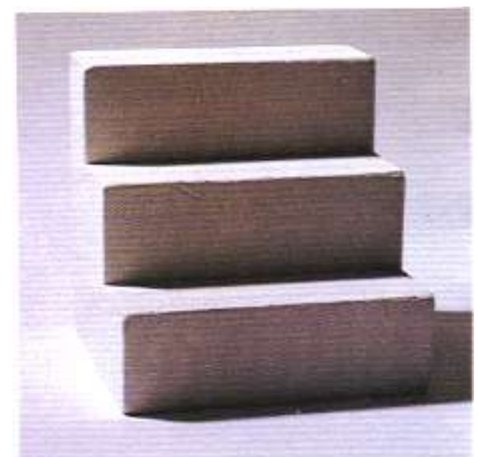
Influence of Light Sources



Average daylight



Incandescent lamp



Fluorescent lamp

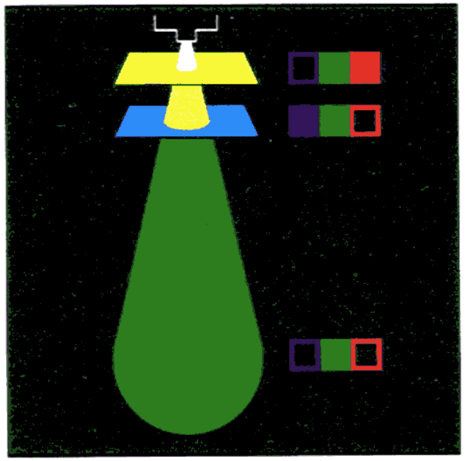
Object Colours

Materials:

- Transparent
- Opaque

Spectral Reflectance

$$\rho(\lambda)$$

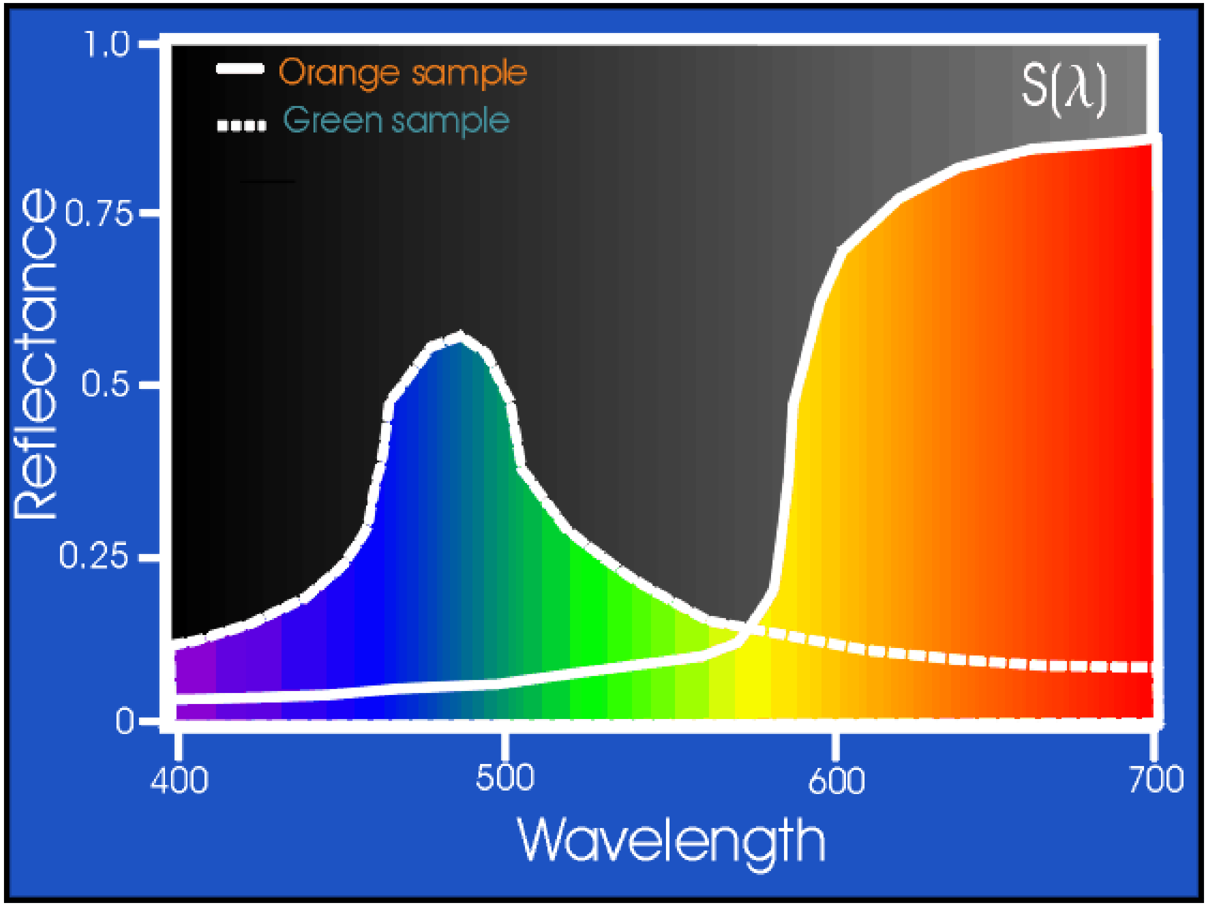


Object Colours

Material

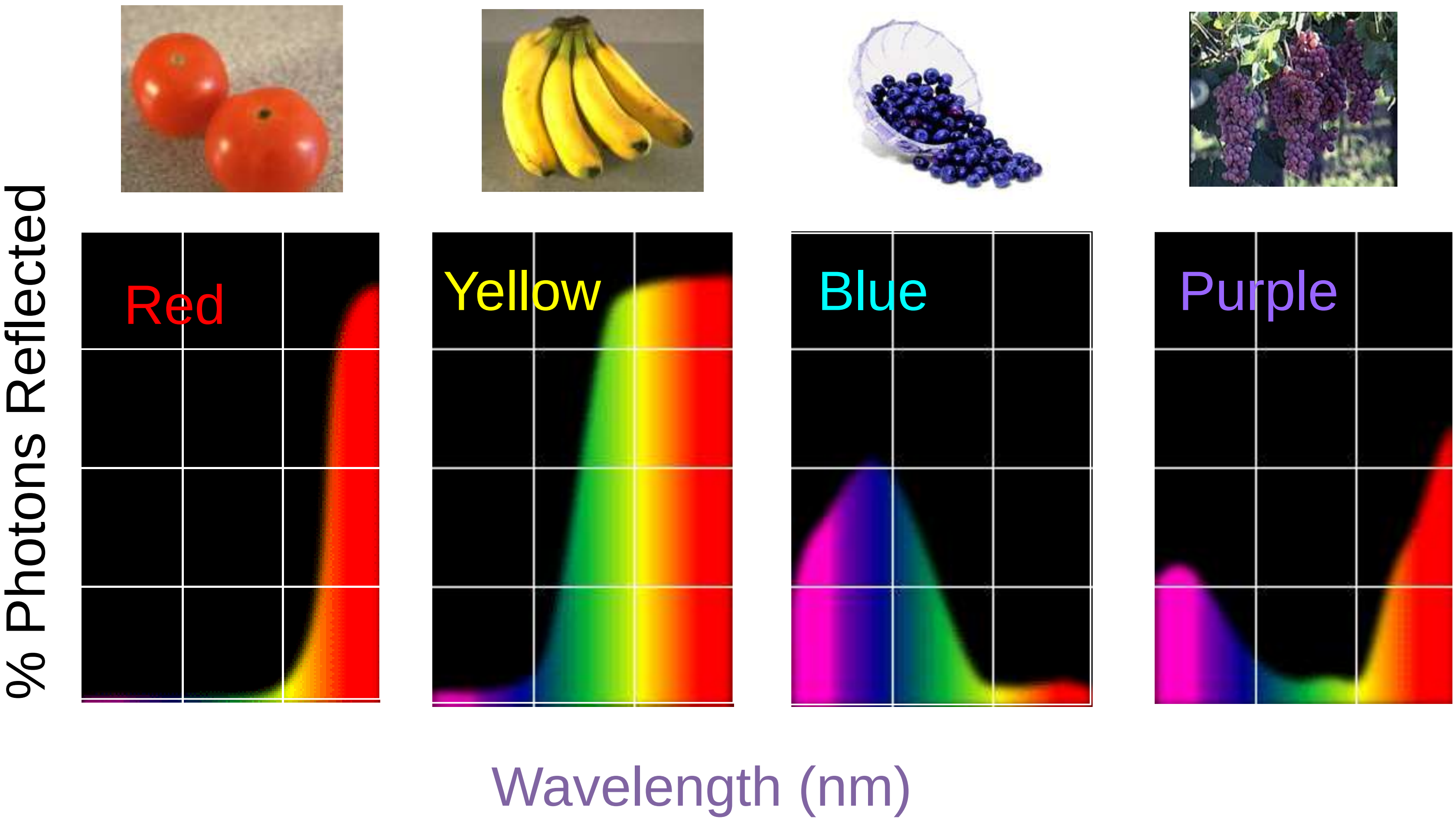
spectrophotometer

Reflectance curve

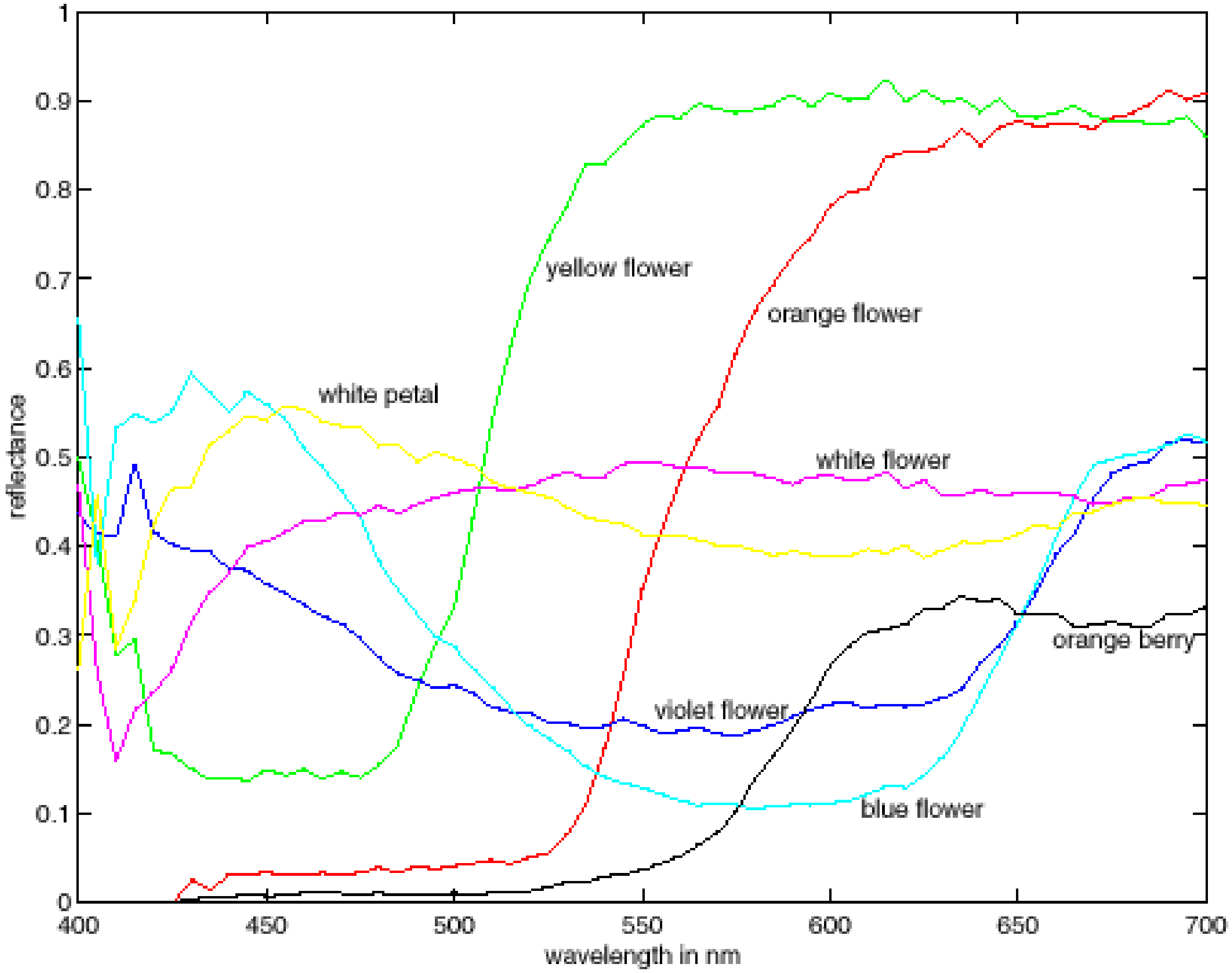


Object Colours

Some examples of the reflectance spectra of surfaces



More Spectra

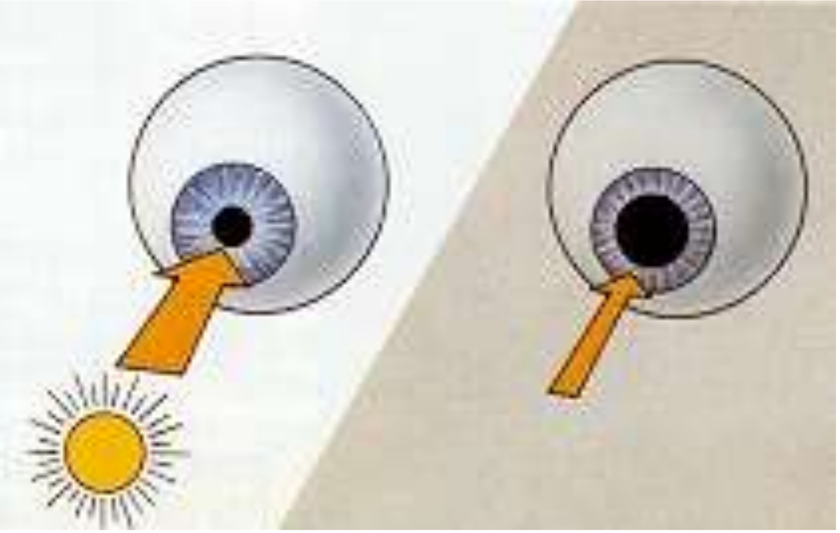


Observer

Eyes: rods and cones

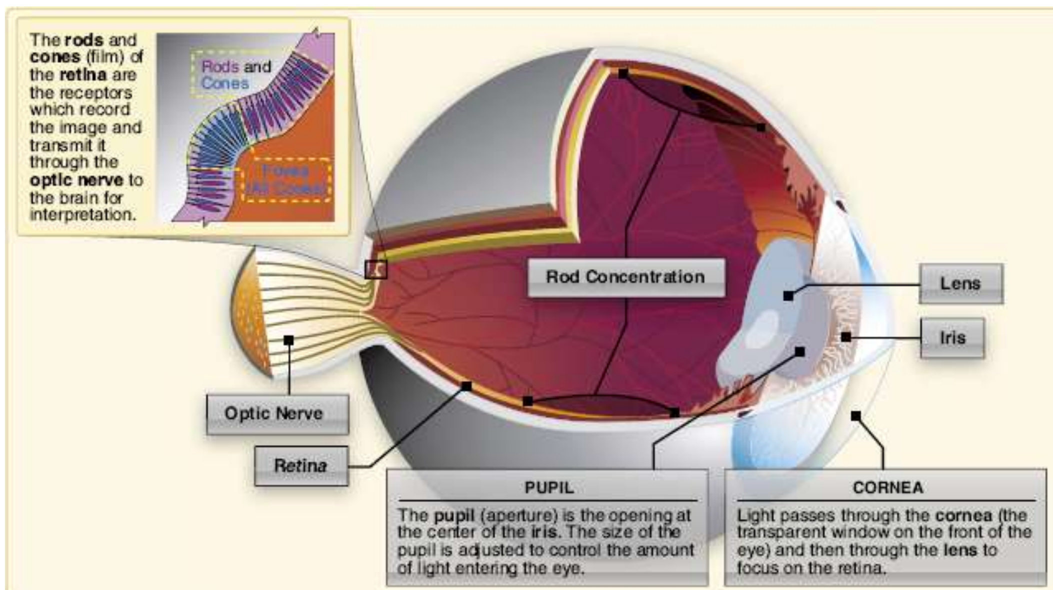
Theories:

- Tri-chromacy theory
- Opponent theory
- Retinex theory



Human Eye

- Retina contains light sensitive cells that convert light energy into electrical impulses that travel through nerves to the brain.
- Brain interprets the electrical signals to form images.



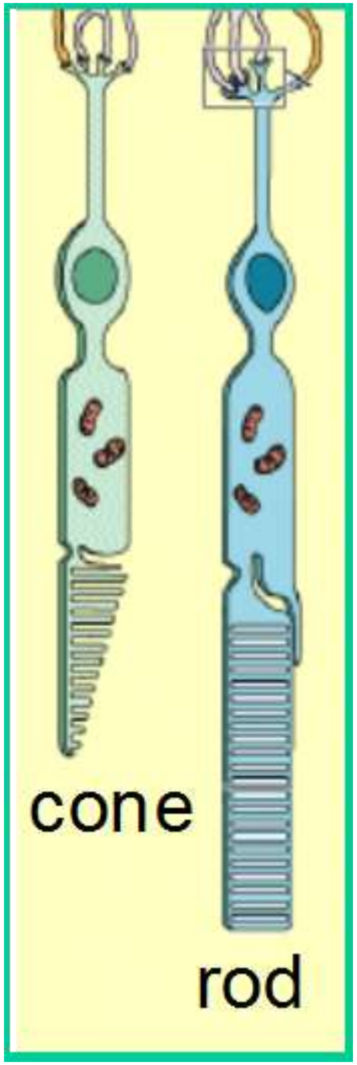
Two Types of Light-Sensitive Receptors

Cones

cone-shaped
less sensitive
operate in high light
color vision

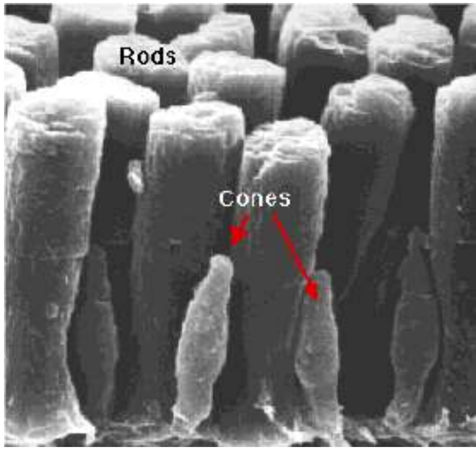
Rods

rod-shaped
highly sensitive
operate at night
gray-scale vision



Slide source: James Hays

Light Detection: Rods and Cones



Rods:

-120 million rods in retina

-1000X more light sensitive than Cones

- Discriminate B/W brightness in low illumination

- Short wave-length sensitive

Cons:

- 6-7 million cones in the retina

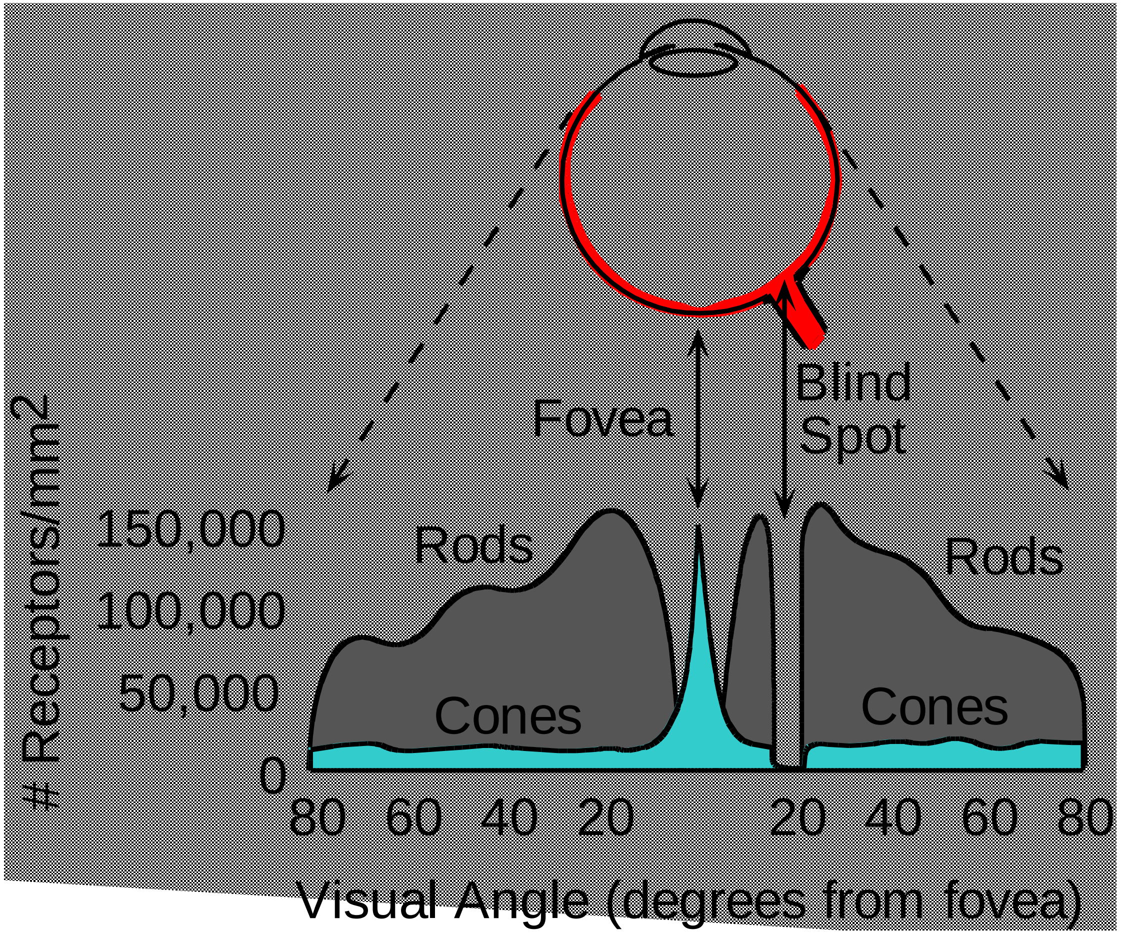
- Responsible for high-resolution vision

- Discriminate Colors

- Three types of color sensors: 64% red, 32% green, 2% blue)

- Sensitive to any combination of three colors

Distribution of Rods and Cones

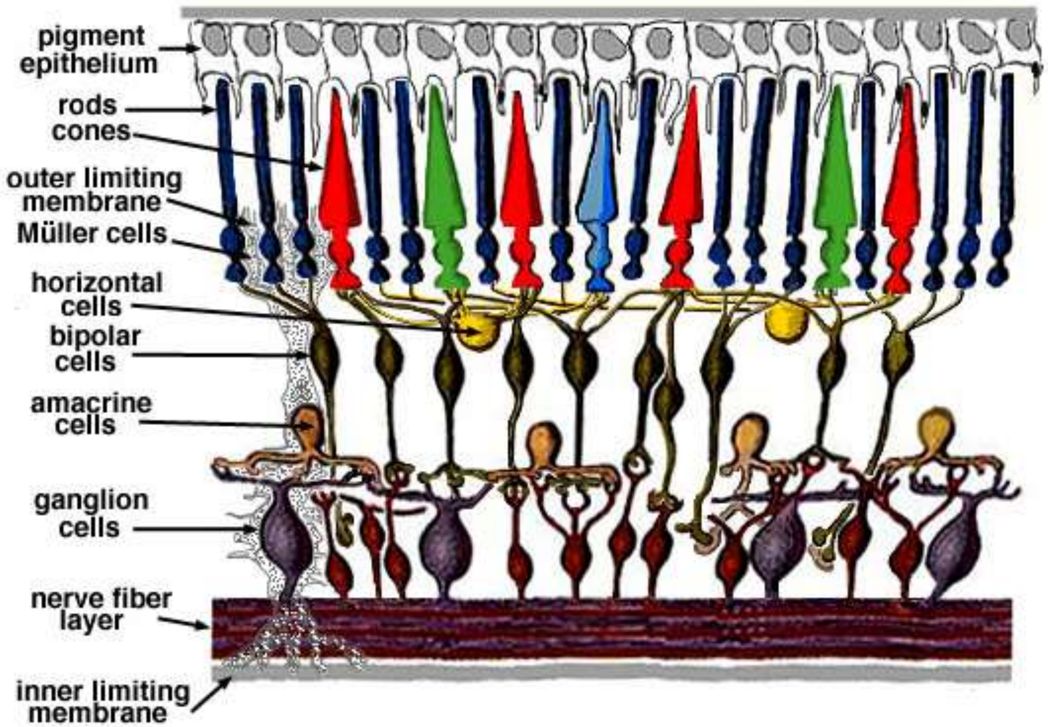


Night Sky: why are there more stars off-center?
Averted vision: http://en.wikipedia.org/wiki/Averted_vision

Slide source: James Hays

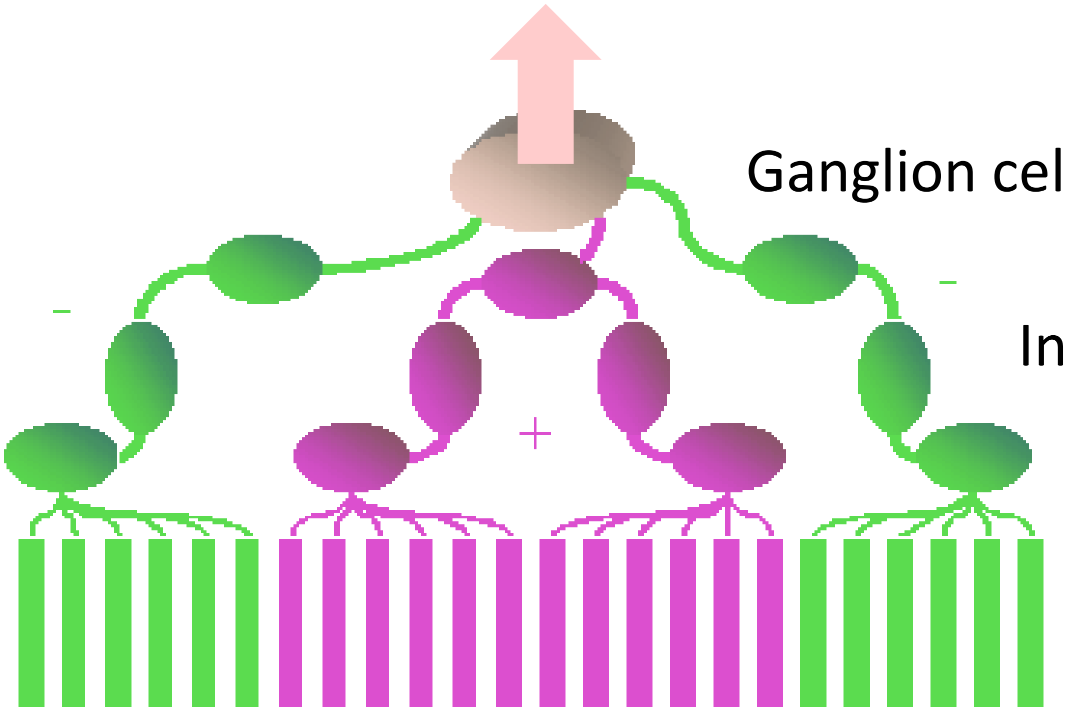
The Retina

- 0.5 mm thick
- The photosensors (the rods and cones) lie outermost in the retina.
- Interneurons
- Ganglion cells (the output neurons of the retina) lie innermost in the retina closest to the lens and front of the eye.

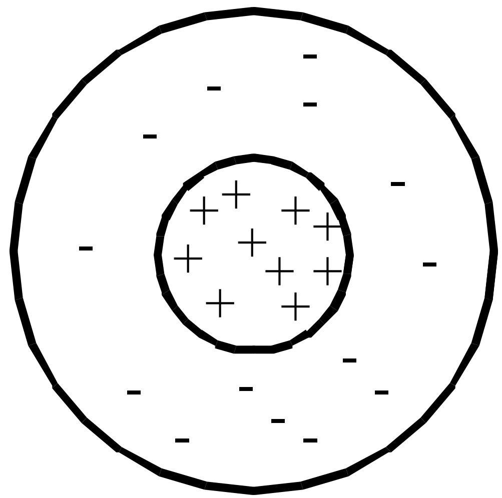


Receptive Fields

The ganglion cell produces some background response even when there is no light on its receptive field



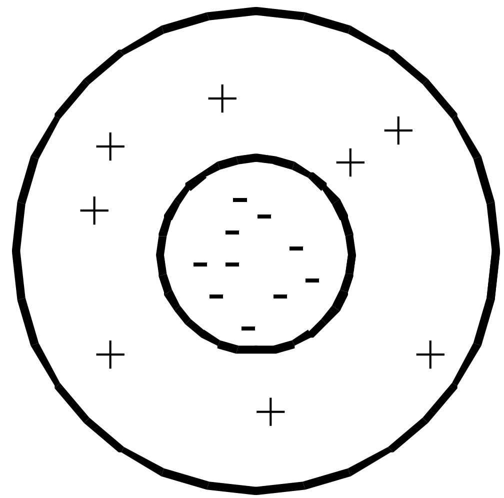
"On-Center" Ganglion Cell



Responds maximally to light increments in the center,

and light decrements in the surround.

“Off-Center” Ganglion Cell



Responds maximally to light decrements in the center,

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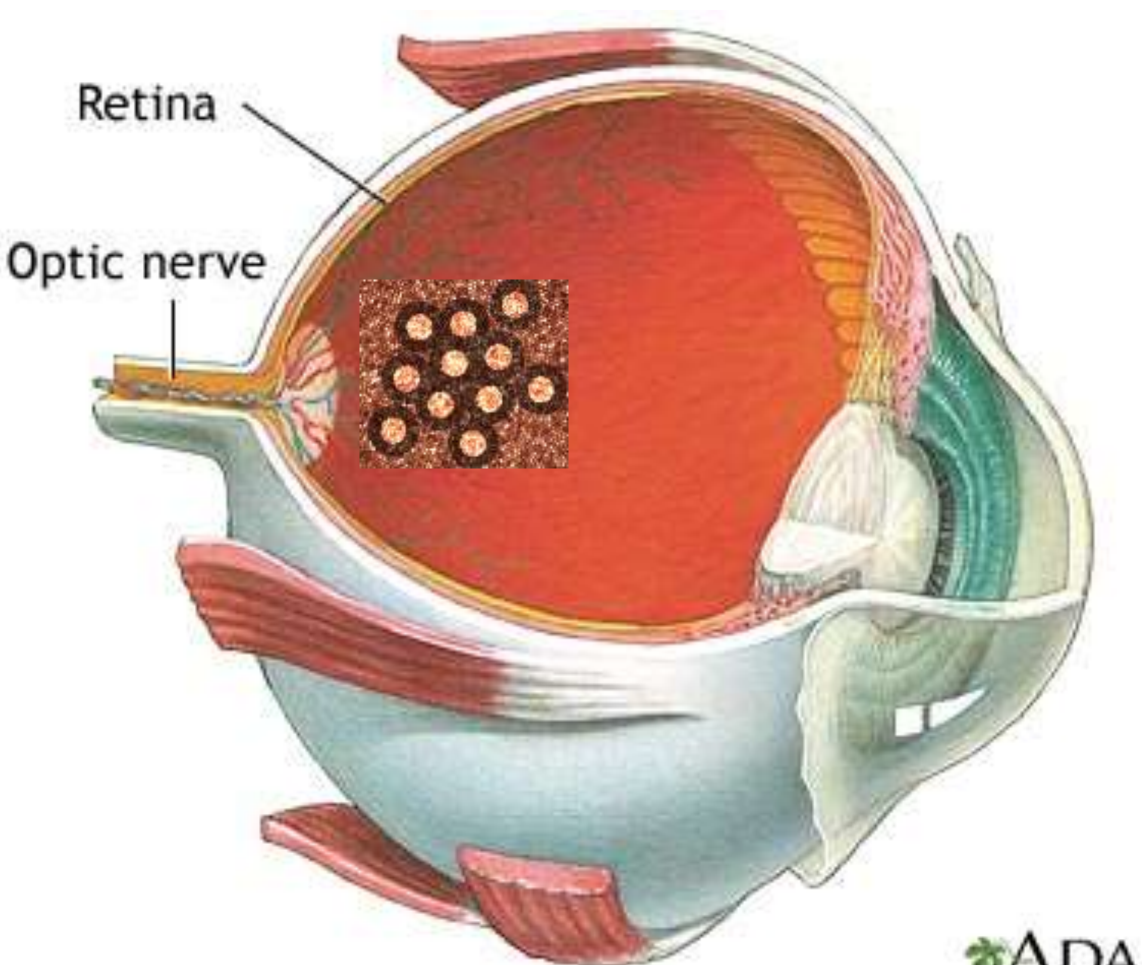
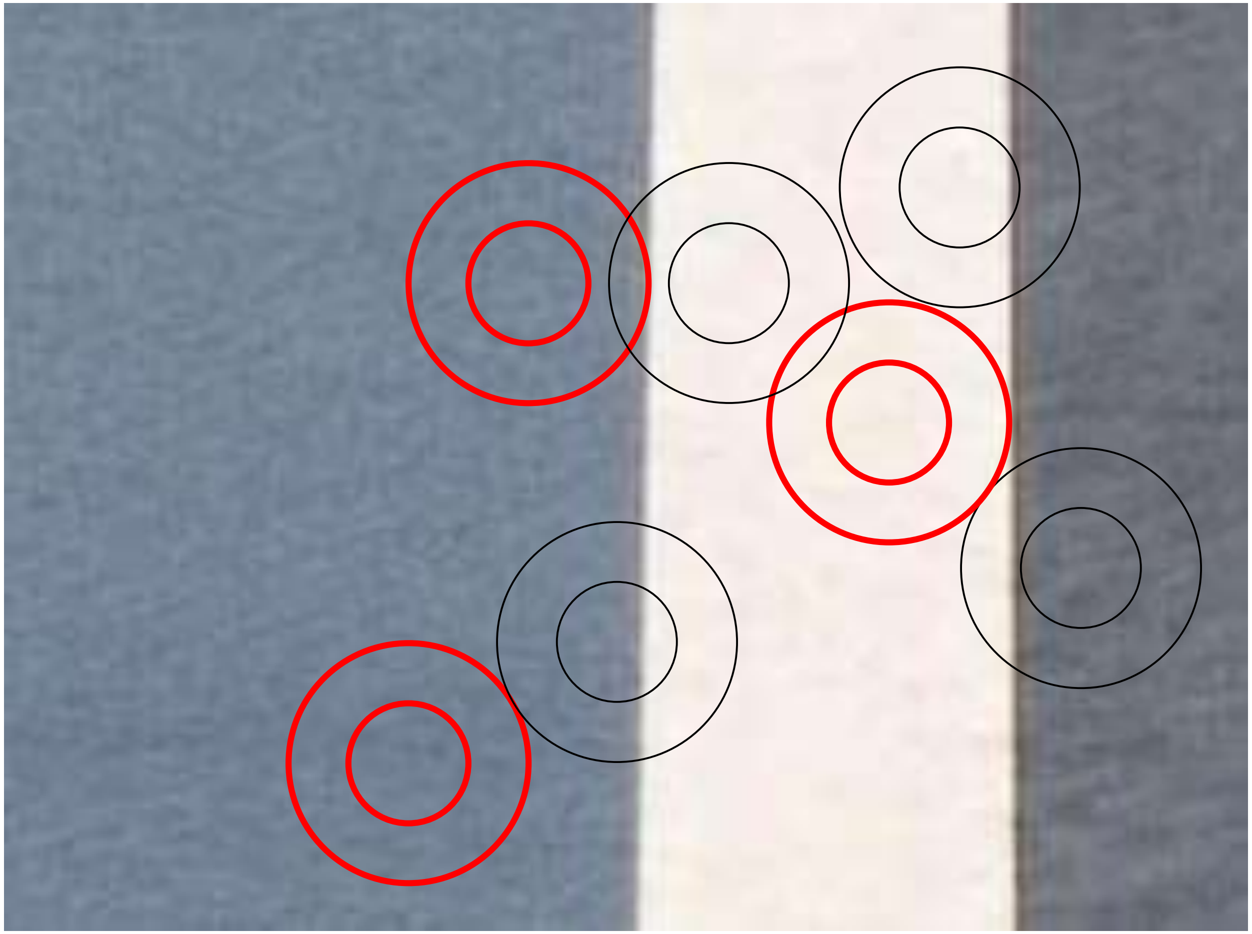
Receptive Fields on the Retina

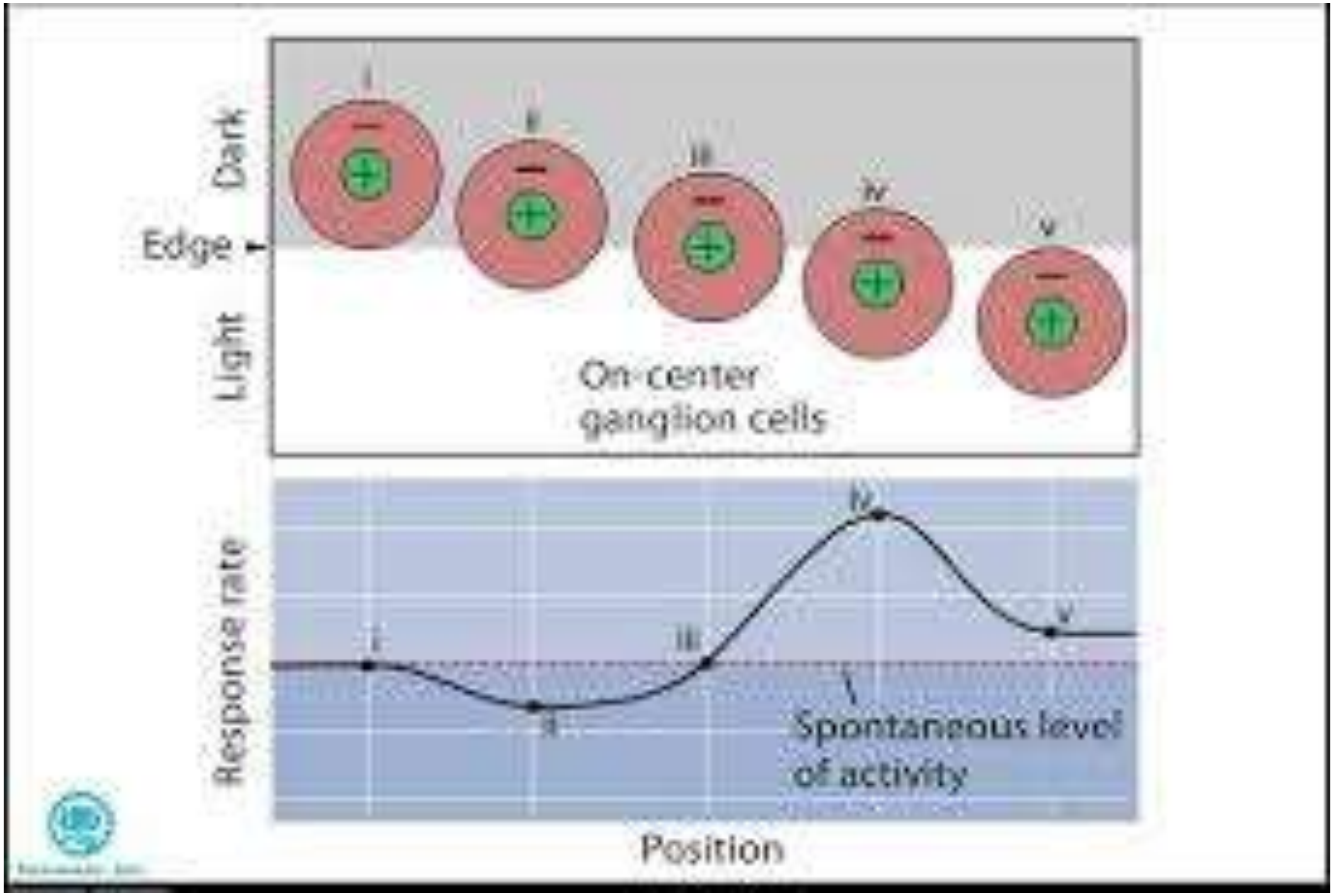


The size of the receptors and the receptive field are shown here much larger than actual size!

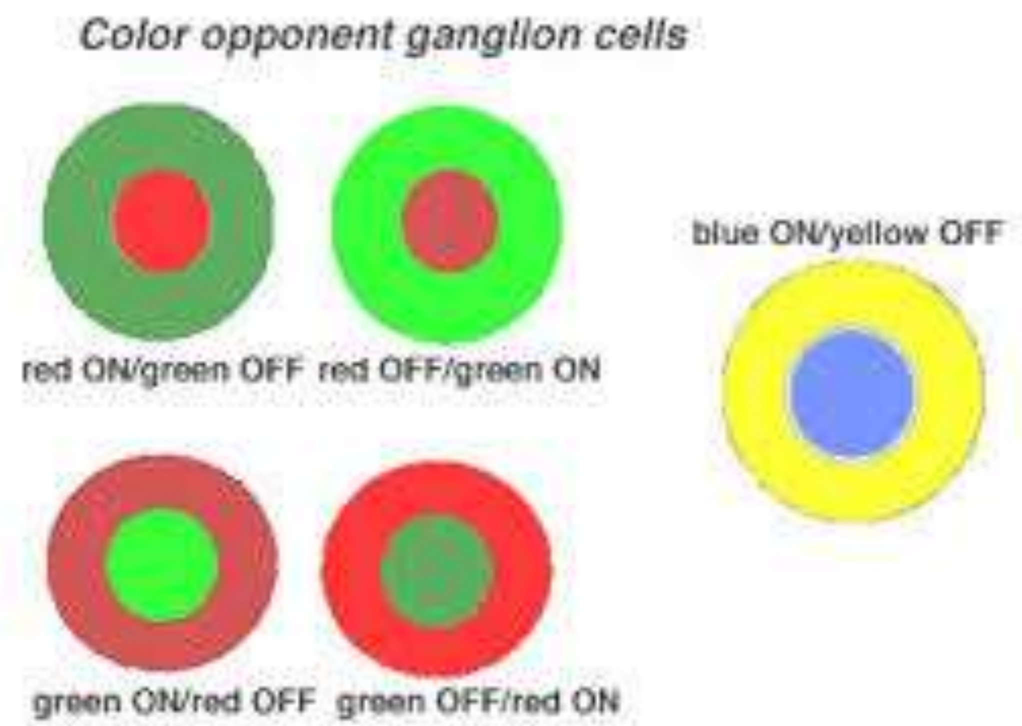
Ganglion Cells: Receptive Fields



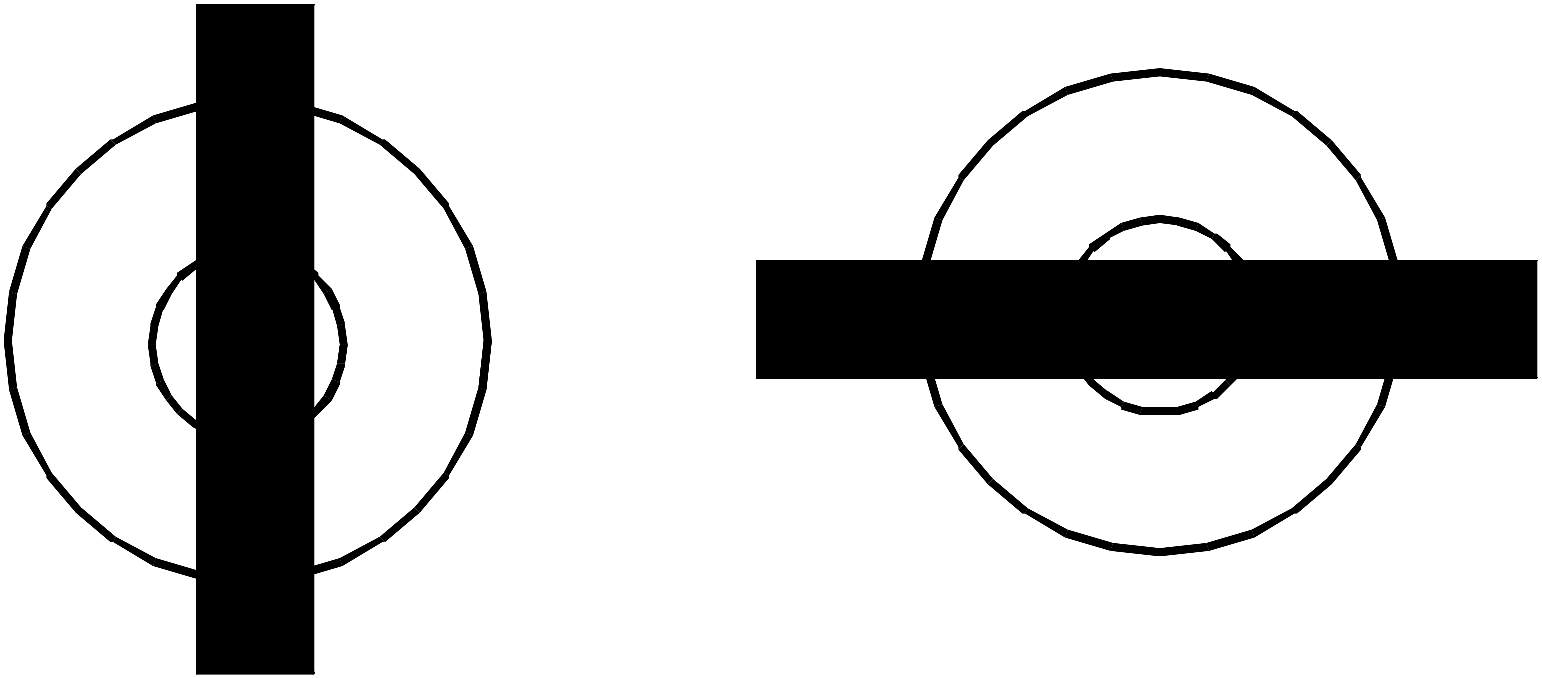
Responses: ON-Centre Ganglion Cells



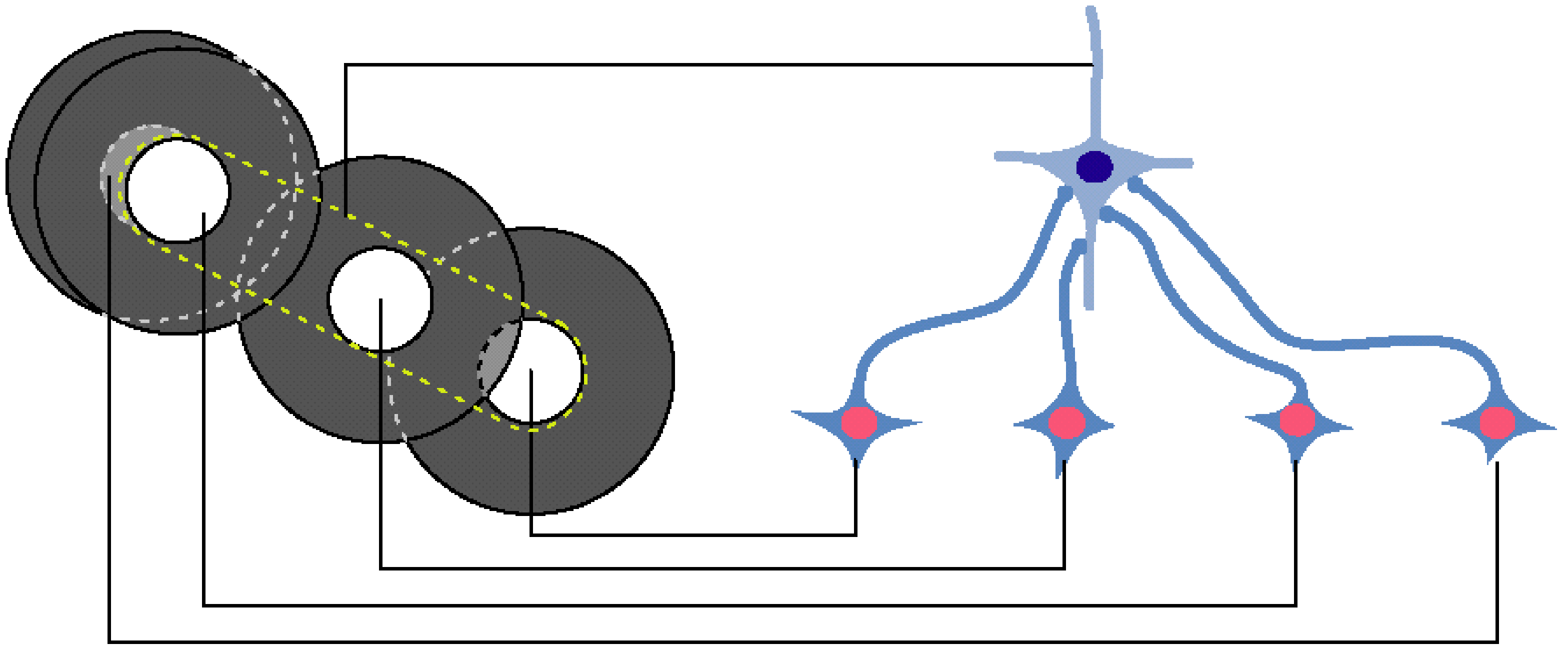
Ganglion Cells: Receptive Fields / Opponent Colors



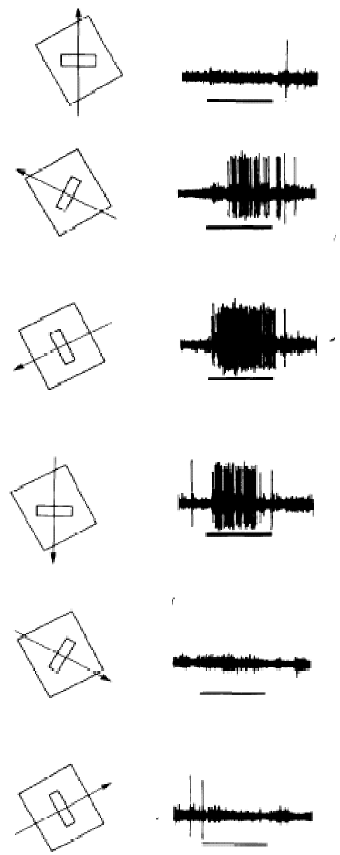
Ganglion cells have no orientation preference.



Model of how center-surround cells can be building blocks for simple cells.



Model of how center-surround cells can be building blocks for simple cells.



Retinal ganglion cells respond to edges

Input image
(cornea)

"Neural image"
(retinal ganglion cells)

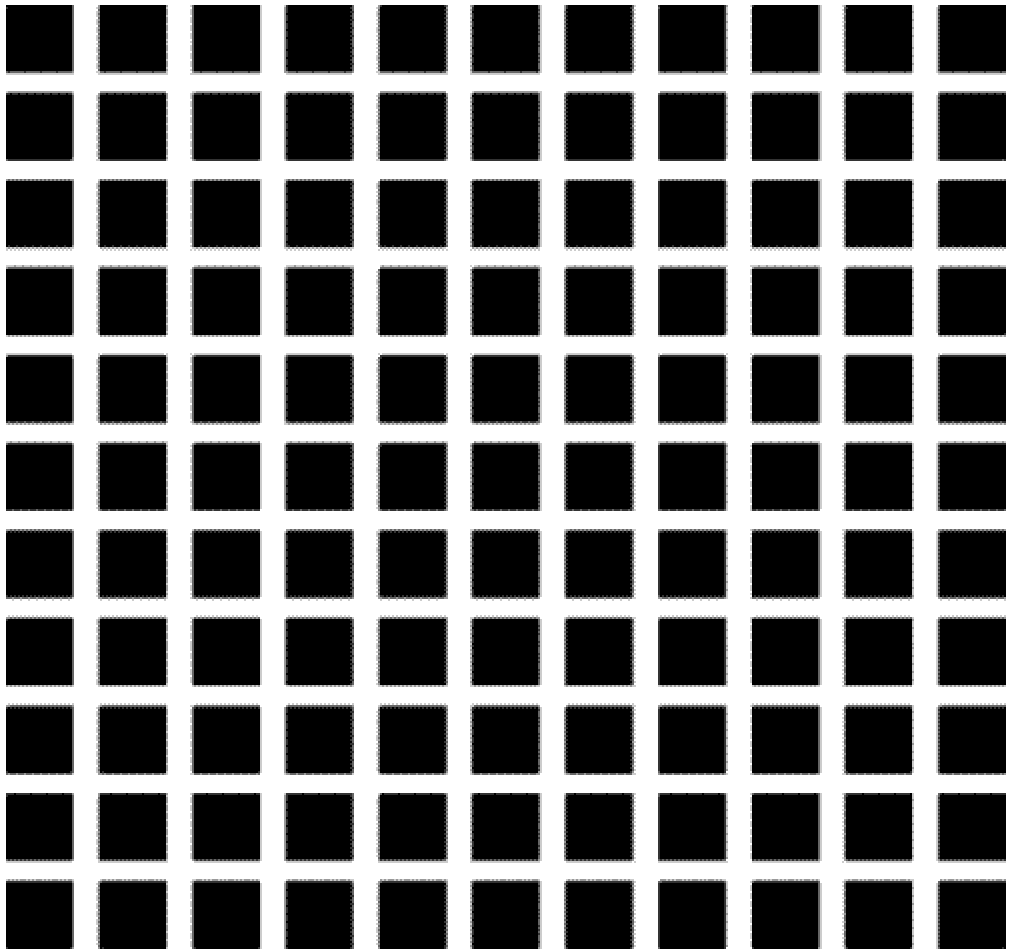
Center-surround receptive fields: emphasize edges.

Deep Learning

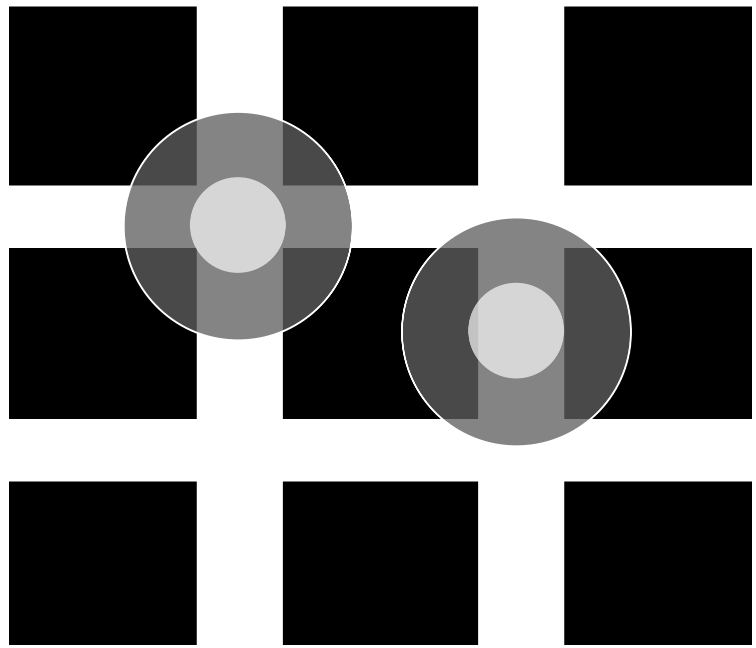
(Source: NVIDIA)

Receptive Fields

Hermann Grid Illusion



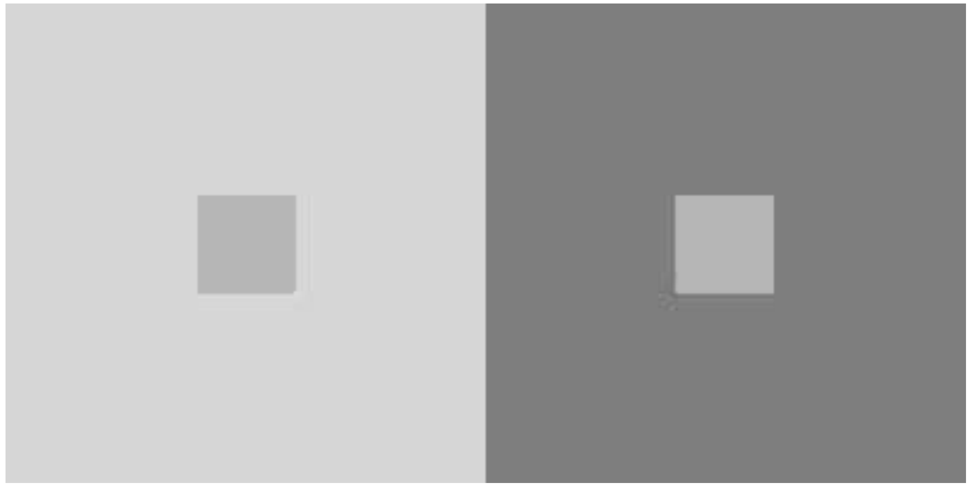
Hermann Grid Illusion: Explanation



When the image is on the first receptive field there is more light falling on the surround (inhibitory) than in the second position

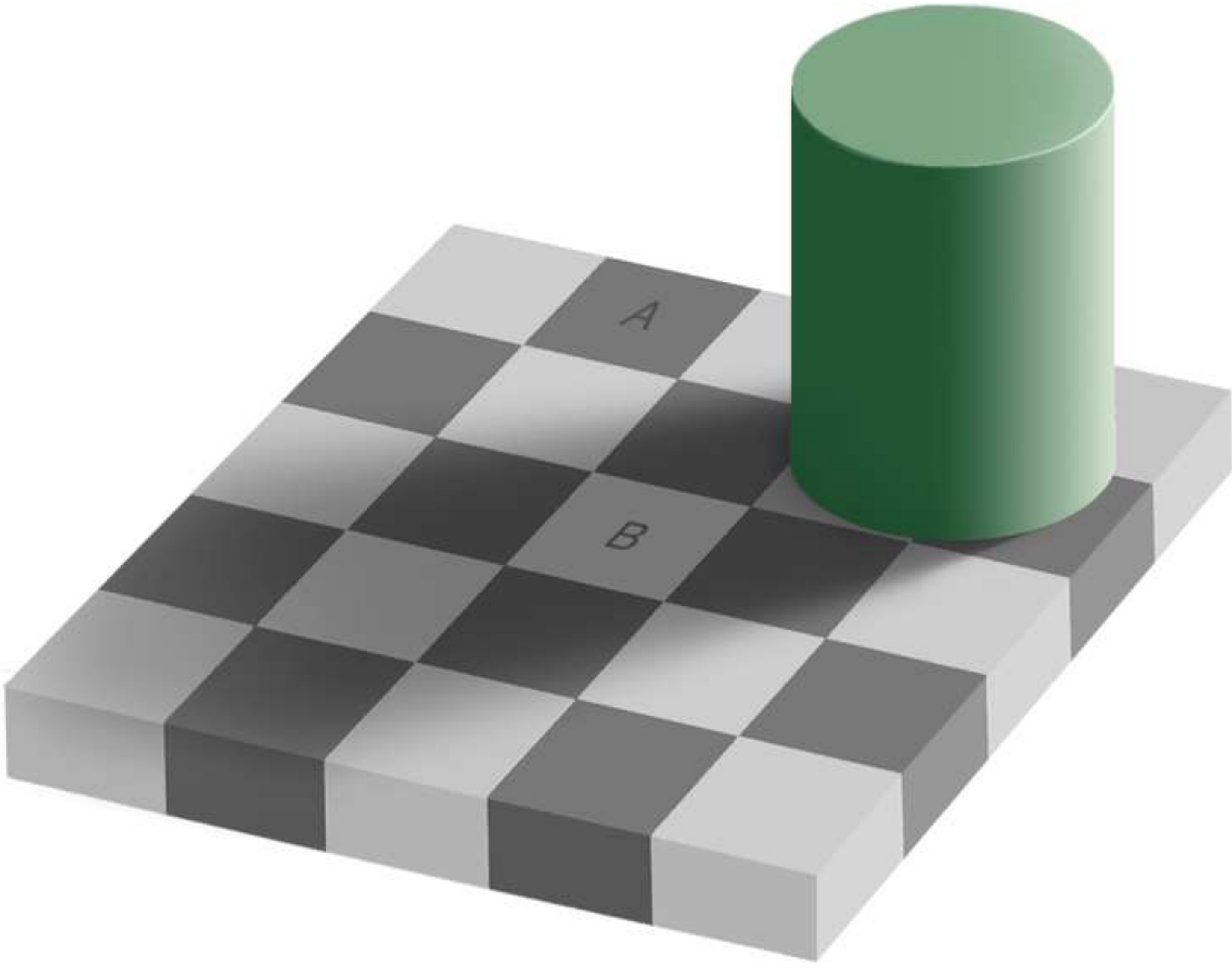
So there is more suppression and the illusion of a dark spot at the first location

Simultaneous Lightness Contrast



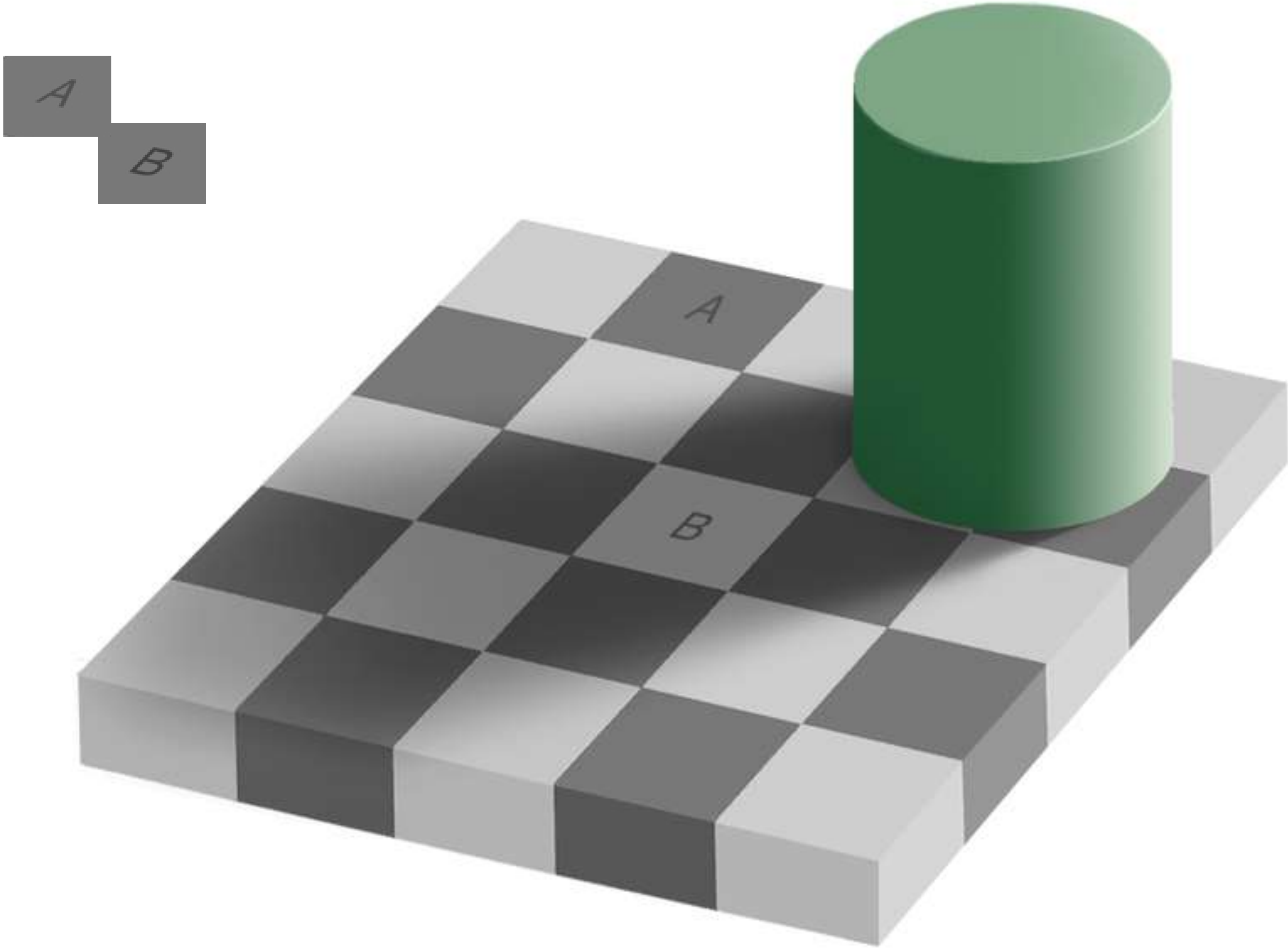
- Occurs when the lightness of an area is influenced by neighboring regions
- Our perception of lightness is not objective, but depends on the surrounding area
- The center square on the right looks lighter because the surrounding area is a darker gray

Perception of Intensity



from Ted Adelson

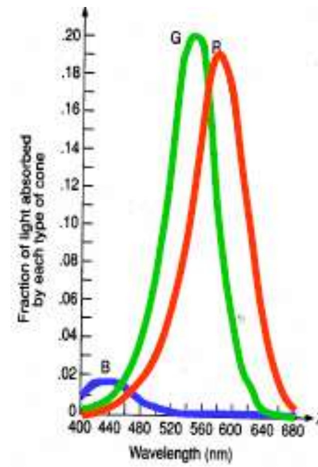
Perception of Intensity



from Ted Adelson

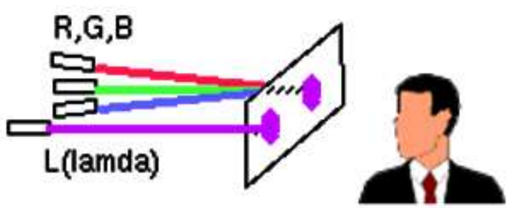
Tristimulus of Color Theory

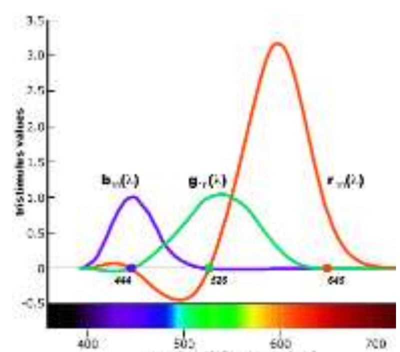
Spectral-response functions of each of the three types of cones



Color matching function based on RGB

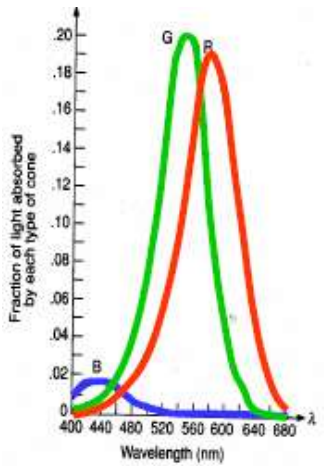
- any spectral color can be represented as a linear combination of these primary colors





Tristimulus of Color Theory

Spectral-response functions of each of the three types of cones



Color matching function based on RGB

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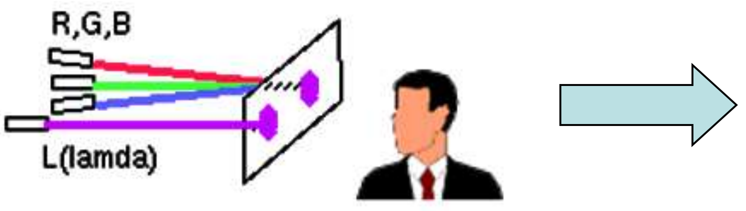
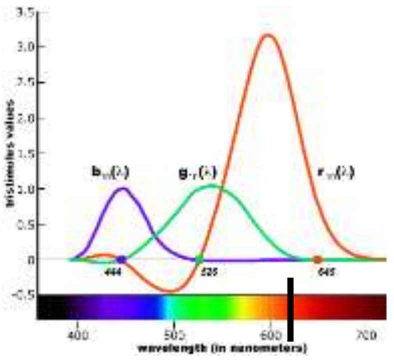
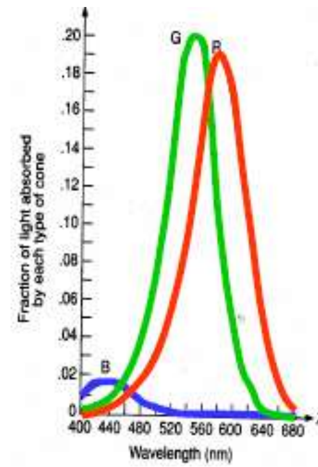




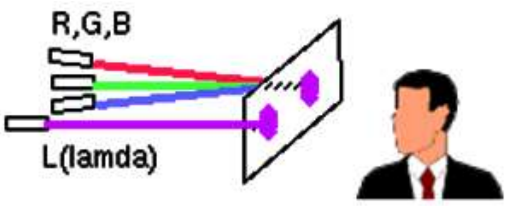
Tristimulus of Color Theory

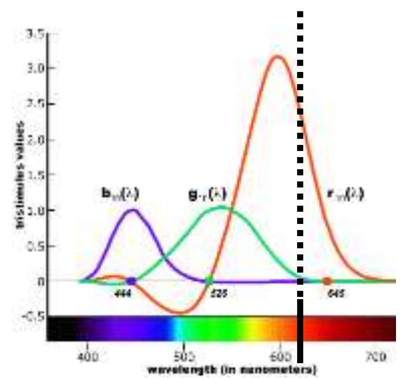
Spectral-response functions of each of the three types of cones



Color matching function based on RGB

- any spectral color can be represented as a linear combination of these primary colors





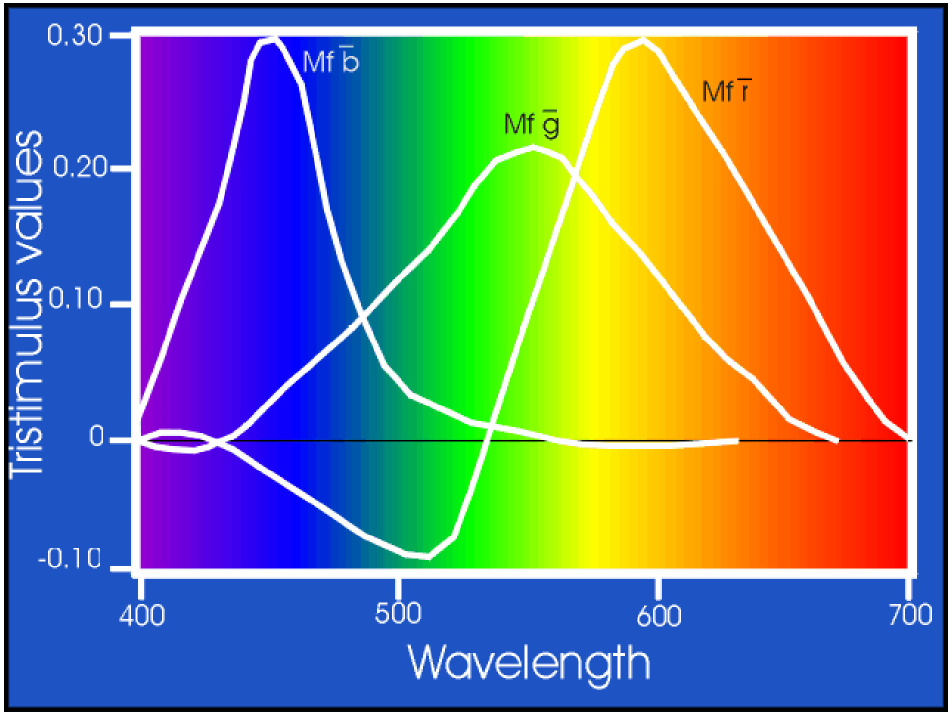
Observer: Trichromacy

Young-Helmholtz approach

Tristimulus values R, G, and B

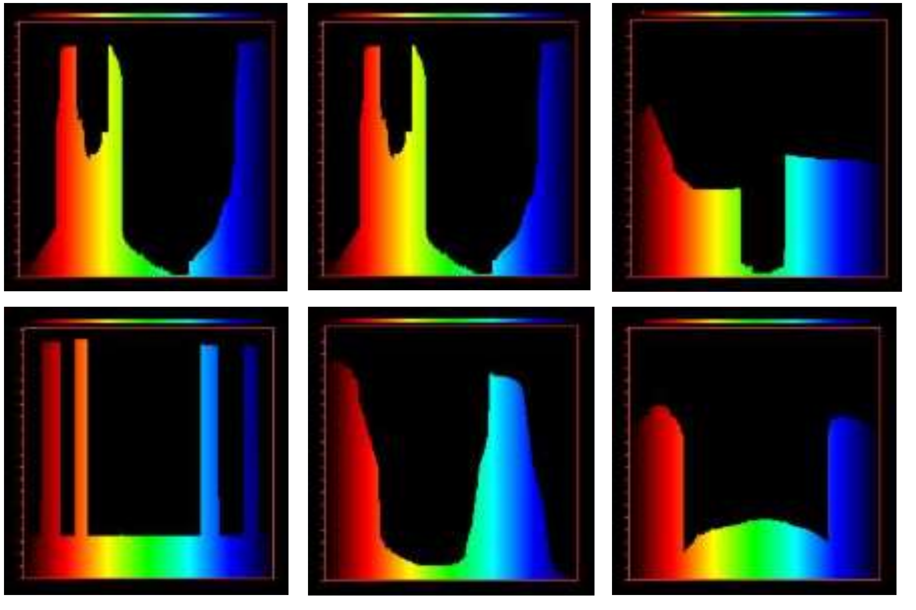
Wright (7) Guild (10)

Stiles and Burch (50)

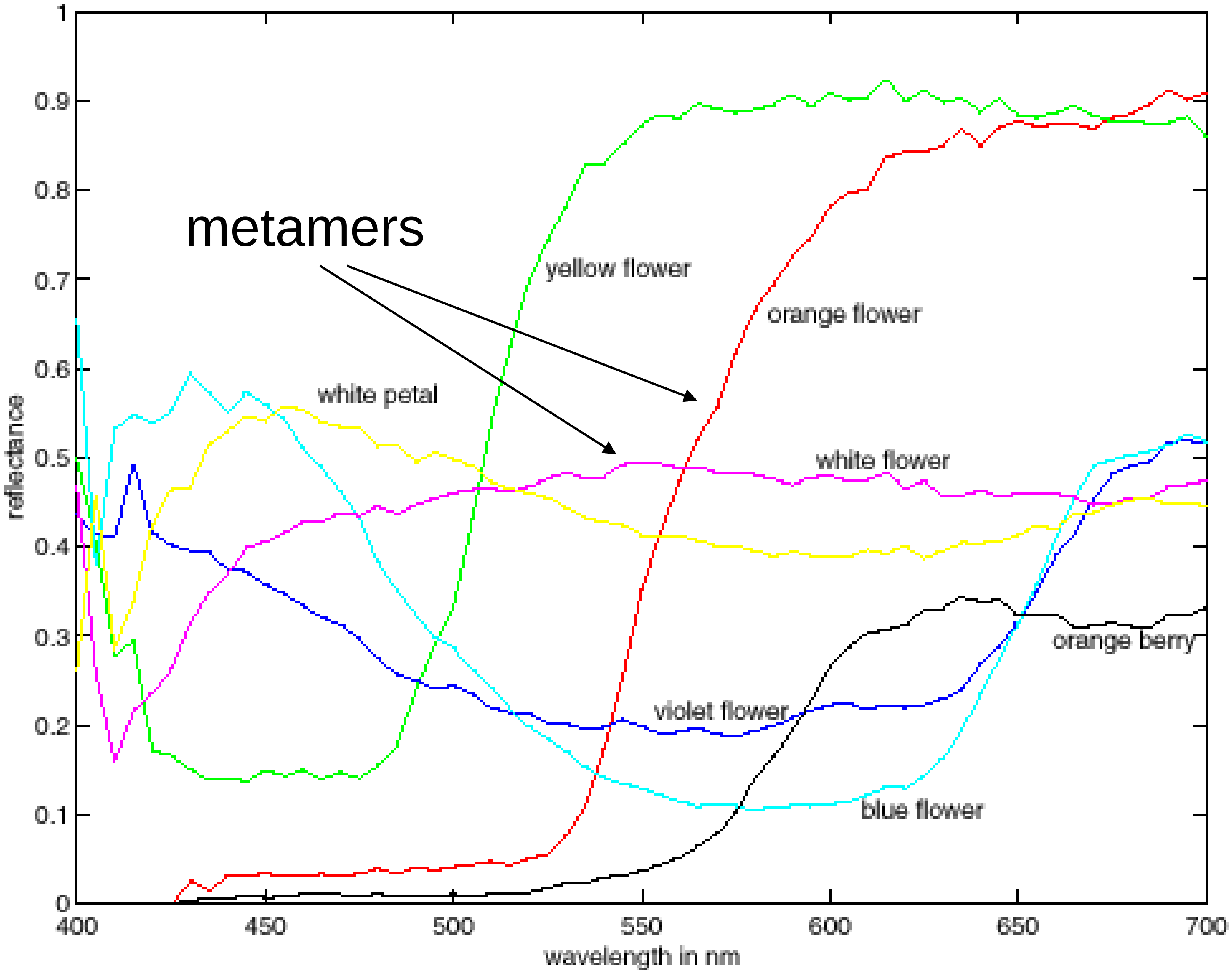


Spectral Energy Distribution

The six spectra below look the same purple to normal color-vision people

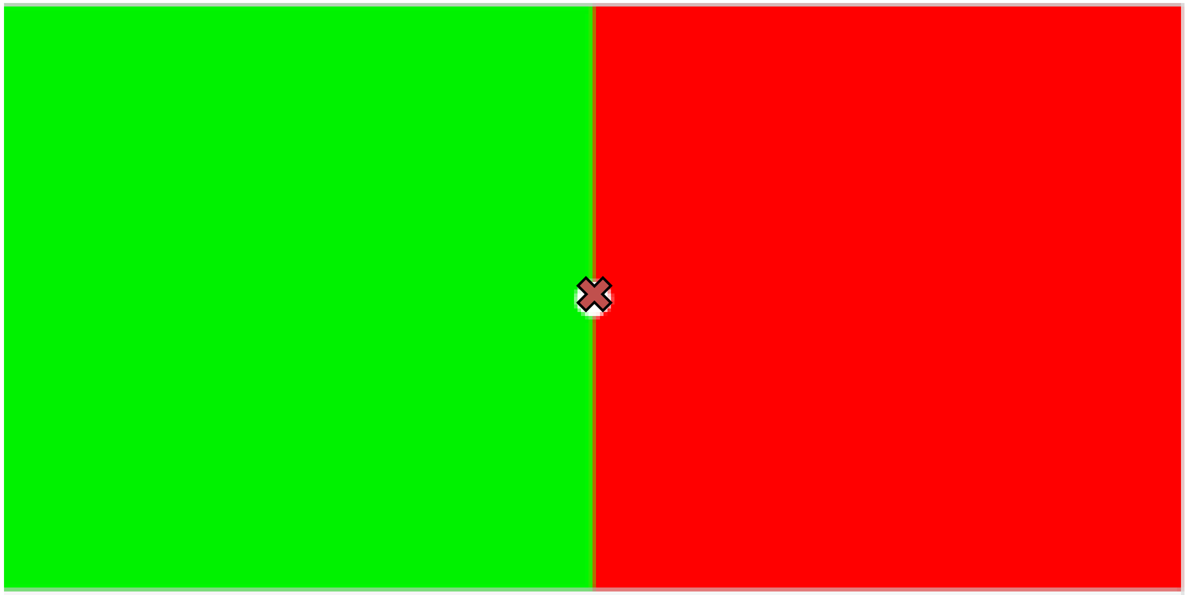


Metamers



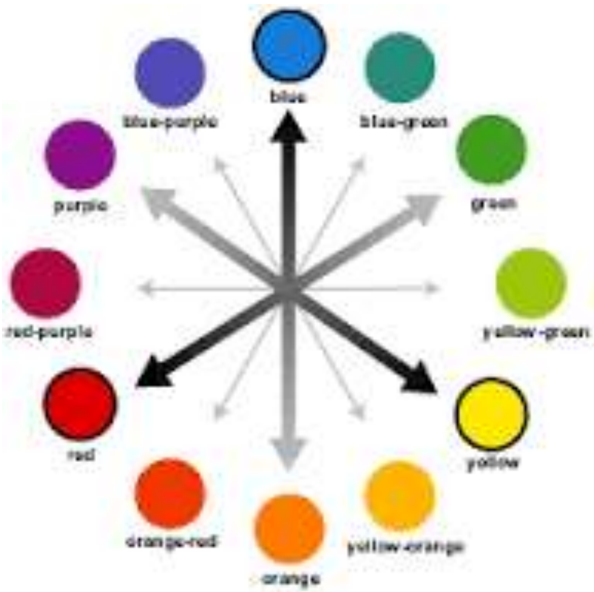
metamers
yellow flower
orange flower
white petal
white flower
orange berry
violet flower
blue flower
reflectance
wavelength in nm
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400
450
500
550
600
650
700

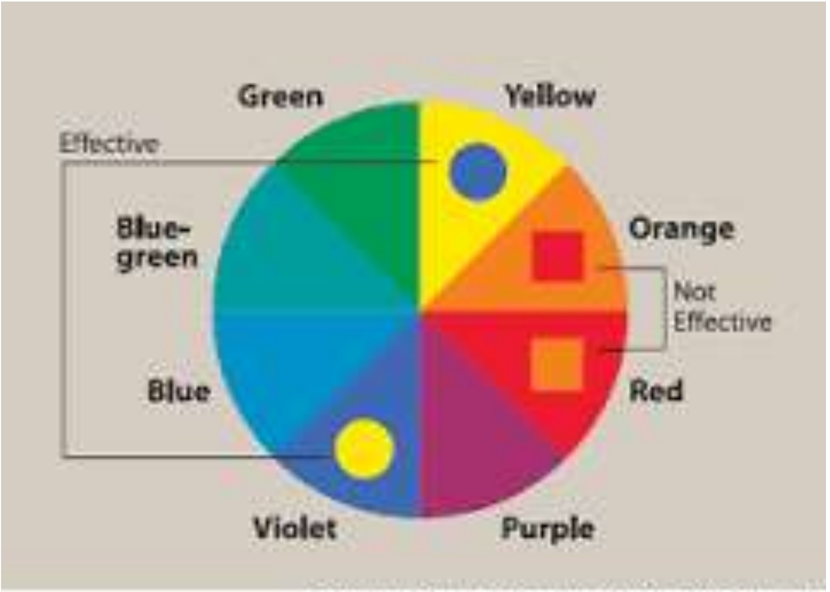
Experiment



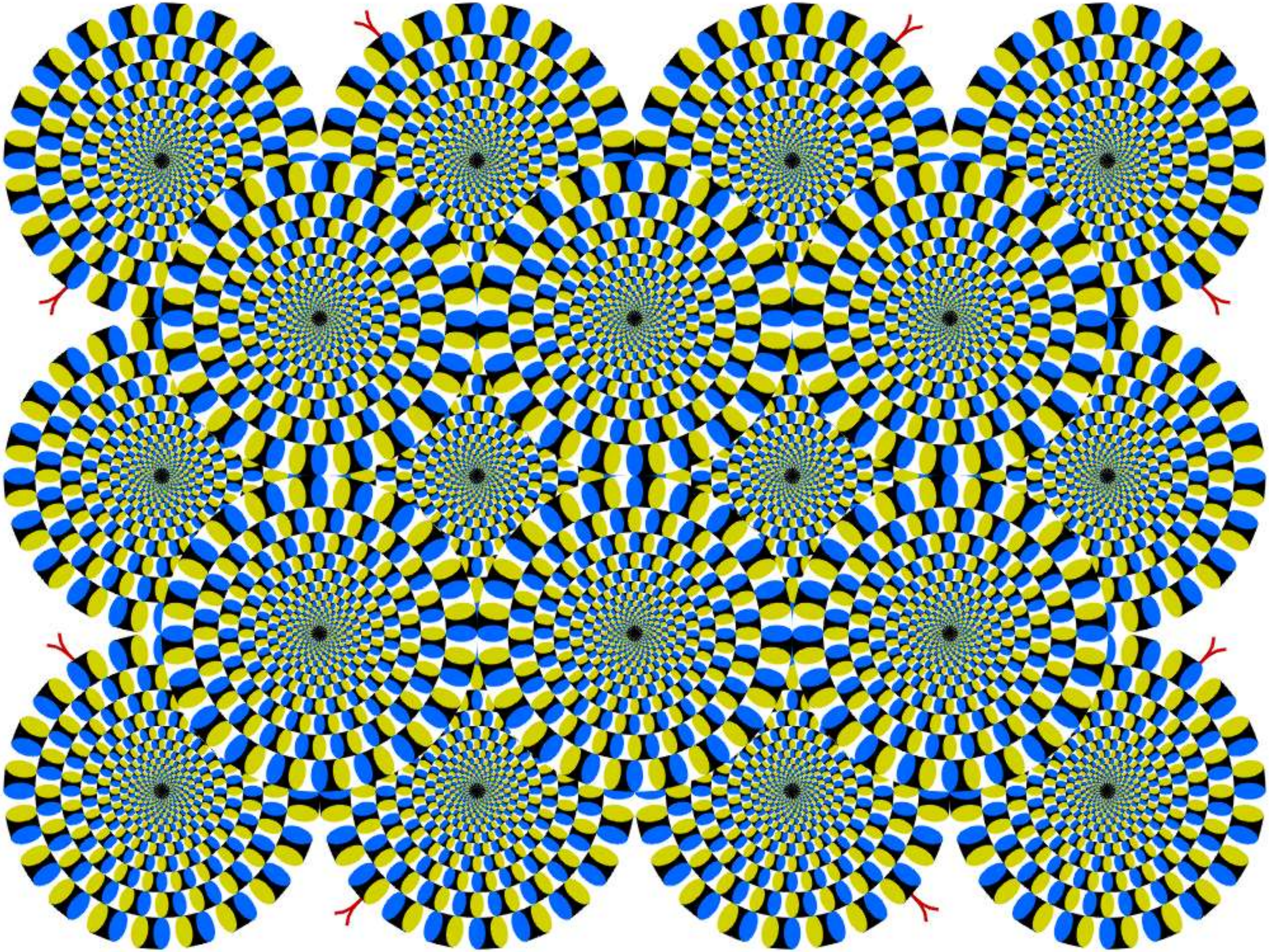
Experiment

Opponent Colors





Van Gogh



Illusions!

http://www.michaelbach.de/

http://www.ritsumei.ac.jp/~akitaoka/index-e.html

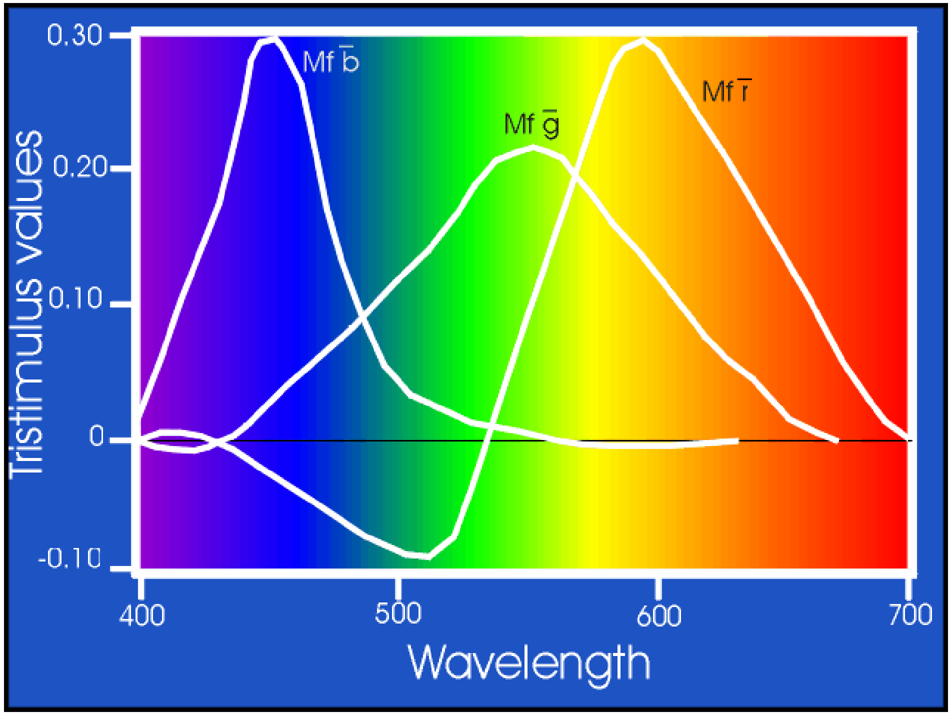
The Eye

Young-Helmholtz approach

Tristimulus values R, G, and B

Wright (7) Guild (10)

Stiles and Burch (50)

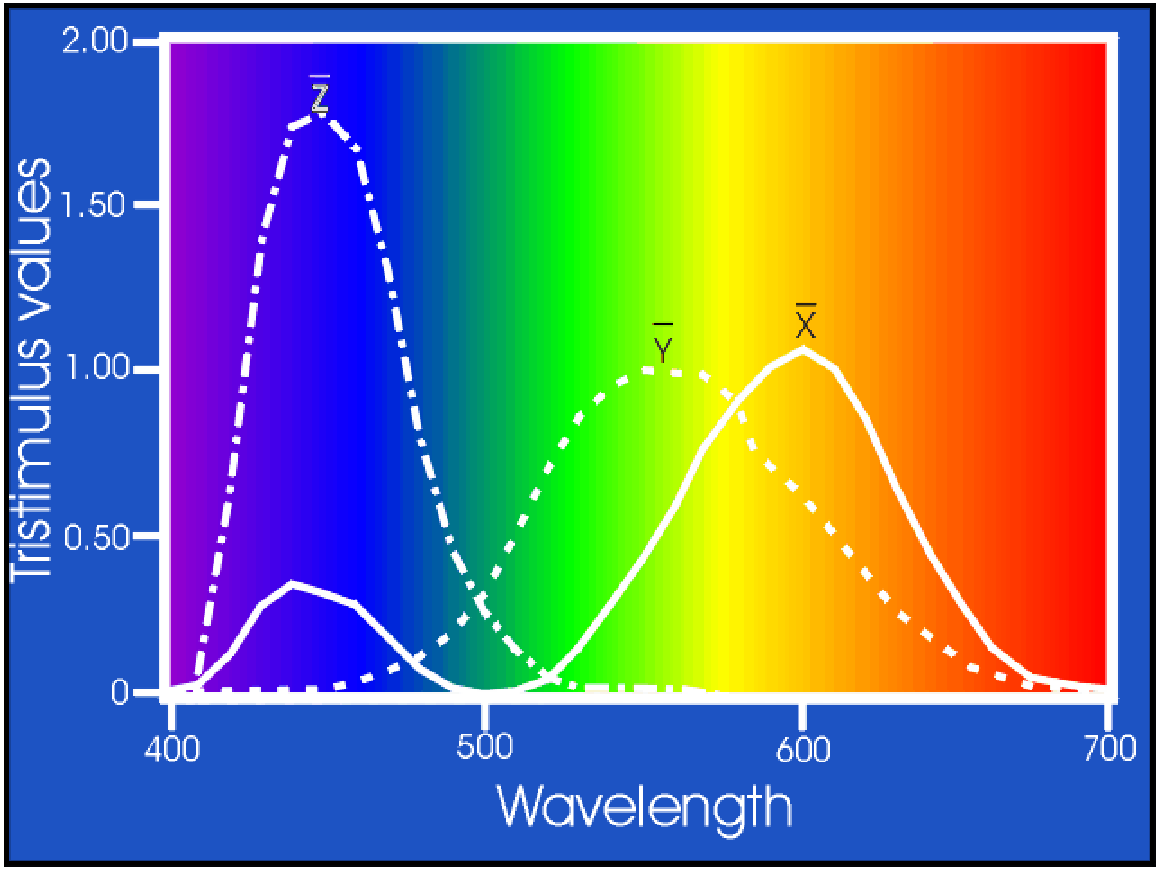


Colorimetry: CIE XYZ-system

$$X = \int_{\lambda} e(\lambda)\rho(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int_{\lambda} e(\lambda)\rho(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int_{\lambda} e(\lambda)\rho(\lambda)\bar{z}(\lambda)d\lambda$$

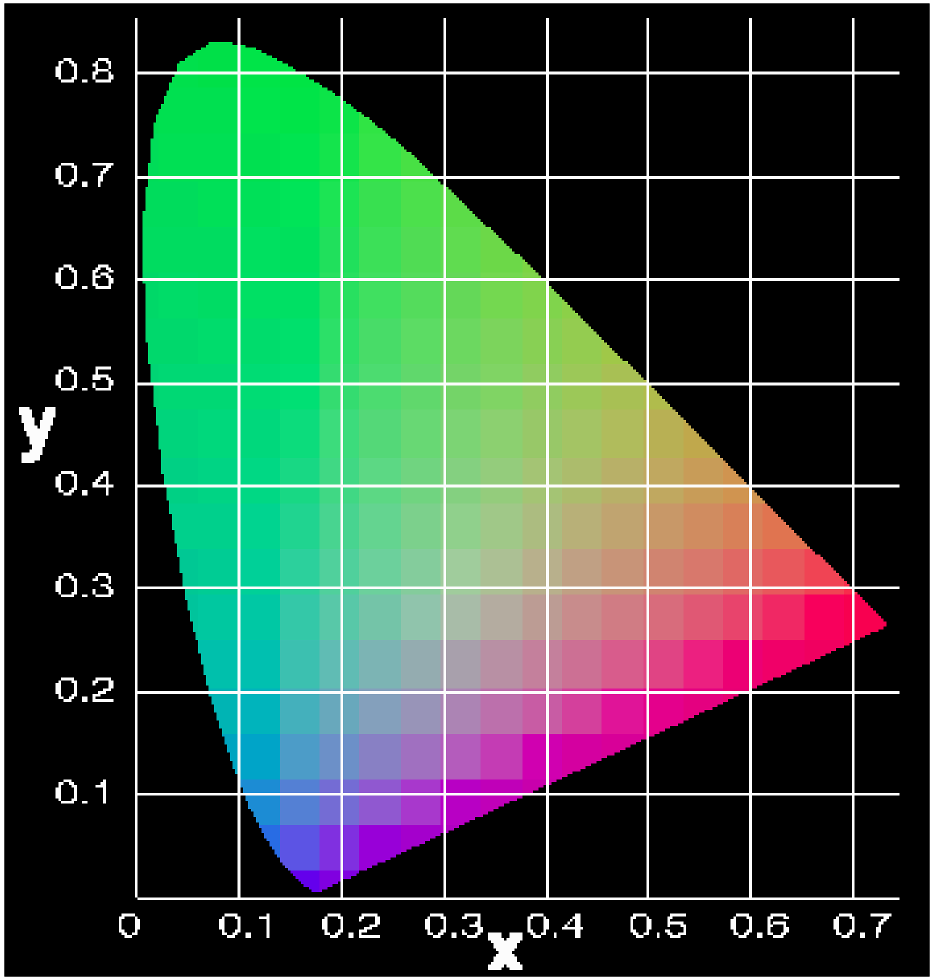


Colorimetry: CIE xy-system

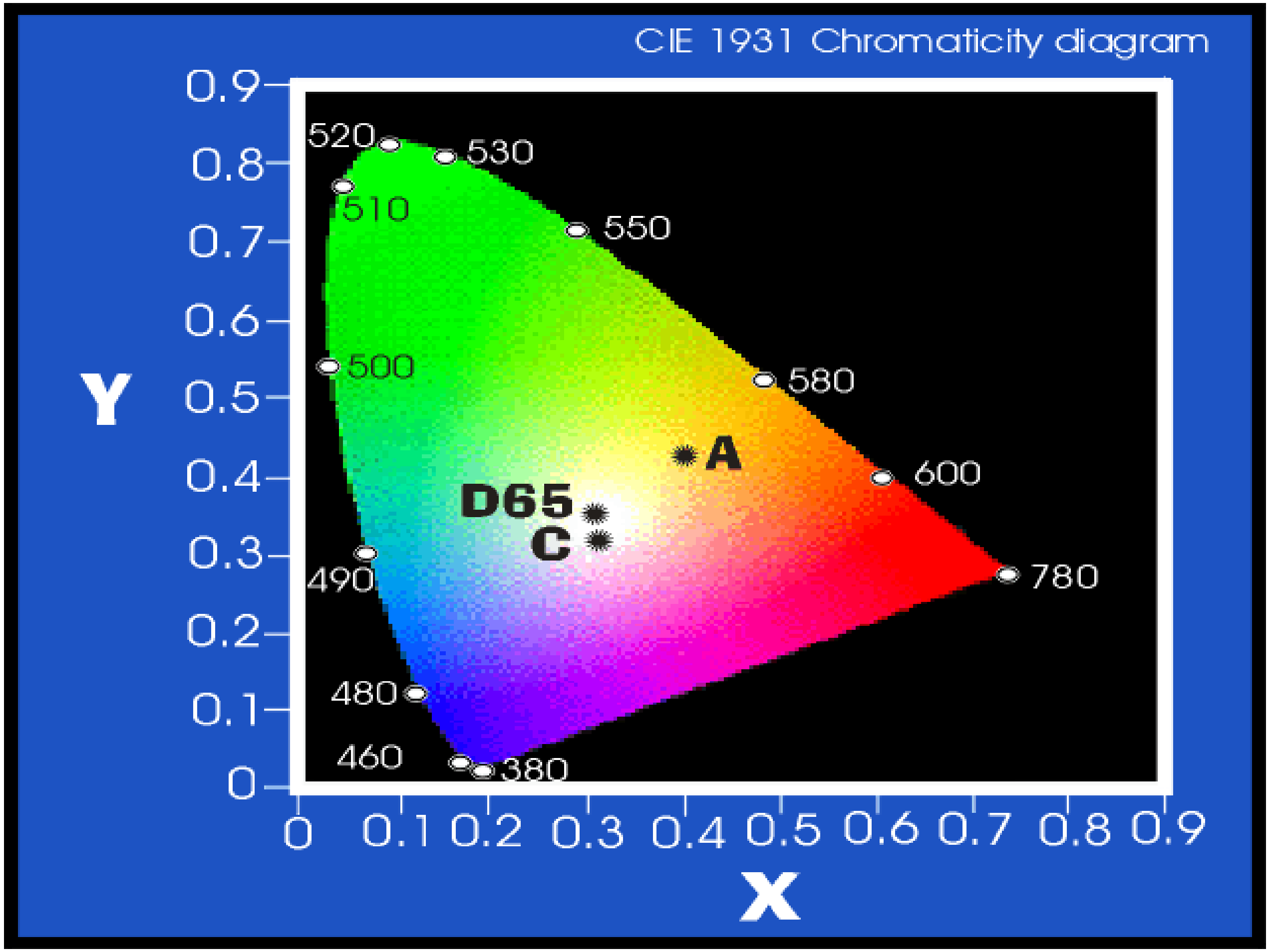
$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z}$$



Colorimetry: Illuminants in the xy-plane



Light Sources and Illuminants

Light sources:

sun, candle,

fluorescent lamp,

incandescent lamp

Illuminants:

illuminant A

illuminant D65

illuminant C

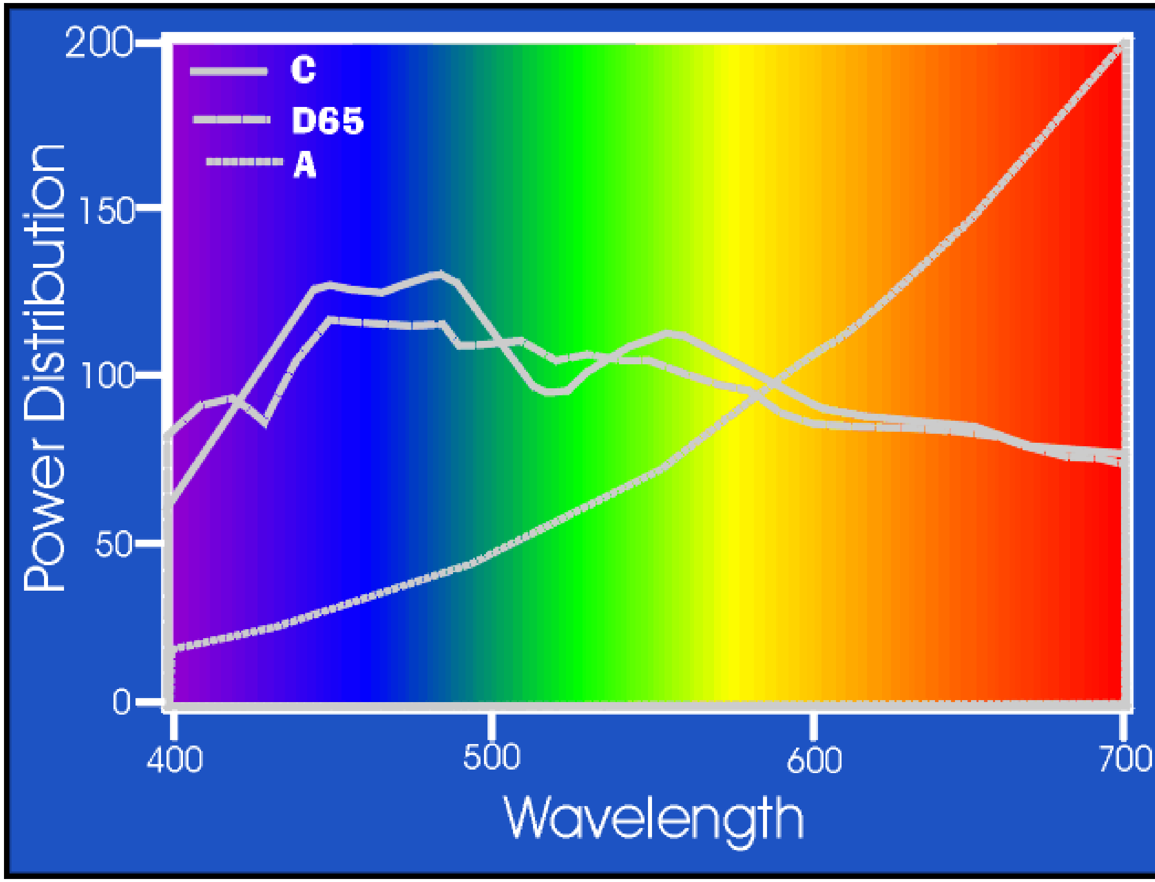
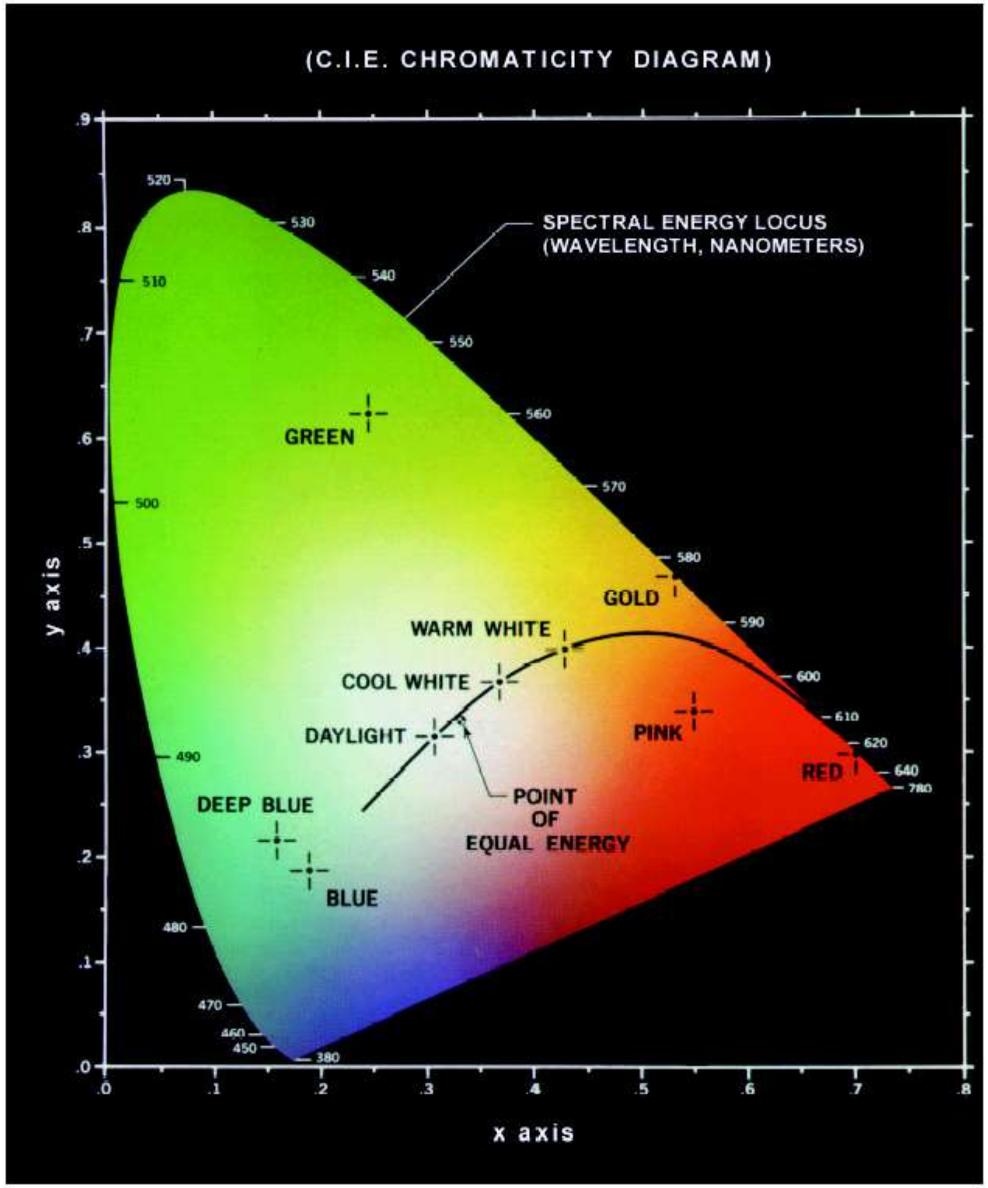
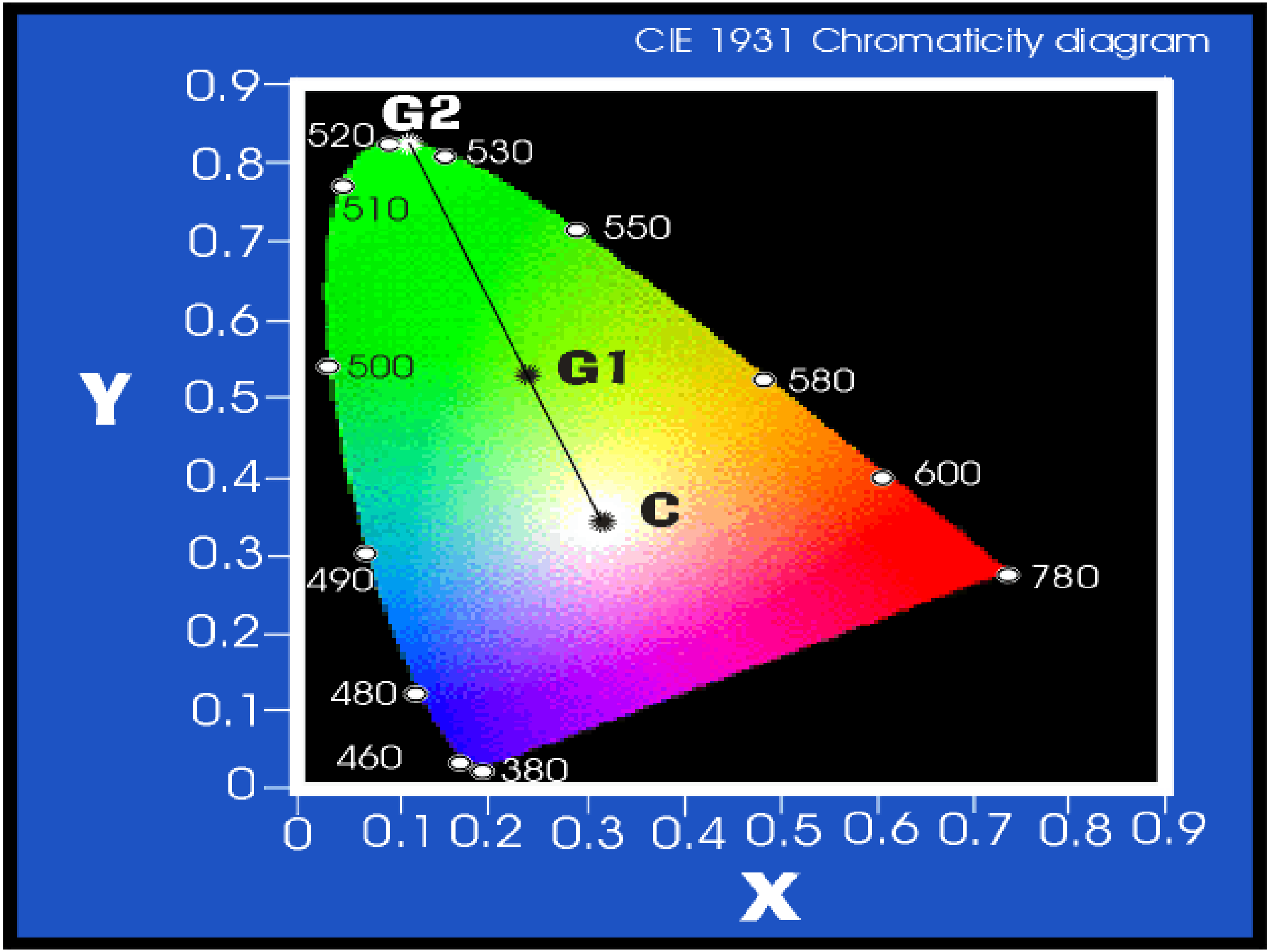


FIGURE 6.5 Chromaticity diagram. (Courtesy of the General Electric Co., Lamp Business Division.)



Colorimetry: HSI in the xy-plane

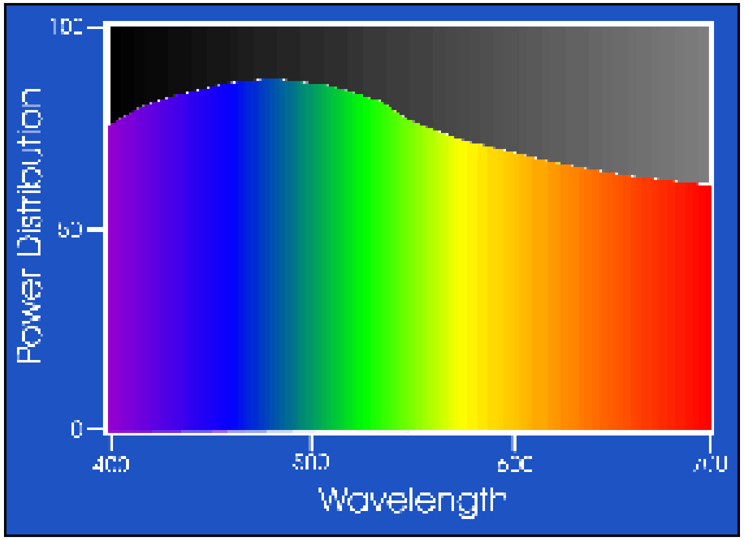


Spectral Power Distribution

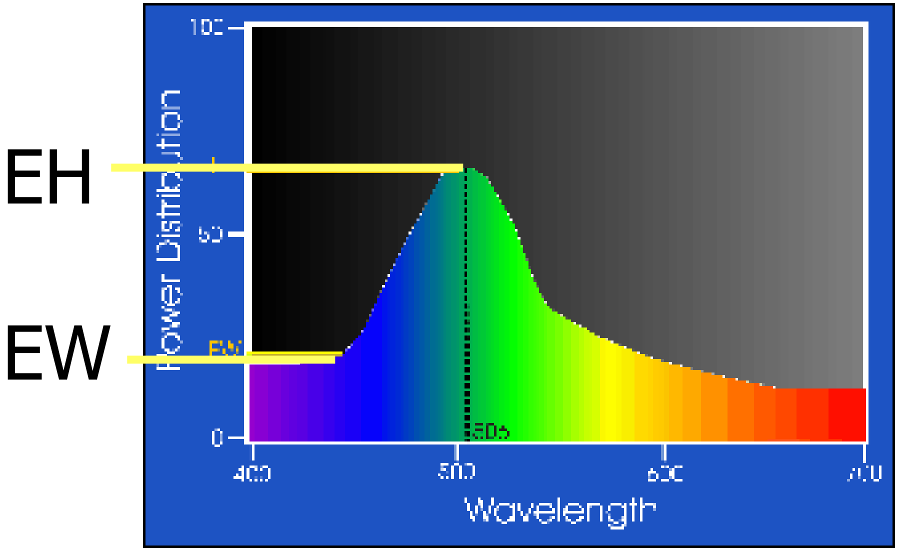
Hue: dominant wavelength of the SPD: EH

Saturation: purity of the colour: EH-EW

Intensity: brightness of the colour: EW



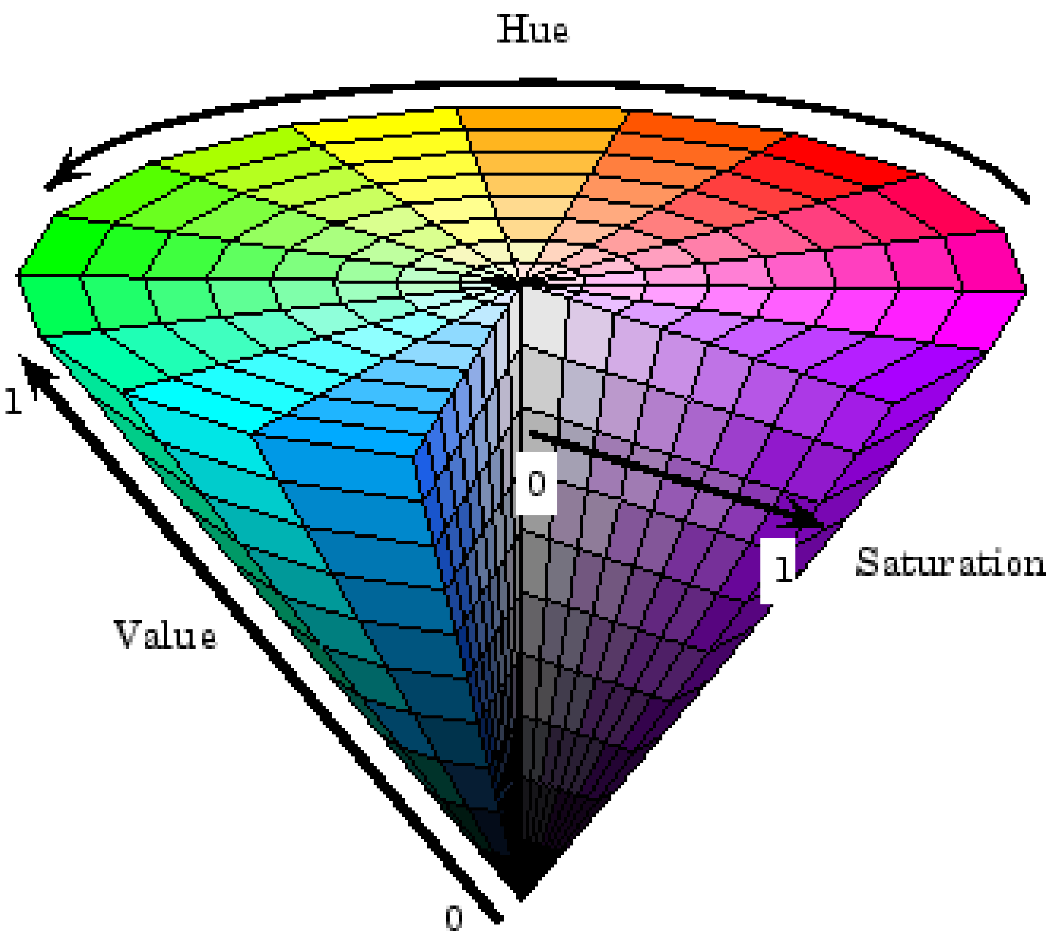
White light

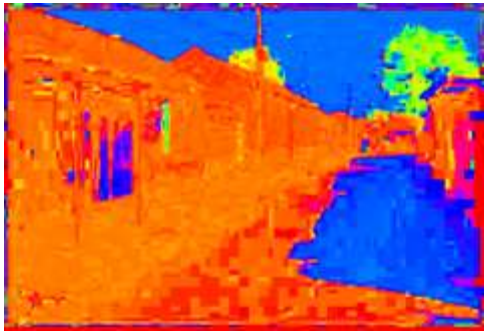


Green light

Color Spaces: HSV

Intuitive color space



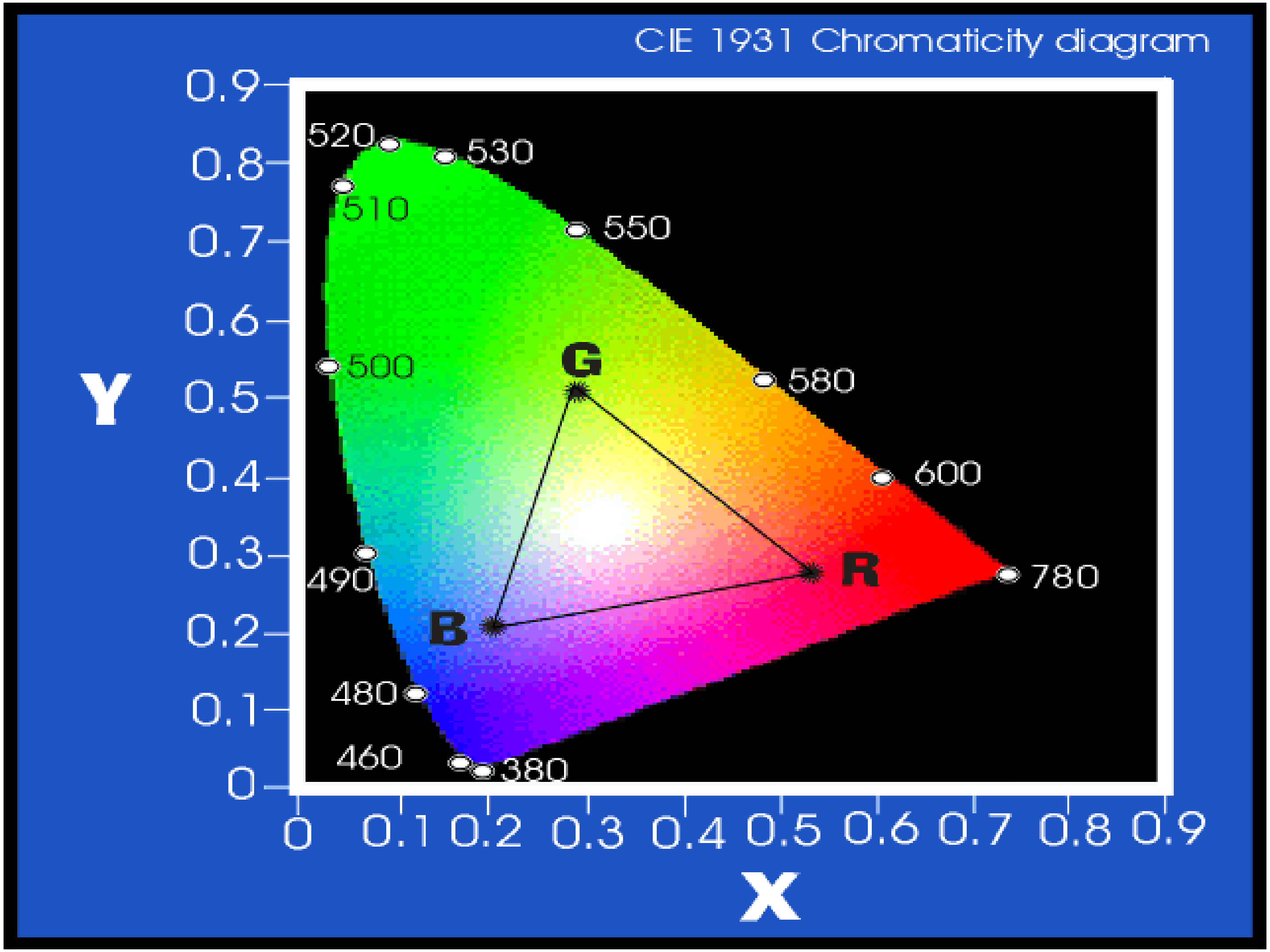


H
(S=1,V=1)

S
(H=1,V=1)

V
(H=1,S=0)

Colour Gamuts in the xy-plane



Monitor/Print/Scanner Gamut

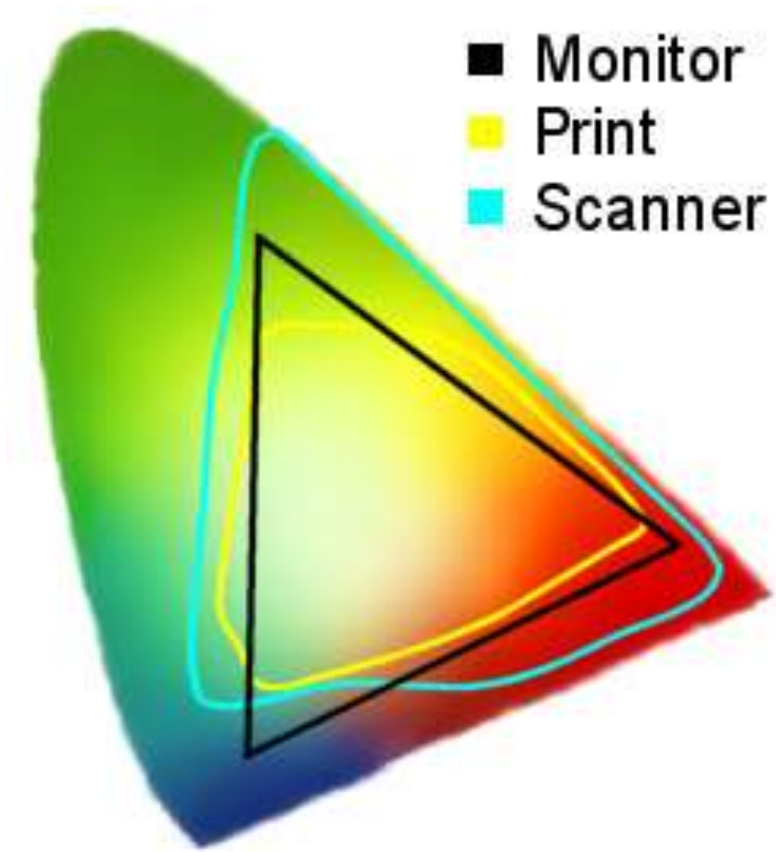
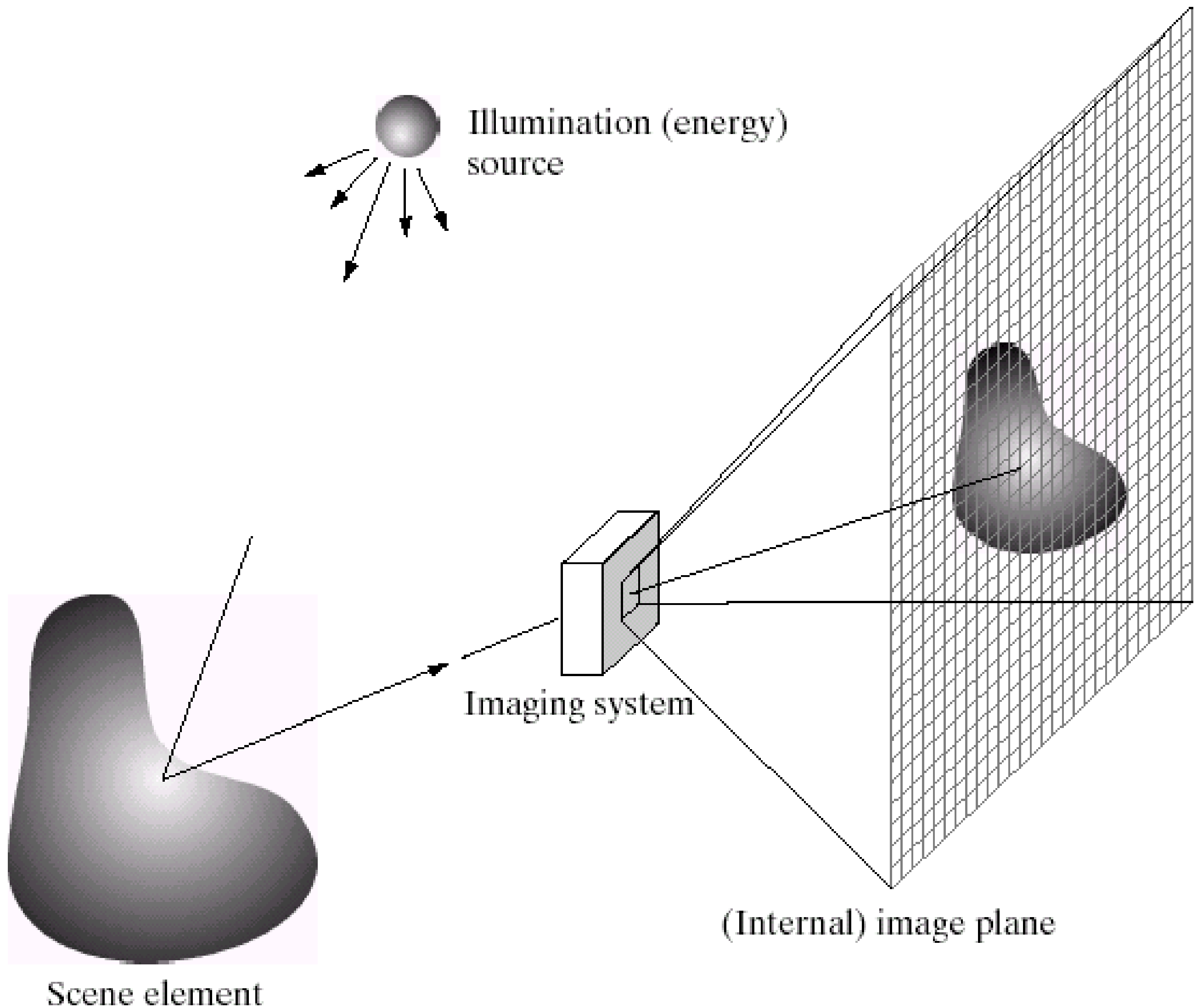


Image Formation



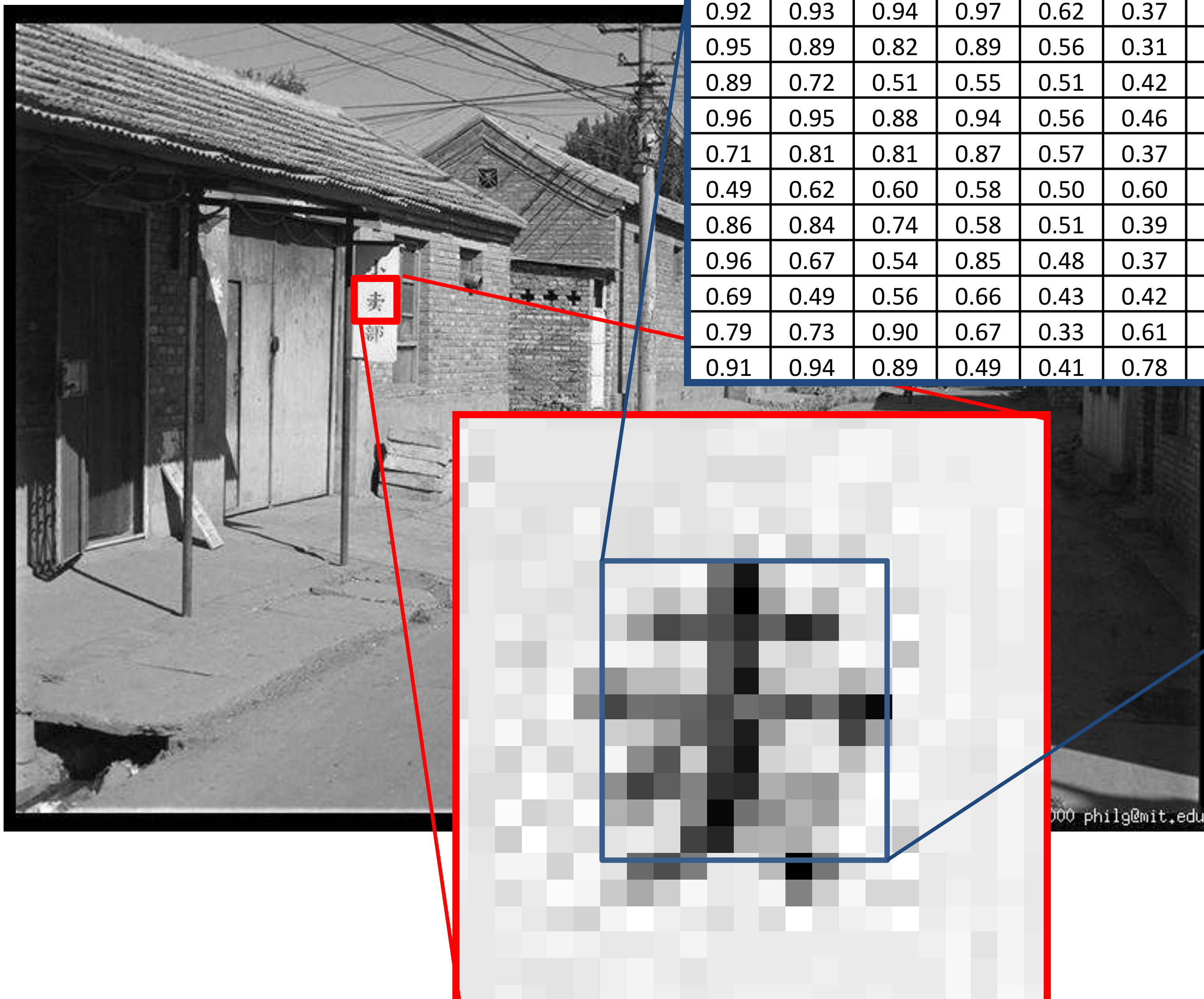
Digital camera

A digital camera replaces film with a sensor array

- Each cell in the array is light-sensitive diode that converts photons to electrons
- Two common types: Charge Coupled Device (CCD) and CMOS
- http://electronics.howstuffworks.com/digital-camera.htm

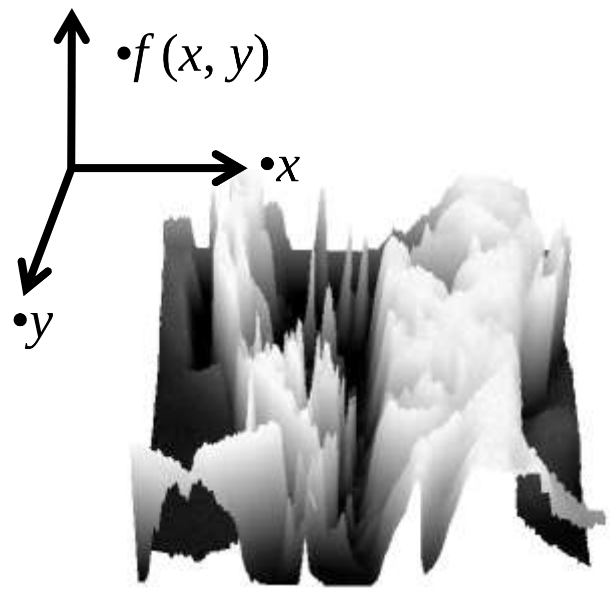
Slide by Steve Seitz

The Raster Image (Pixel Matrix)



0.92	0.93	0.94	0.97	0.62	0.37	0.85	0.97	0.93	0.92	0.99
0.95	0.89	0.82	0.89	0.56	0.31	0.75	0.92	0.81	0.95	0.91
0.89	0.72	0.51	0.55	0.51	0.42	0.57	0.41	0.49	0.91	0.92
0.96	0.95	0.88	0.94	0.56	0.46	0.91	0.87	0.90	0.97	0.95
0.71	0.81	0.81	0.87	0.57	0.37	0.80	0.88	0.89	0.79	0.85
0.49	0.62	0.60	0.58	0.50	0.60	0.58	0.50	0.61	0.45	0.33
0.86	0.84	0.74	0.58	0.51	0.39	0.73	0.92	0.91	0.49	0.74
0.96	0.67	0.54	0.85	0.48	0.37	0.88	0.90	0.94	0.82	0.93
0.69	0.49	0.56	0.66	0.43	0.42	0.77	0.73	0.71	0.90	0.99
0.79	0.73	0.90	0.67	0.33	0.61	0.69	0.79	0.73	0.93	0.97
0.91	0.94	0.89	0.49	0.41	0.78	0.78	0.77	0.89	0.99	0.93

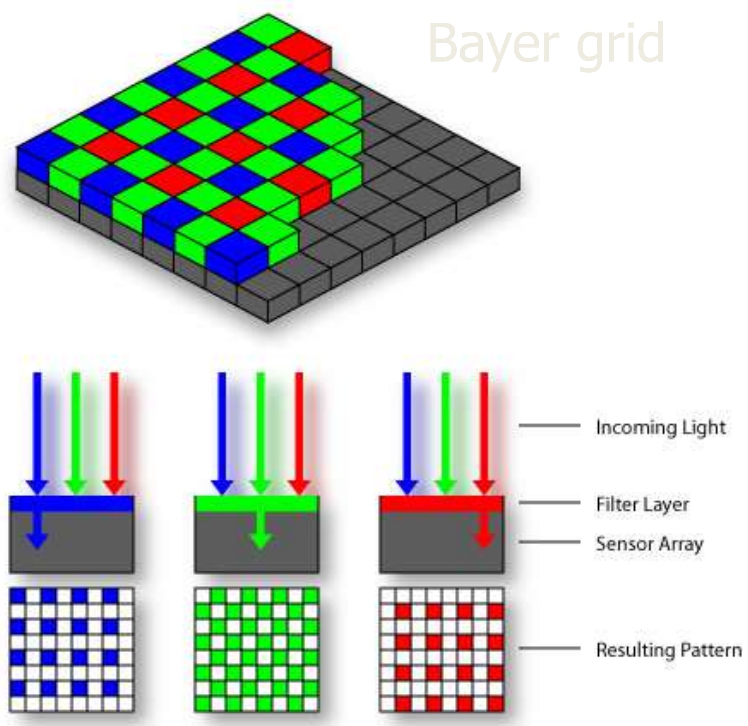
- We can think of a (grayscale) image as a **function**, *f*, from R^2 to R (or a 2D *signal*):
  - *f* (*x,y*) gives the **intensity** at position (*x,y*)



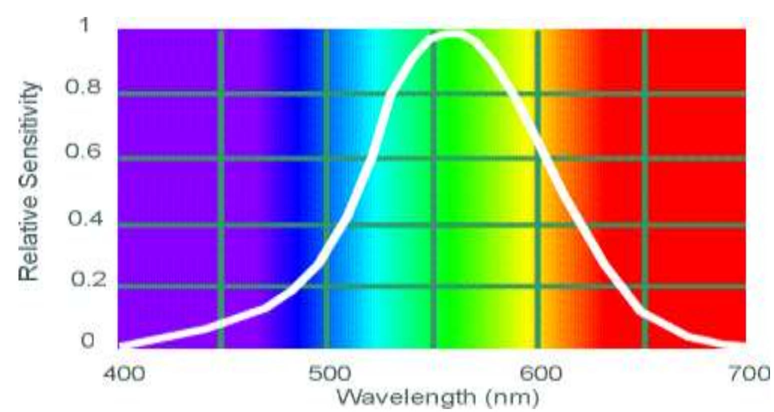
  - A **digital** image is a discrete (**sampled**, **quantized**) version of this function

Color Sensing in Camera: Color Filter Array

- In traditional systems, color filters are applied to a single
- layer of photodetectors in a tiled mosaic pattern.



Why more green?



Human Luminance Sensitivity Function

Today’s class: Image Formation

1. Projective Geometry and
Camera Models

2. Light and Color Models

3. Reflection Models (Reading 2.2, paper on color models)

Including slides from Derek Hoiem, Alexei Efros, Steve Seitz, and David Forsyth, Jame Hays, Jinxiang Chai

Basic Principles of Surface Reflectance

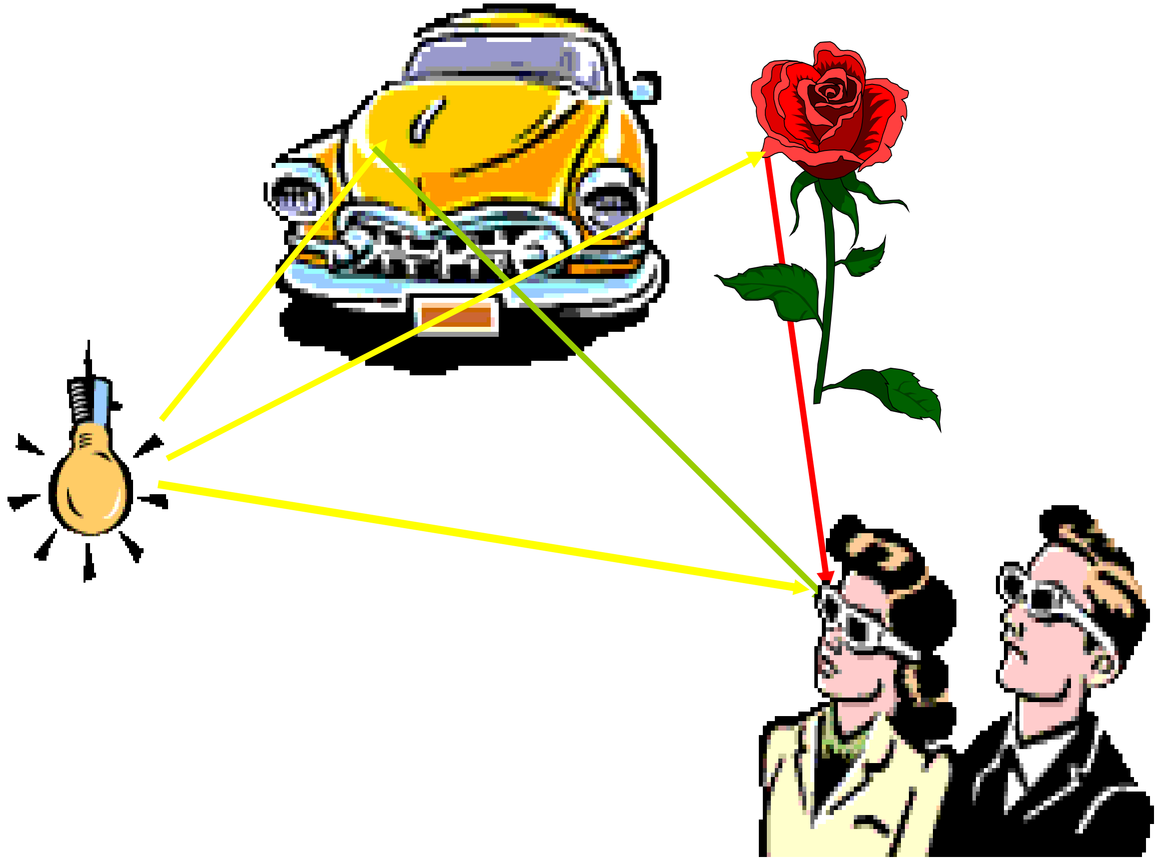
Slides from Shree Nayar, Ravi Ramamoorthi, Pat Hanrahan

What makes an image?
the triplet light-objects-observer

Light source

Object(s)

Sensor



Surface Appearance

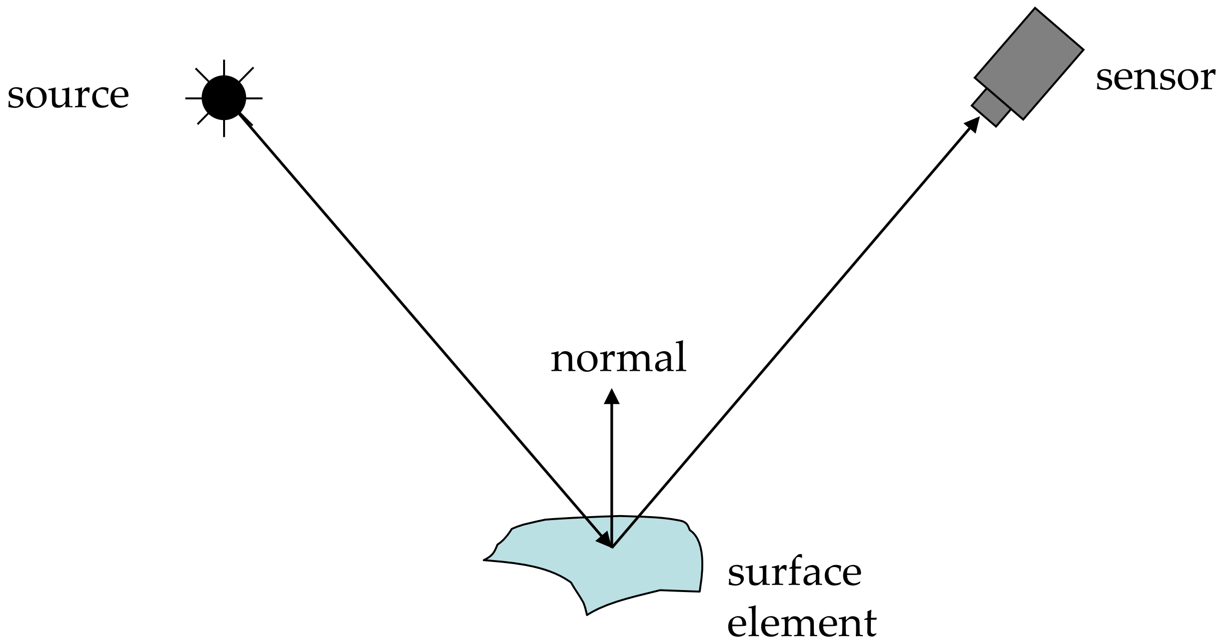
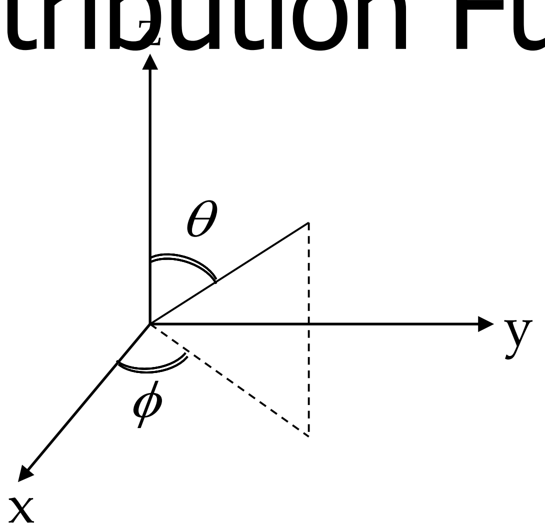
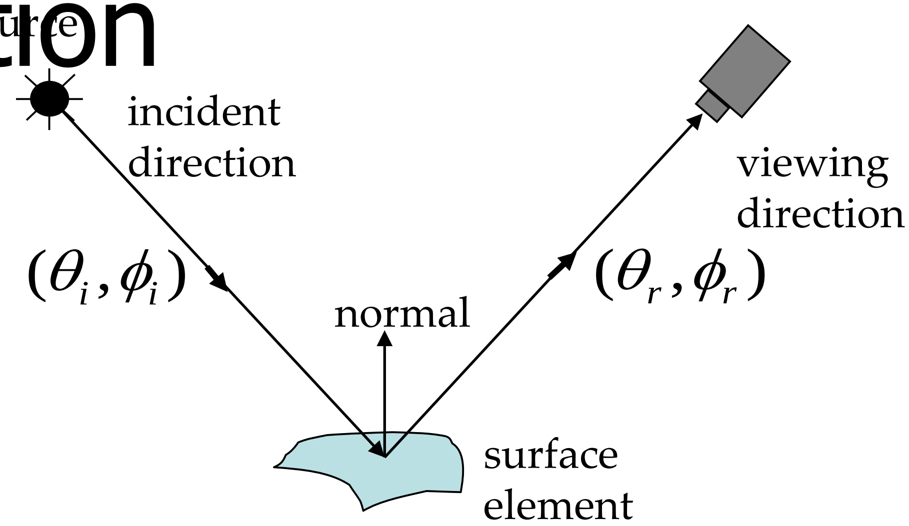


Image intensities = *f* (normal, surface reflectance, illumination)

Surface Reflection depends on both the viewing and illumination direction.

BRDF: Bidirectional Reflectance Distribution Function



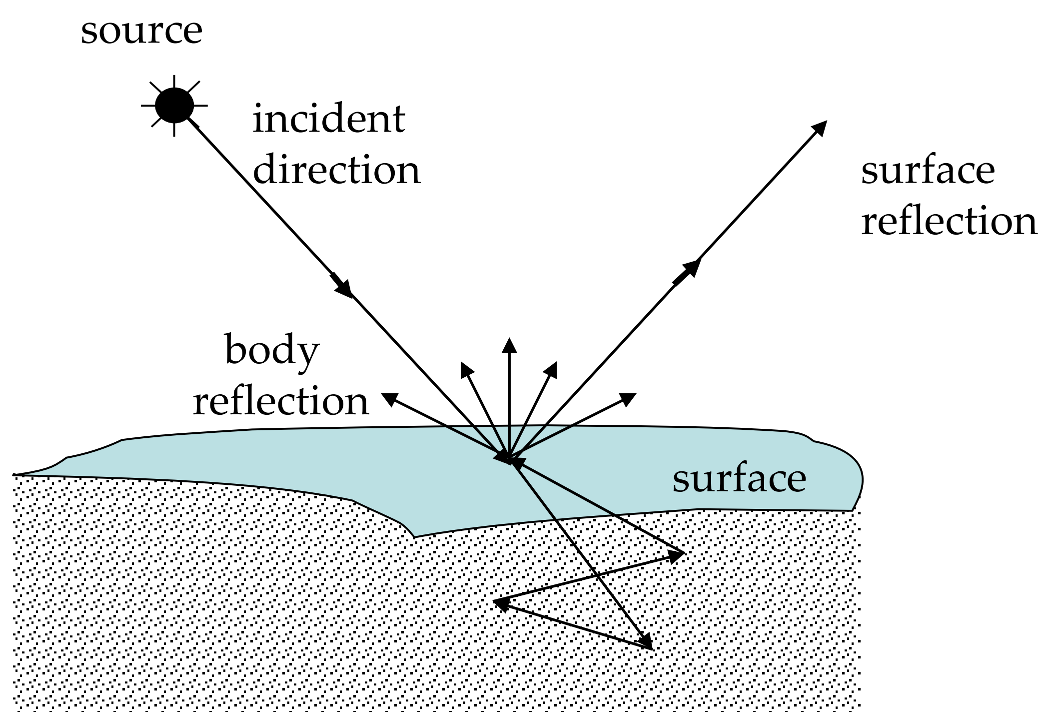


$E^{surface}(\theta_i, \phi_i)$ Irradiance at Surface in direction (θ_i, ϕ_i)

$L^{surface}(\theta_r, \phi_r)$ Radiance of Surface in direction (θ_r, ϕ_r)

$$\boxed{\text{BRDF : } f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{L^{surface}(\theta_r, \phi_r)}{E^{surface}(\theta_i, \phi_i)}}$$

Mechanisms of Surface Reflection



Body Reflection:

Diffuse Reflection
Matte Appearance
Non-Homogeneous Medium
Clay, paper, etc

Surface Reflection:

Specular Reflection
Glossy Appearance
Highlights
Dominant for Metals

Image Intensity = Body Reflection + Surface Reflection

Mechanisms of Surface Reflection

Body Reflection:

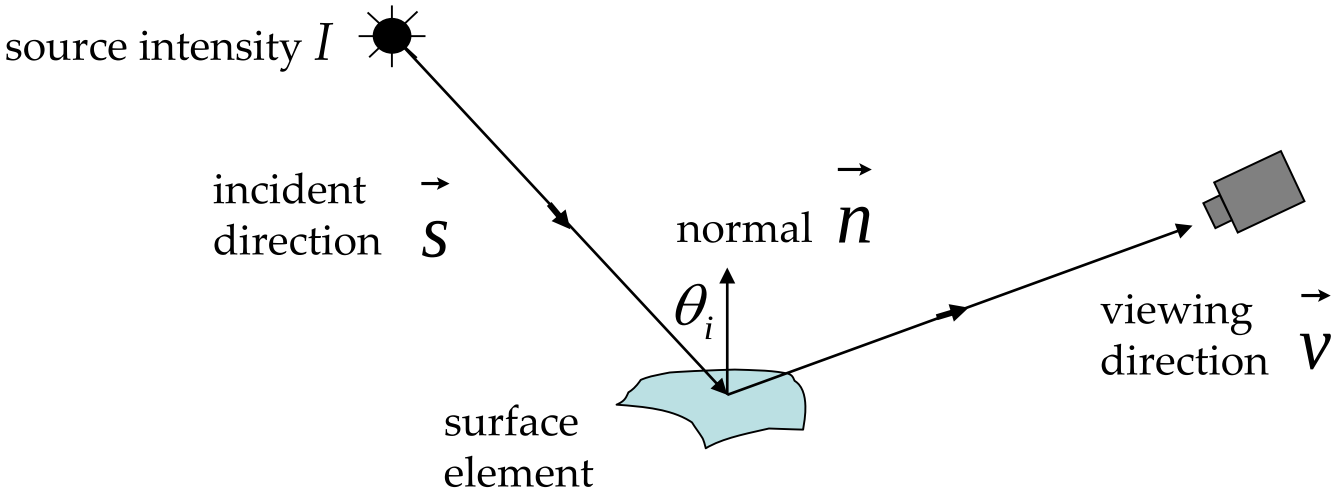
Diffuse Reflection
Matte Appearance
Non-Homogeneous Medium
Clay, paper, etc

Surface Reflection:

Specular Reflection
Glossy Appearance
Highlights
Dominant for Metals

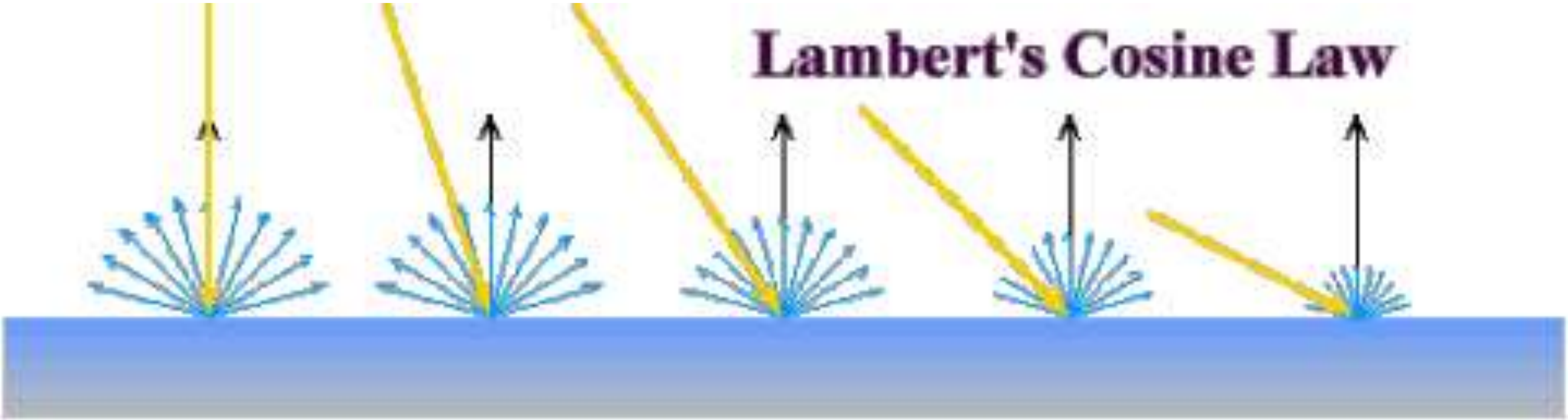
Many materials exhibit both Reflections:

Diffuse Reflection and Lambertian BRDF



- Surface appears equally bright from ALL directions! (independent of $\vec{v}$)
- Lambertian BRDF is simply a constant : $f(\theta_i, \phi_i; \theta_r, \phi_r) = \frac{\rho_d}{\pi}$ albedo
- Surface Radiance : $L = \frac{\rho_d}{\pi} I \cos\theta_i = \frac{\rho_d}{\pi} I \; \vec{n} \cdot \vec{s}$ source intensity
- Commonly used in Vision and Graphics!

Diffuse Reflection and Lambertian BRDF



Overcast Sky

Can’t perceive the shape of the snow covered terrain

Face Analysis

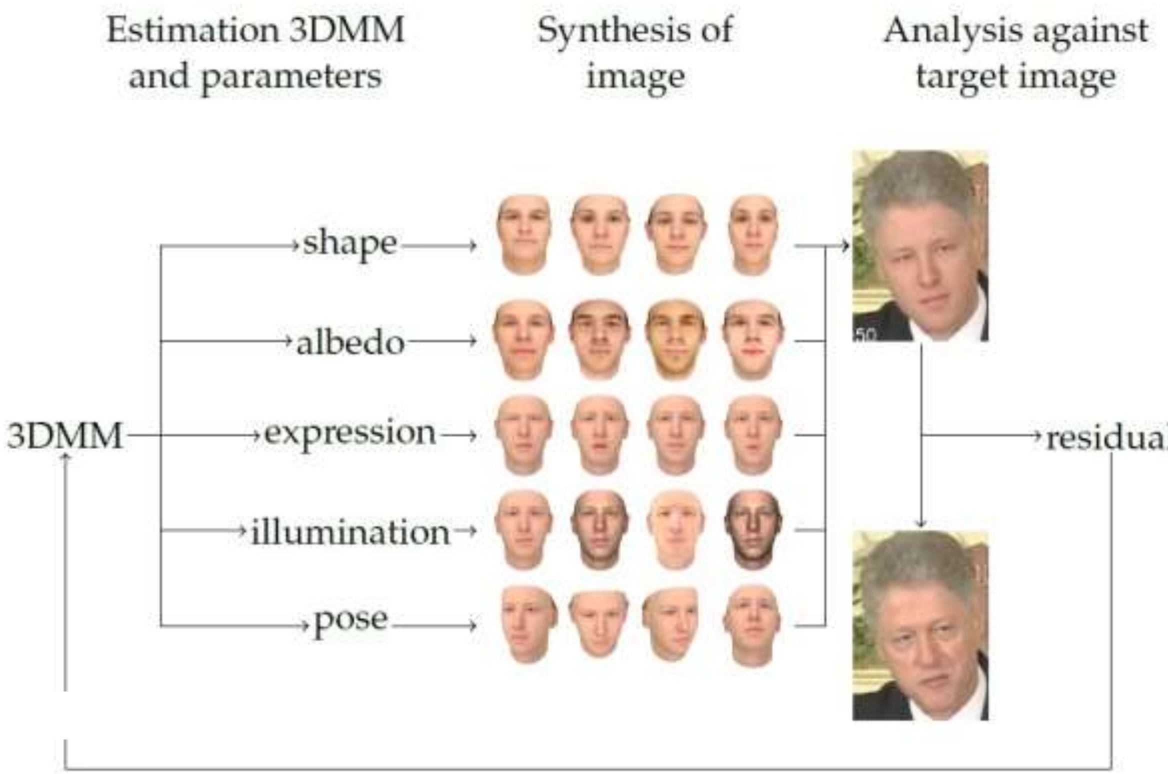
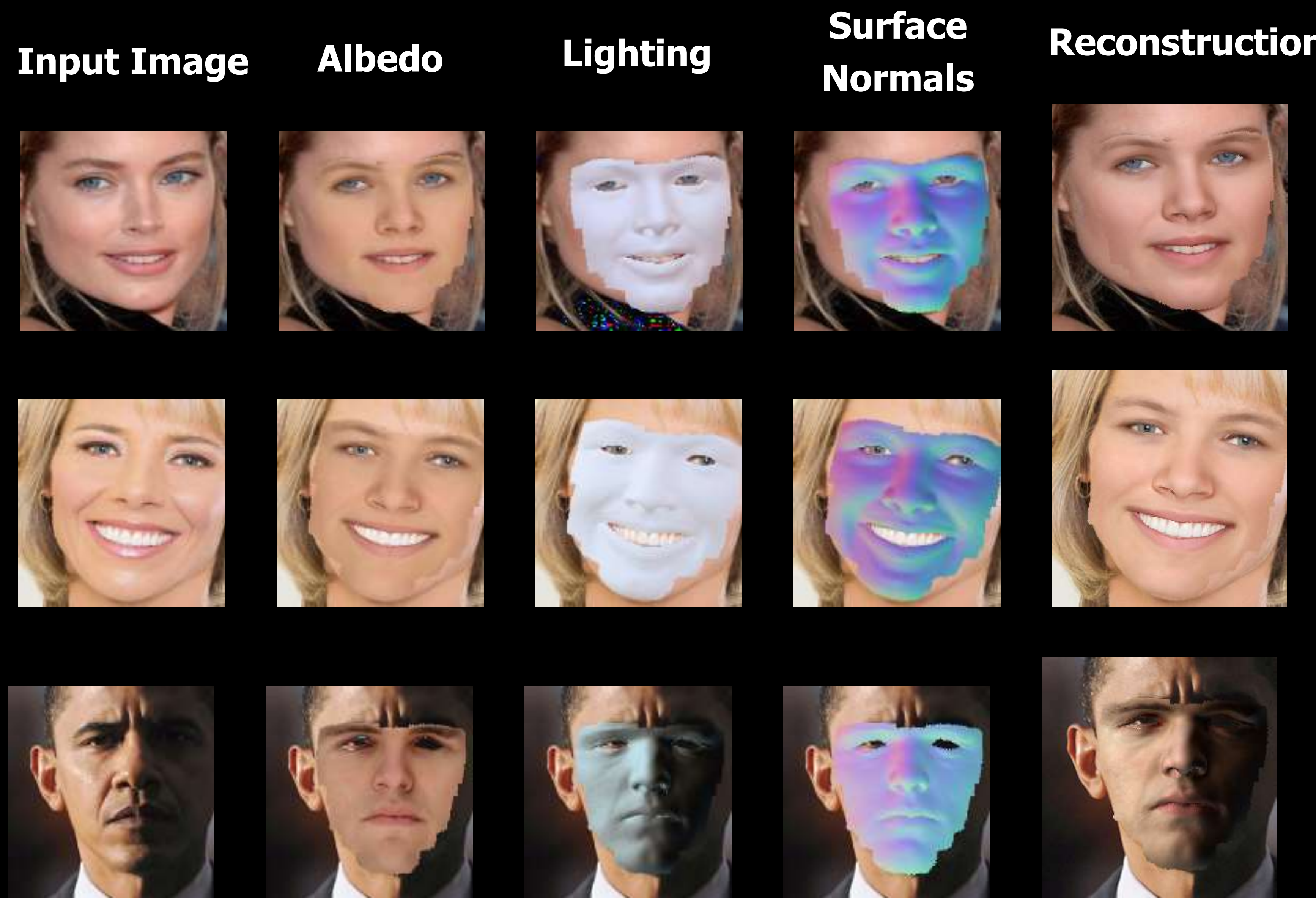


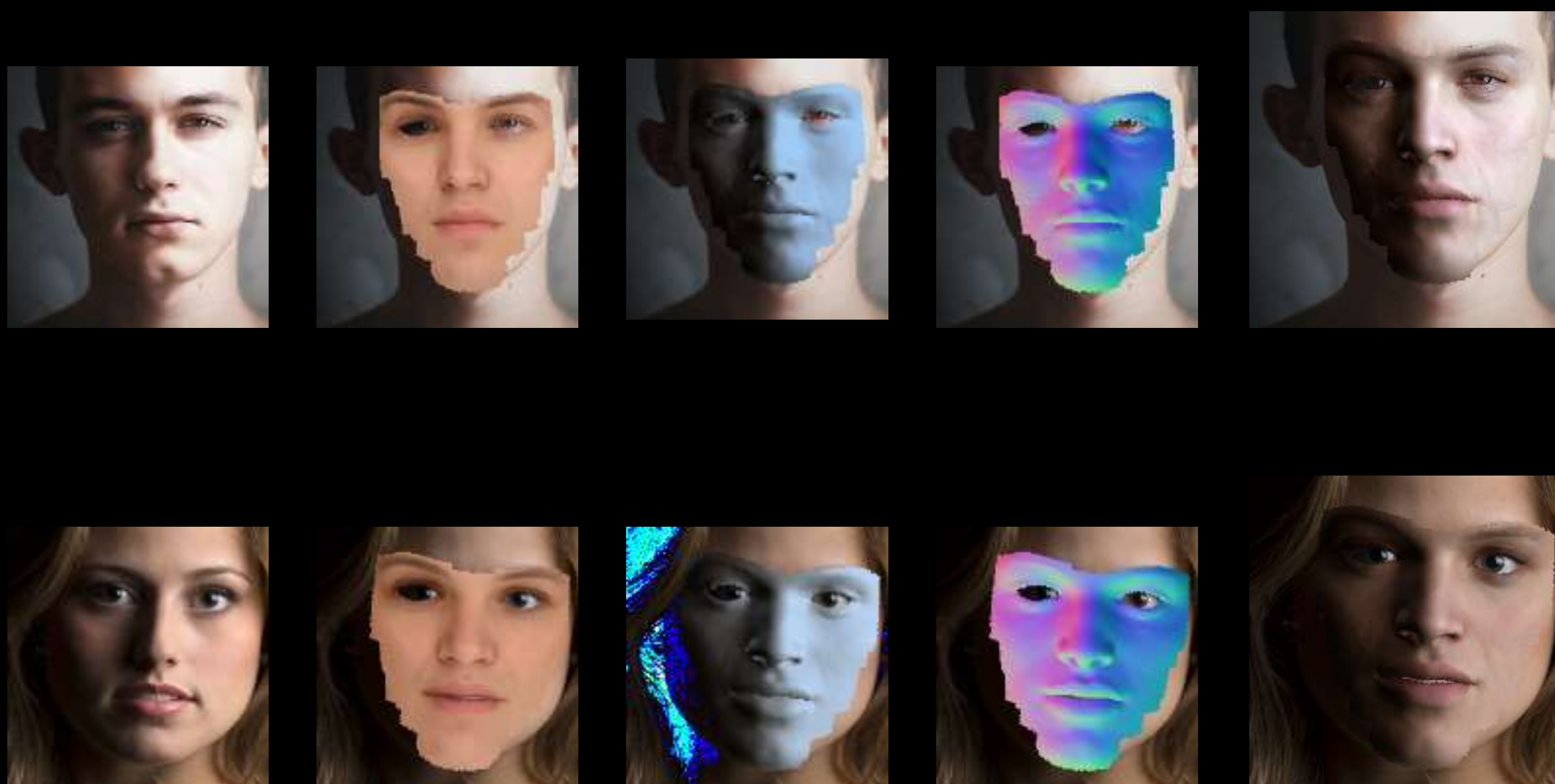
FIGURE 1.1: Example of 3DMM fitting following an analysis-by-synthesis approach. From left to right: The 3D Morphable Model, prediction of parameters for the different components of the optimization problem and rendered results, analyses against target image, and feedback loop.

Diffuse Reflection



Diffuse Reflection

Input Image | **Albedo** | **Lighting** | **Surface Normals** | **Reconstruction**

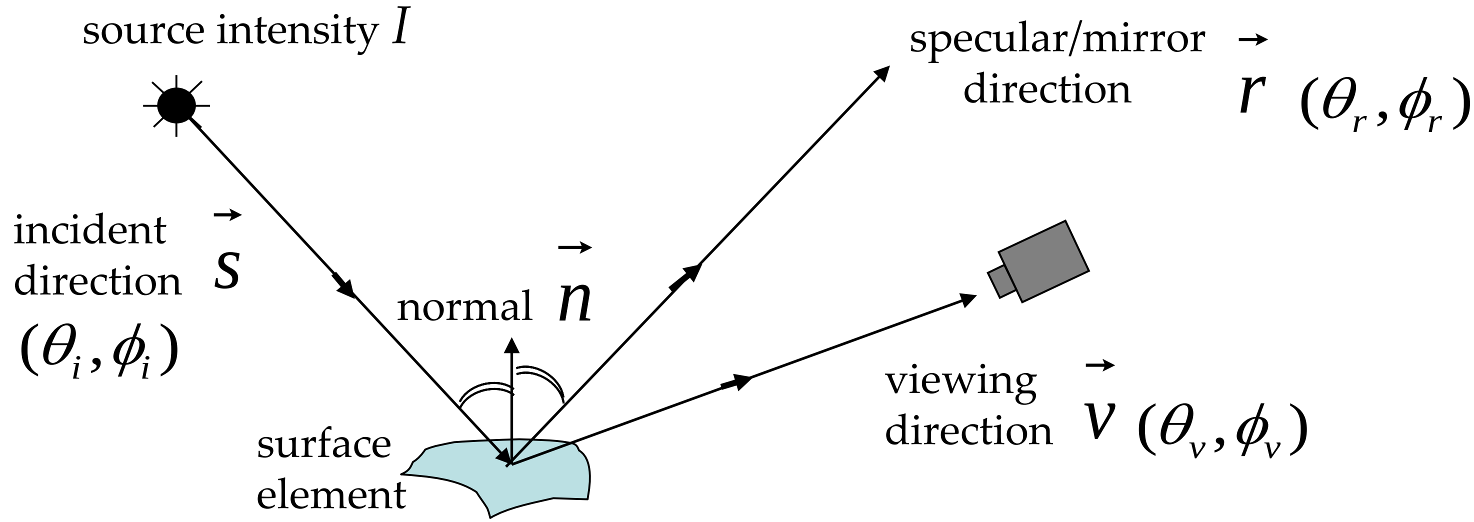


Diffuse Reflection: Albedo

Diffuse Reflection: Illumination

Diffuse Reflection: Illumination/SH

Specular Reflection and Mirror BRDF



- Very smooth surface.
- All incident light energy reflected in a SINGLE direction. (only when $\vec{v} = \vec{r}$)
- Mirror BRDF is simply a double-delta function :

specular albedo

$$f(\theta_i, \phi_i; \theta_v, \phi_v) = \rho_s \; \delta(\theta_i - \theta_v) \; \delta(\phi_i + \pi - \phi_v)$$

- Surface Radiance : $L = I \; \rho_s \; \delta(\theta_i - \theta_v) \; \delta(\phi_i + \pi - \phi_v)$

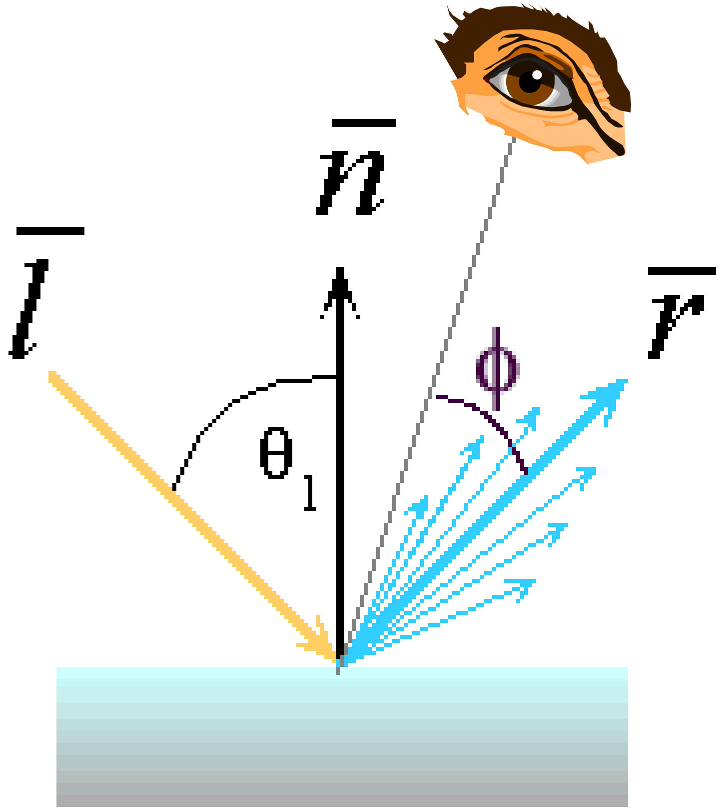
Glossy Surfaces

- Many glossy surfaces show broader highlights in addition to specular reflection.

- Example Models : Phong Model (no physical basis, but sort of works (empirical)

Phong Model: An Empirical Approximation

- An illustration of the angular falloff of highlights:

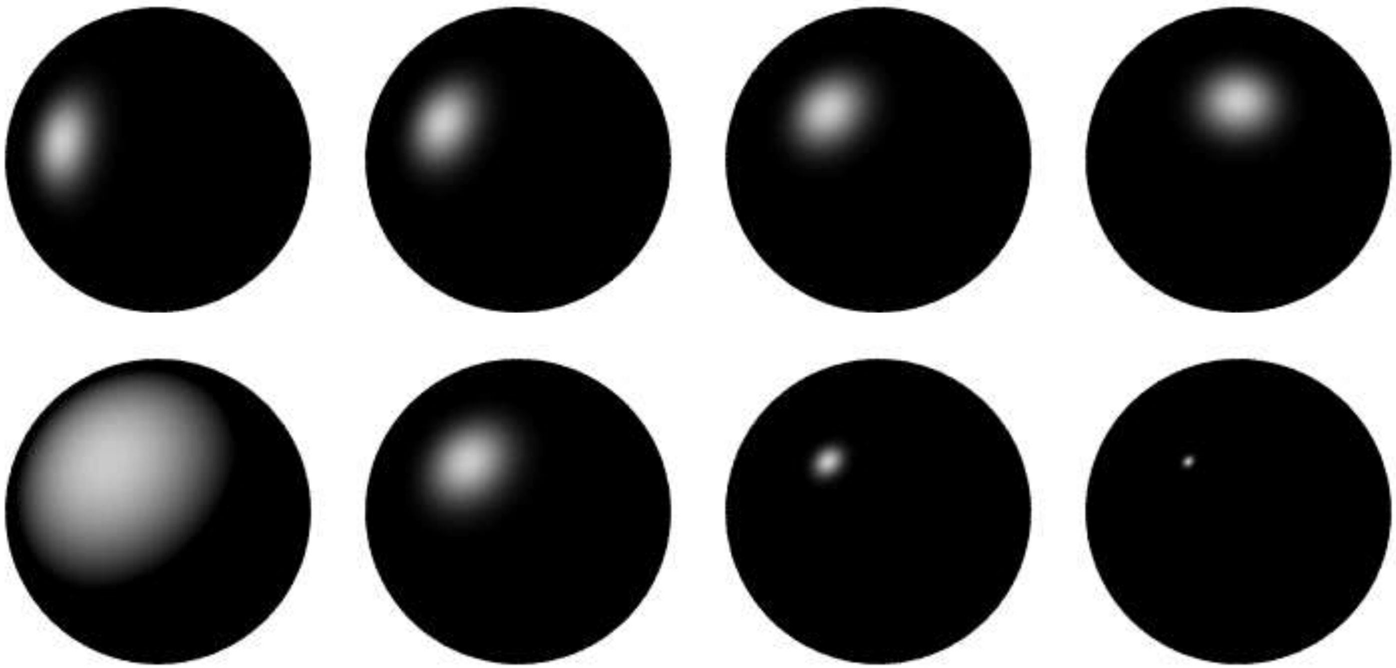


$$L = I \, \rho_s \, (\cos\phi)^{n_{shiny}}$$

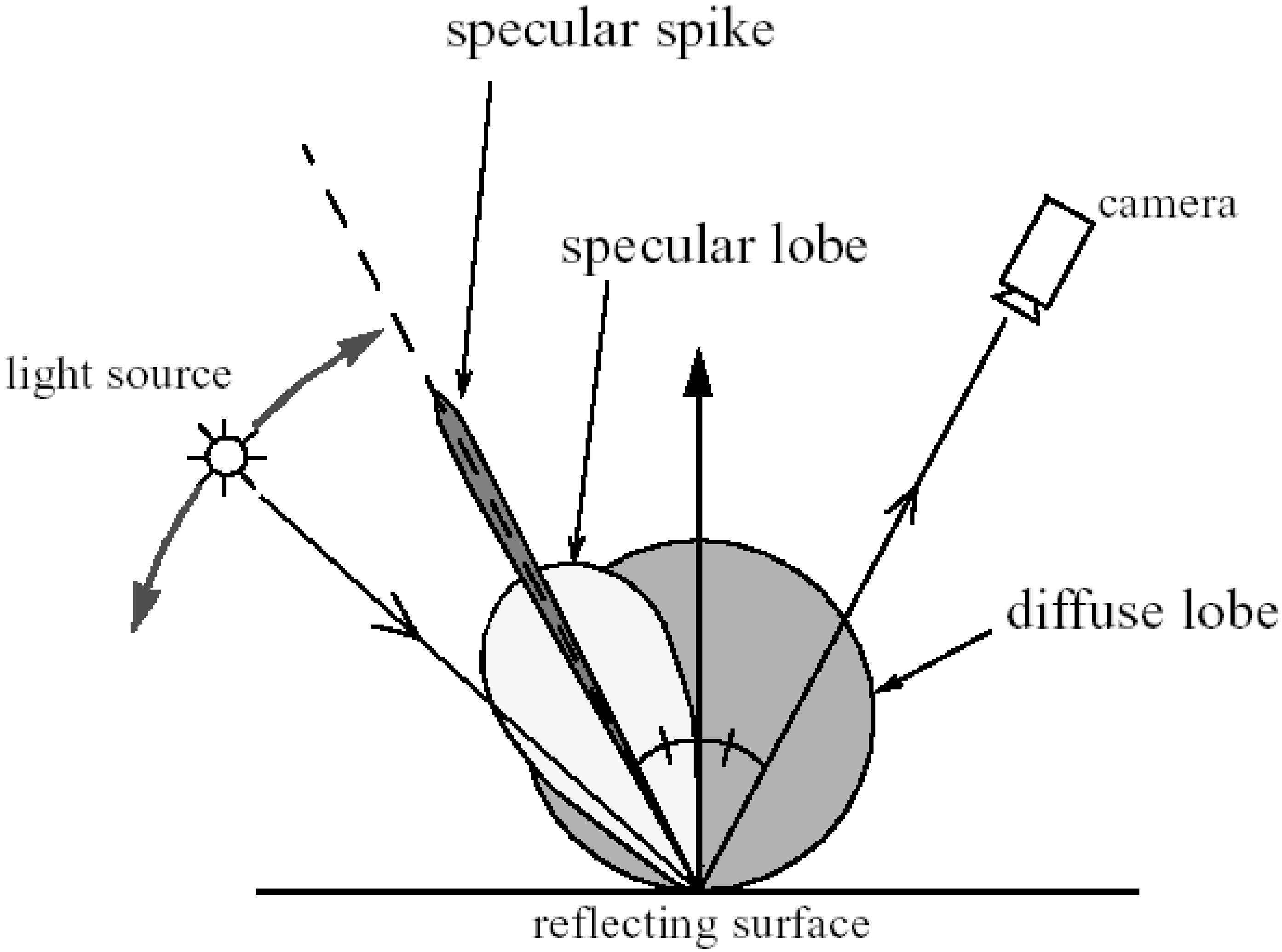
- Very commonly used in Computer Graphics

Phong Examples

- These spheres illustrate the Phong model as *lighting*
- *direction* and n_{shiny} are varied:



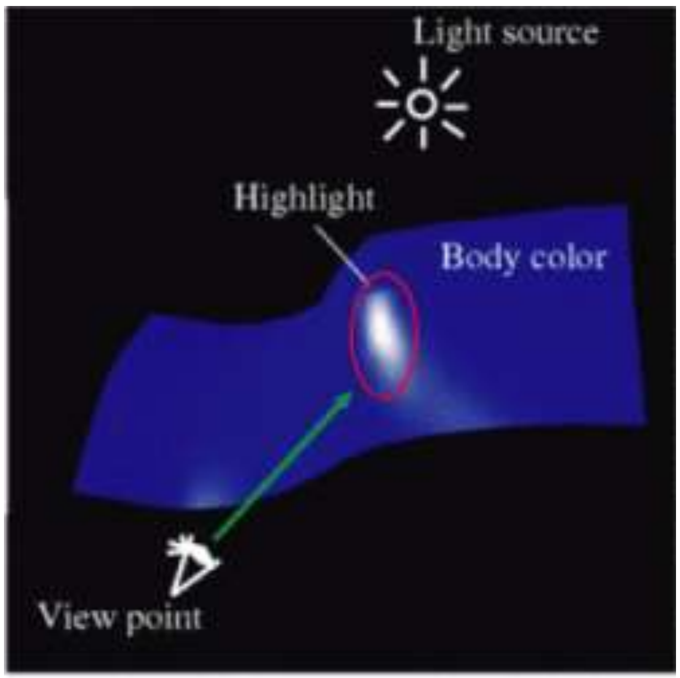
All components of Surface Reflection

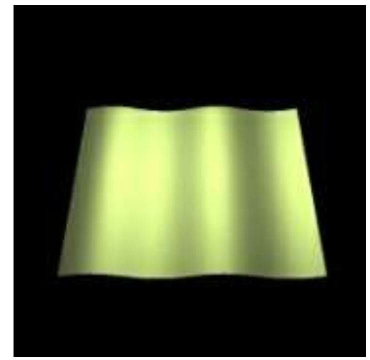


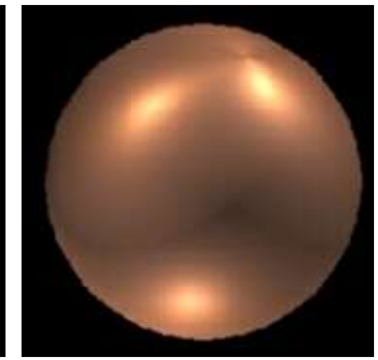
A Simple Reflection Model - Dichromatic Reflection

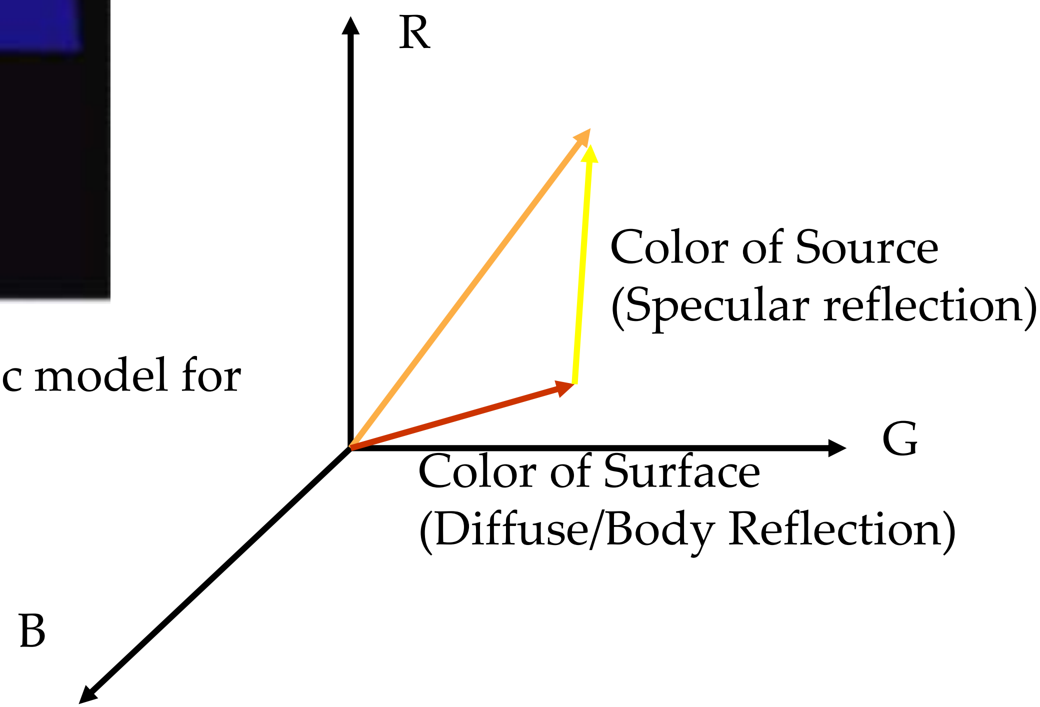
Observed Image Color = a x Body Color + b x Specular Reflection Color

Klinker-Shafer-Kanade 1988





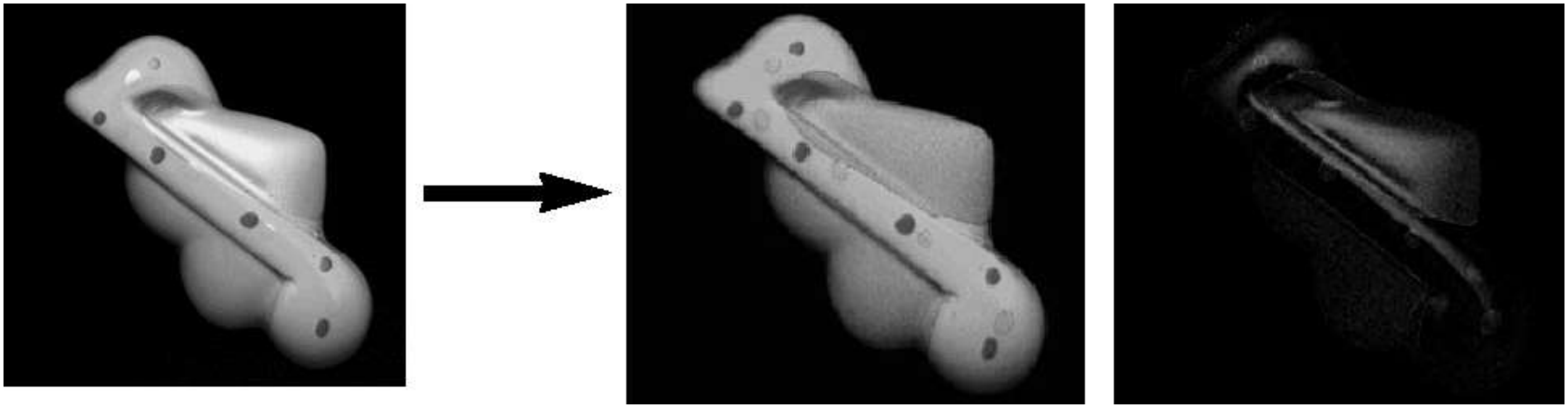


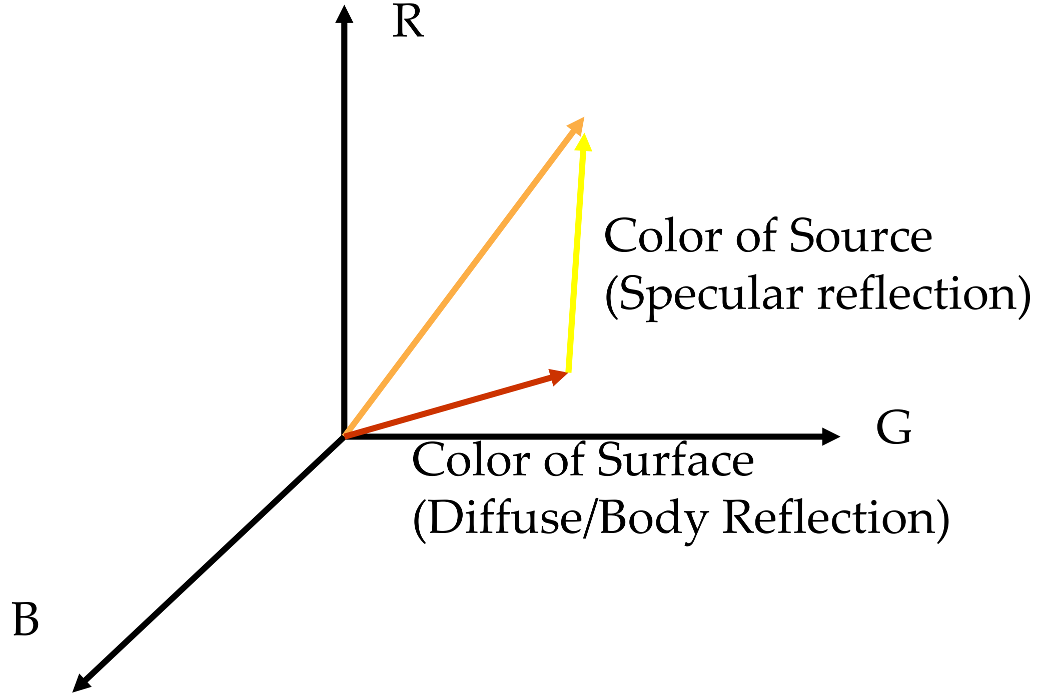


Does not specify any specific model for
Diffuse/specular reflection

Separating Diffuse and Specular Reflections

Observed Image Color = a x Body Color + b x Specular Reflection Color





Computer Vision 1 (total #slides 110 | Lecture 2)

Summary on Image Formation

1. Projective Geometry and Camera Models

2. Light and Color Models

3. Reflection Models