Cameras and Imaging
http://www.ugrad.cs.jhu.edu/~cs461

Professor Hager
http://www.cs.jhu.edu/~hager

Unit Outline

- Camera imaging sensor basics
- Storing images
- Color

- Reading:
  - F&P Chap 1.
  - F&P Chaper 6 (mostly 6.1-6.4)
  - T&V Chapter 2.1 and 2.2, (although T&V does not cover some of this material.

A Word On Computer-Imaging

- Video imaging has gone from an exotic technology to everyday commodity.

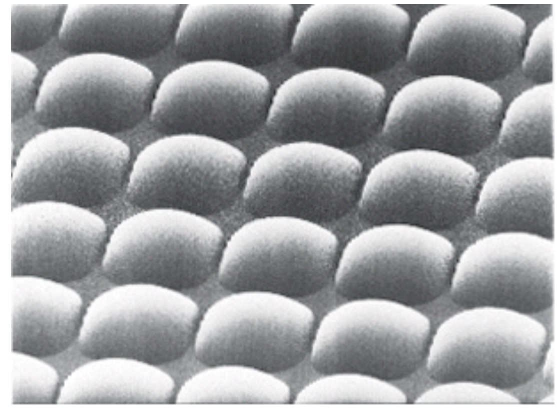
- Originally (since ~1930) NTSC standard
  - 480 x 640 YUV
  - Interlaced

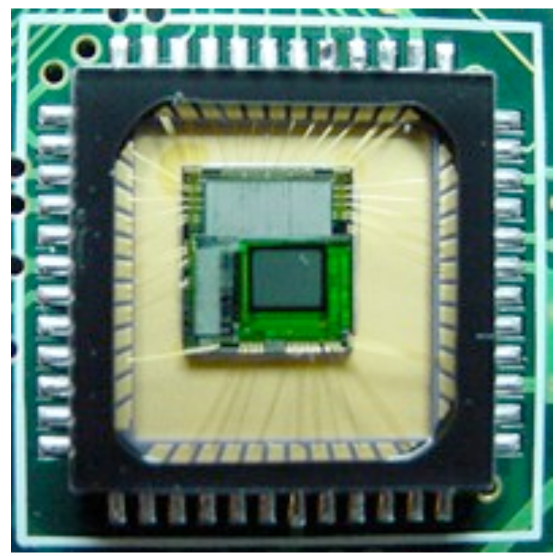
- Now, a wide variety of resolutions and quality
  - VGA (= NTSC)
  - SVGA (= 600x800)
  - XVGA (= 768x1024)
  - SXGA (=1024x1280)
  - UGA (= 1200x1600)

How Cameras Produce Images

- Basic process:
  - photons hit a detector
  - the detector becomes charged
  - the charge is read out as brightness

- Sensor types:
  - CCD (charge-coupled device)
    - most common
    - high sensitivity
    - high power
    - cannot be individually addressed
    - blooming
  - CMOS
    - simple to fabricate (cheap)
    - lower sensitivity, lower power
    - can be individually addressed

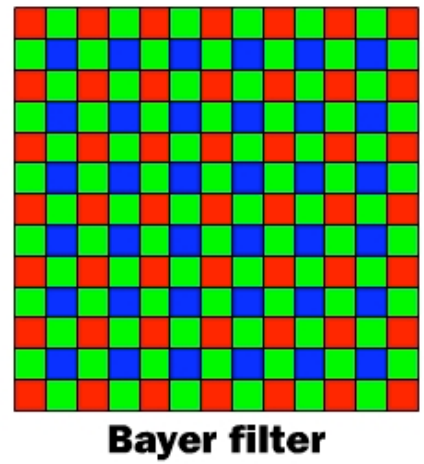


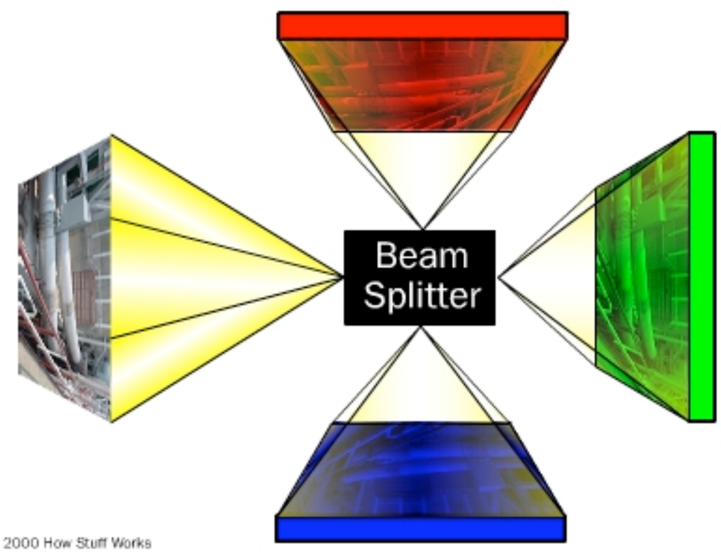


How Color Cameras Work

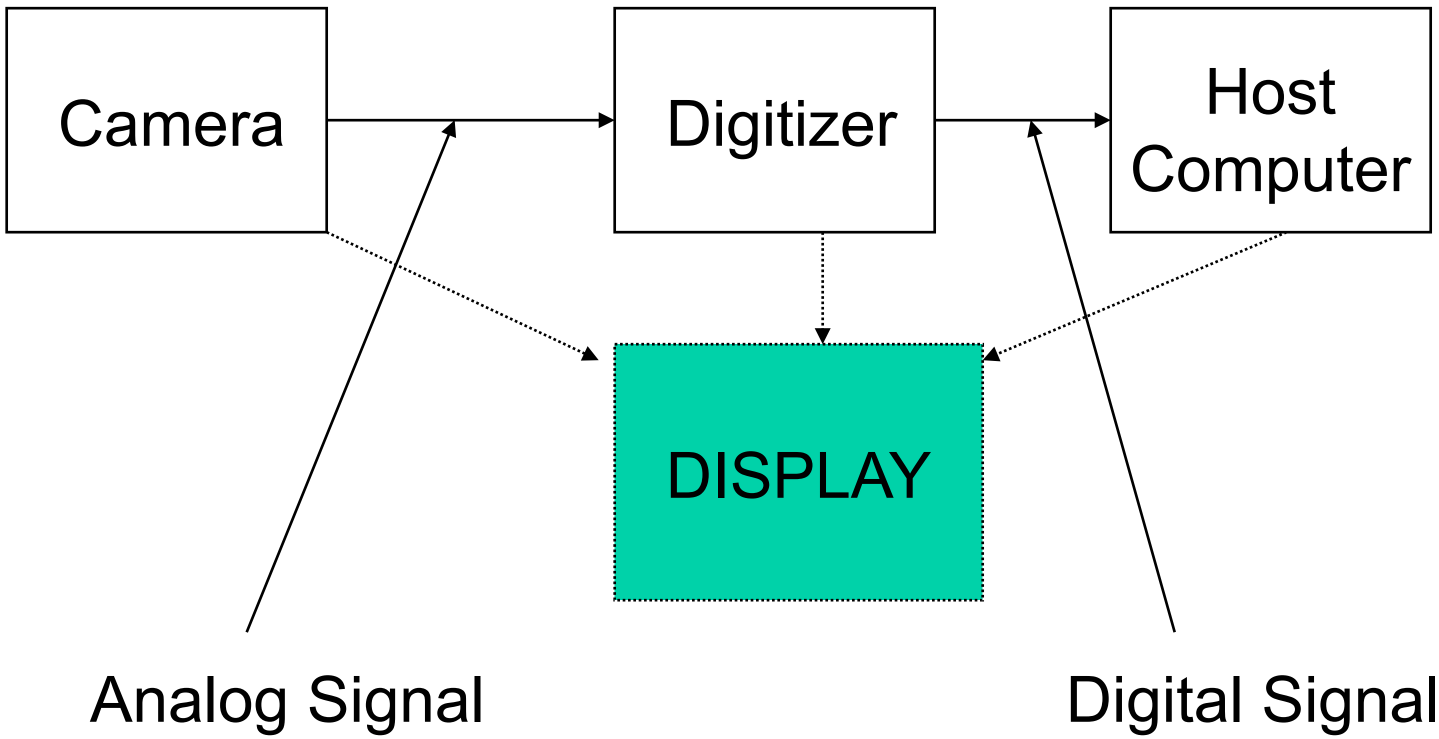
- 1 CCD cameras
  - A **Bayer** pattern is placed in front of the CCD
  - A **Demosaicing** process reads the pixels in a region and computes color and intensity

- 3 CCD camera use a beam splitter and 3 separate CCDs
  - higher color fidelity
  - needs lots of light
  - requires careful alignment of ccds

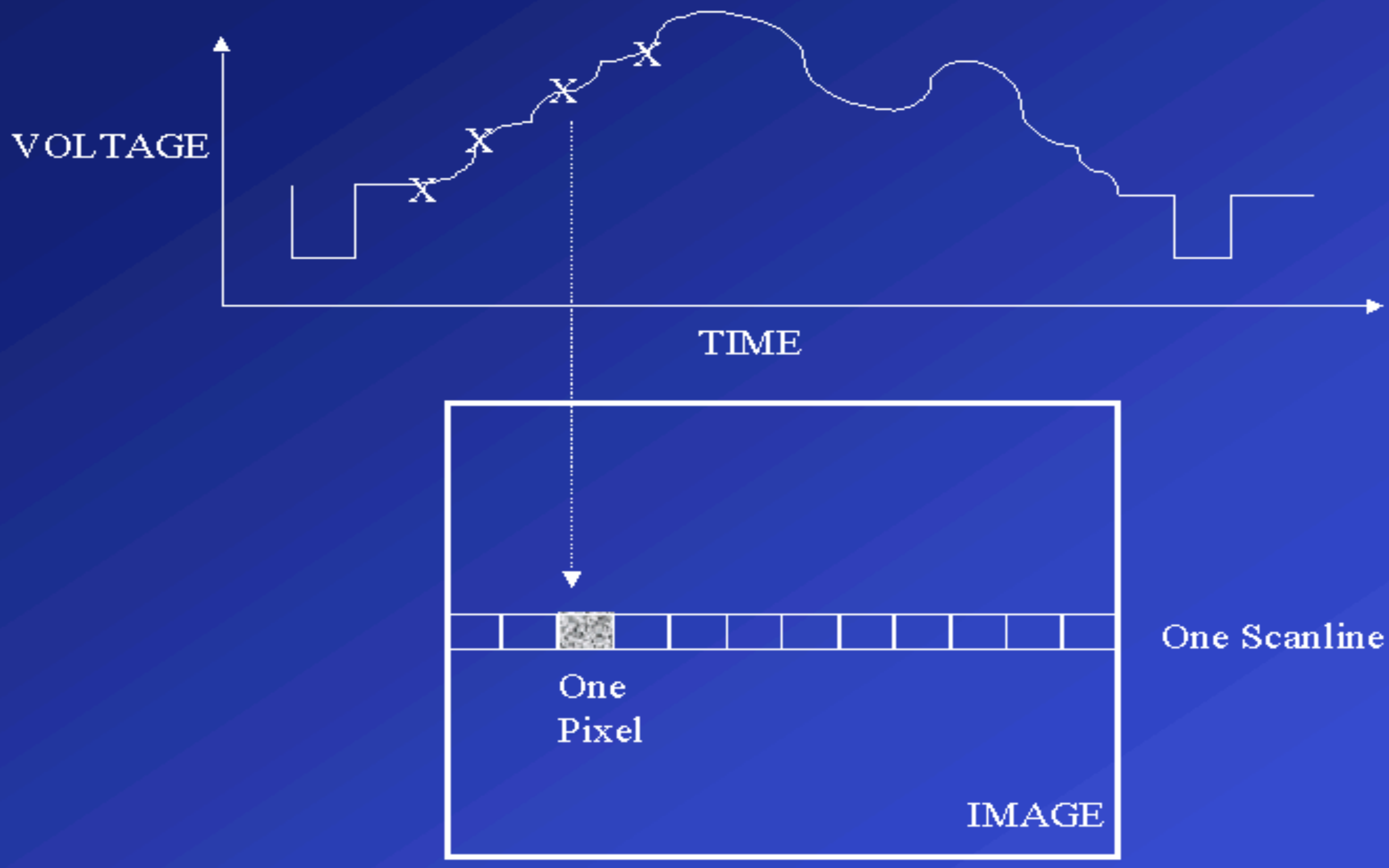




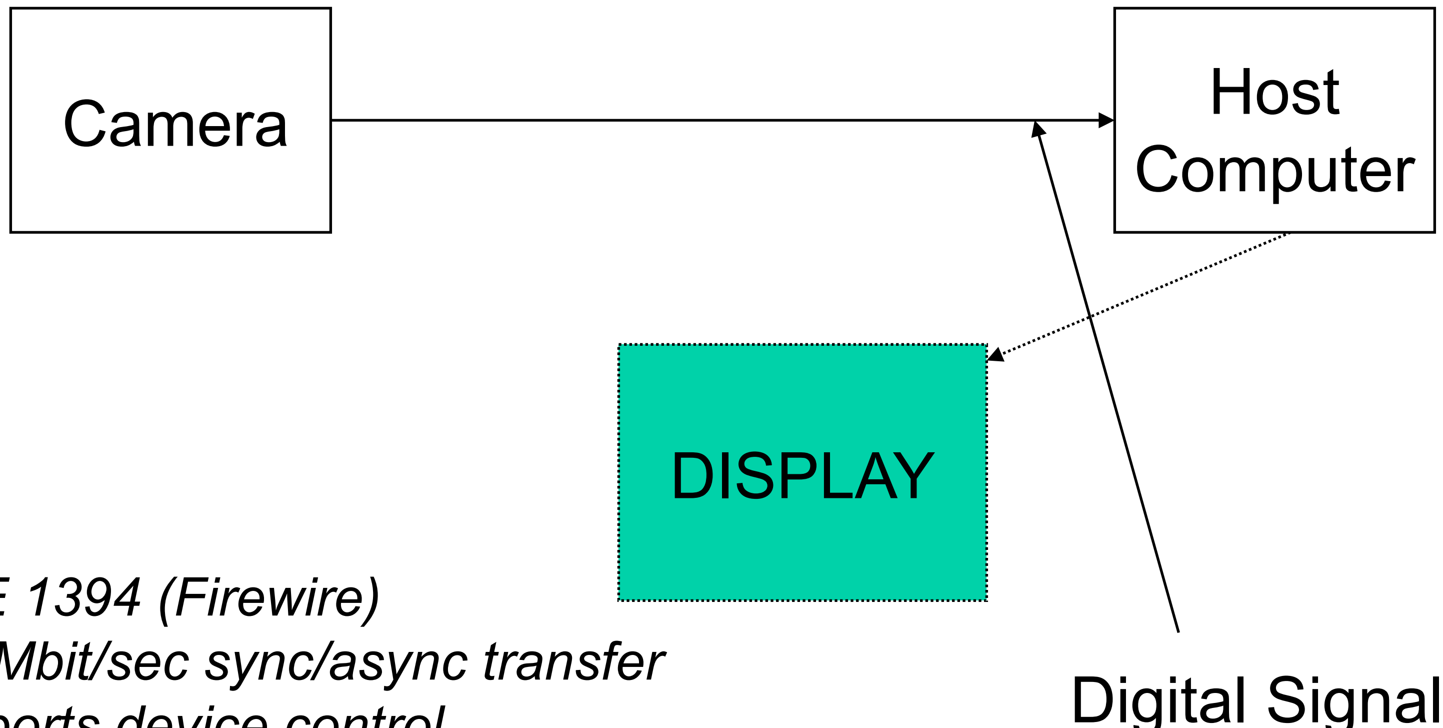
A “Traditional” Camera



What's under the Hood



A Modern Digital Camera



IEEE 1394 (Firewire)
400 Mbit/sec sync/async transfer
Supports device control

USB 2.0
480 Mbit/sec (~280Mbit/sec in practice)
Less flexible, but simpler to implement

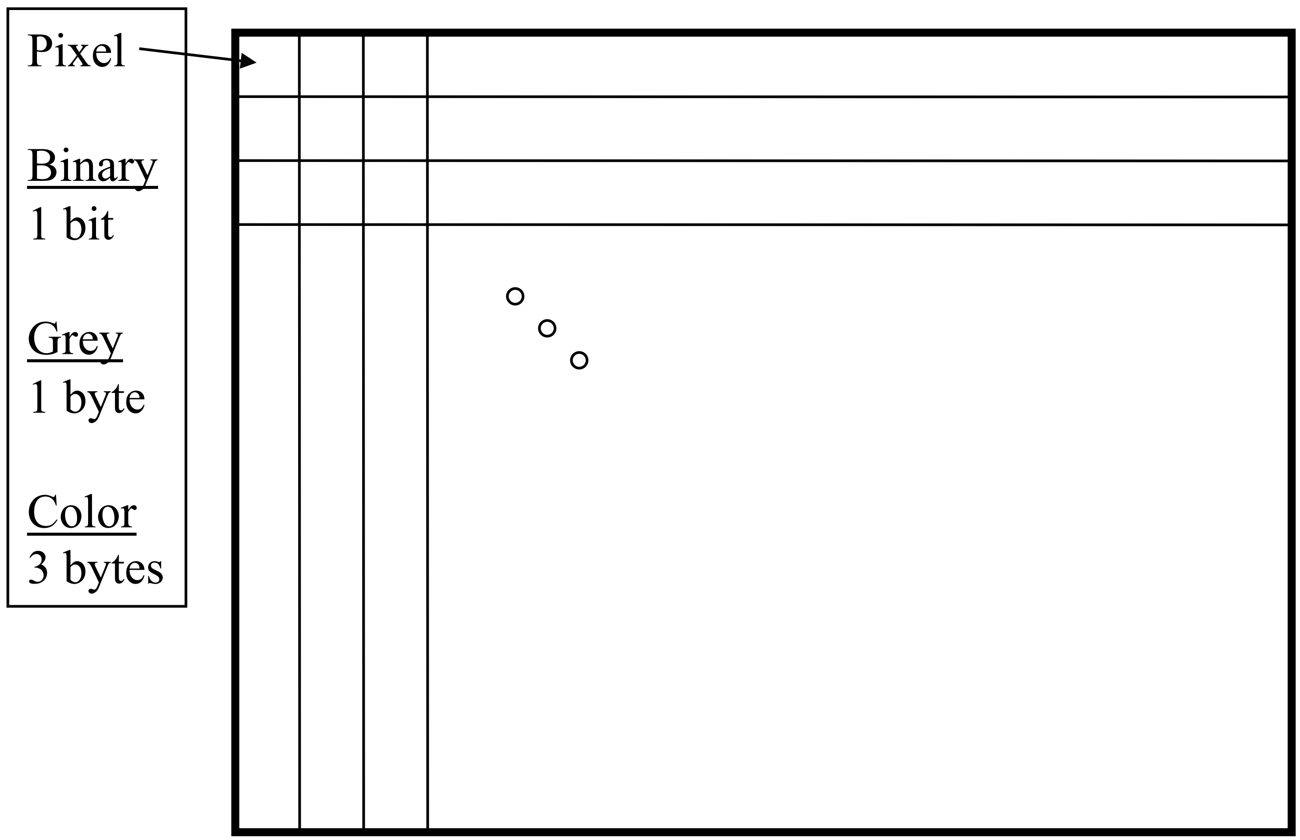
Other Issues

- Automatic Gain Control (AGC): adjusting amplification and black level to get a “good fit” of the incident light power to the range of the image

- Shuttering: Electronic “switch” that controls how long the CCD is “exposed.”

- White balance: Adjustment of the mapping from measured spectral quantities to image RGB quantities (we’ll talk about this more when we get to color).

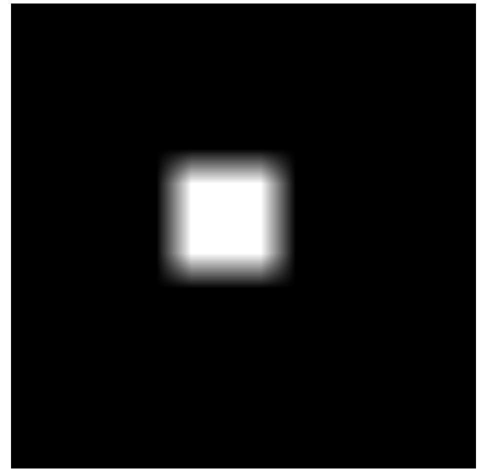
THE ORGANIZATION OF A 2D IMAGE

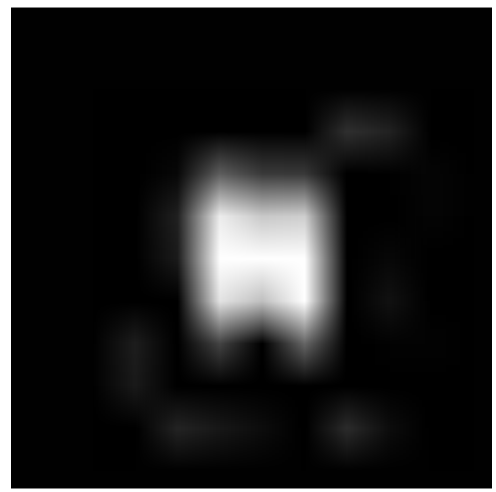


Storing Images

- Non-lossy schemes
  - pbm/pgm/ppm/pnm
    - code for file type, size, number of bands, and maximum brightness
  - tif (lossless and lossy versions)
  - bmp
  - gif (grayscale)

- Lossy schemes
  - gif (color)
  - jpg
    - uses Y Cb Cr color representation; subsamples the color
    - Uses DCT on result
    - Uses the fact the human system is less sensitive to color than spatial detail





GIF IMAGE FORMAT

- GIF (Graphics Interchange Format)
  - Limited to 8 bits/pixel for both color and gray-scale.

8-bit index	RED	GREEN	BLUE
0	R0	G0	B0
1	R1	G1	B1
2	R2	G2	B2
⋮	⋮	⋮	⋮
254	R254	G254	B254
255	R255	G255	B255

TIFF IMAGE FORMAT

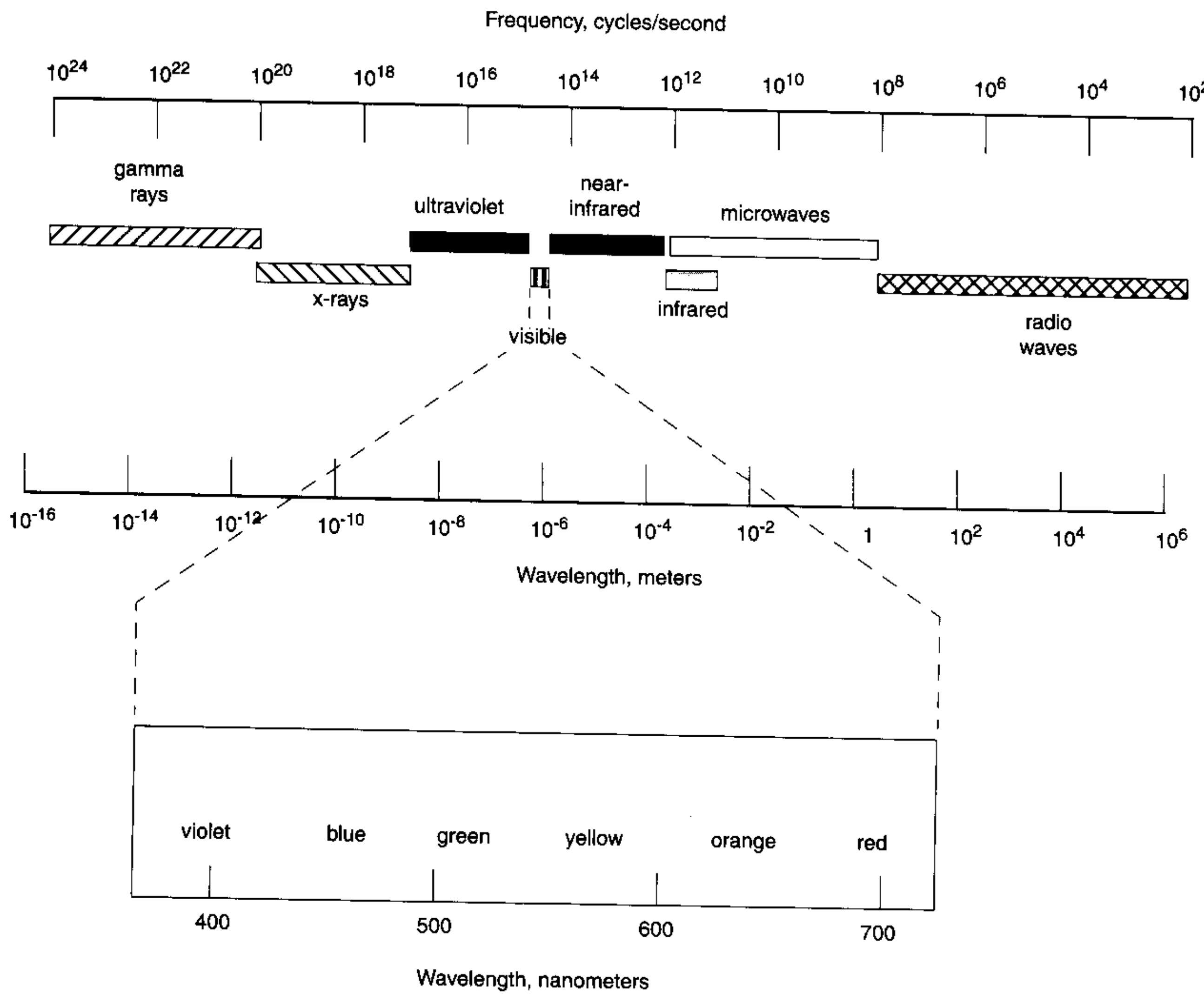
- TIFF (Tagged Image File Format)
  - More general than GIF
  - Allows 24 bits/pixel
  - Supports 5 types of image compression including:
    - RLE (Run length encoding)
    - LZW (Lempel-Ziv-Welch)
    - JPEG (Joint Photographic Experts Group)

The Imaging process

- Light is generated by some source
  - point source
  - extended source
  - white/colored ....
- Light is reflected from some surface
  - matte,
  - mirrorlike
  - colored/light/dark ....
- Light is sensed by some instrument
  - sensitivity
  - field of view
  - gray scale/color/....

Color

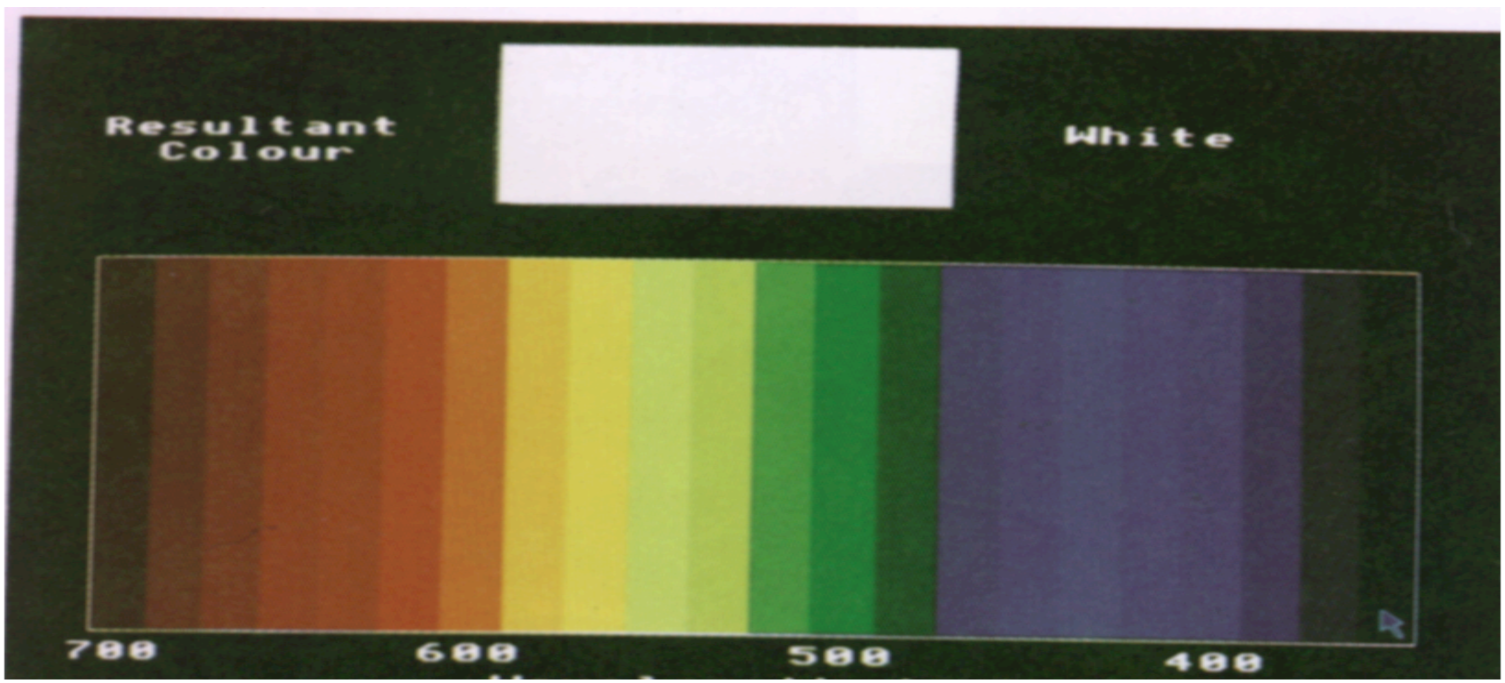
What is Color?



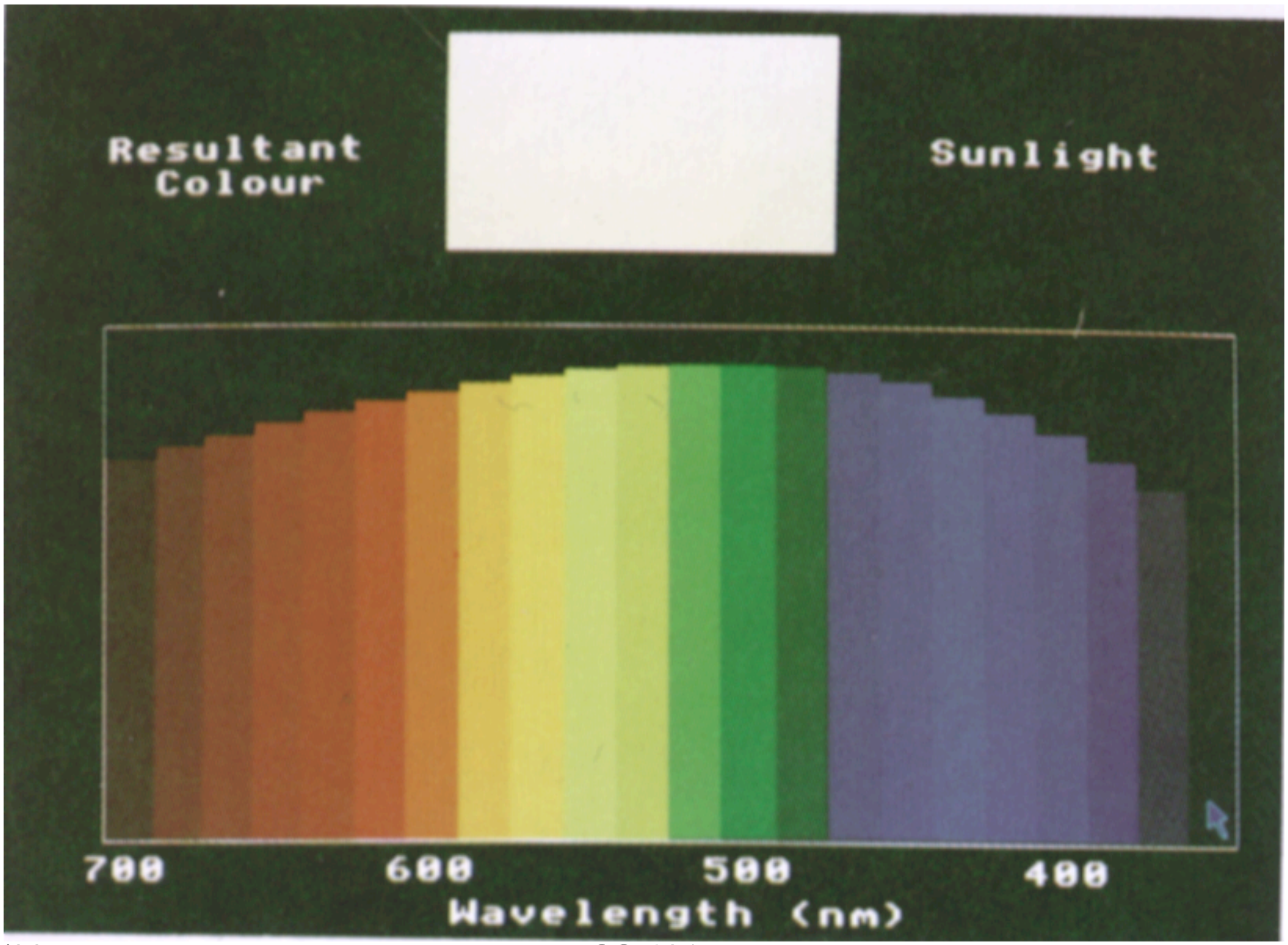
What is Color?

- We almost never see a "pure" wavelength of light; rather a mixture of wavelengths, each with a different "power"

- Only some colors occur as pure wavelengths; many are mixtures of pure colors (e.g. white)



Sunlight



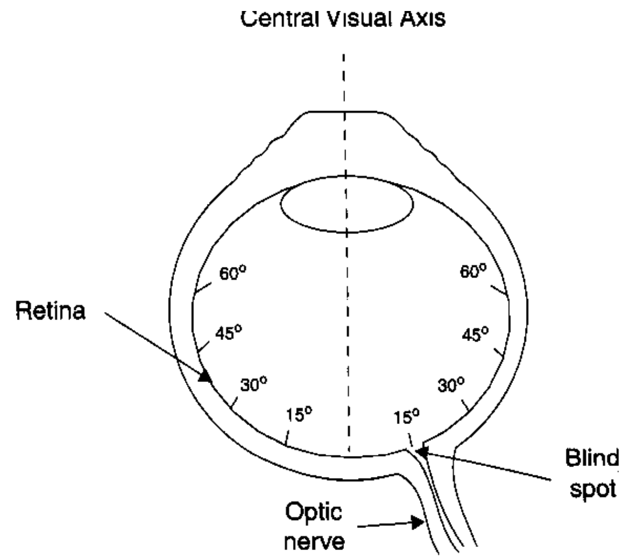
Thermal Imaging for Tracking Humans

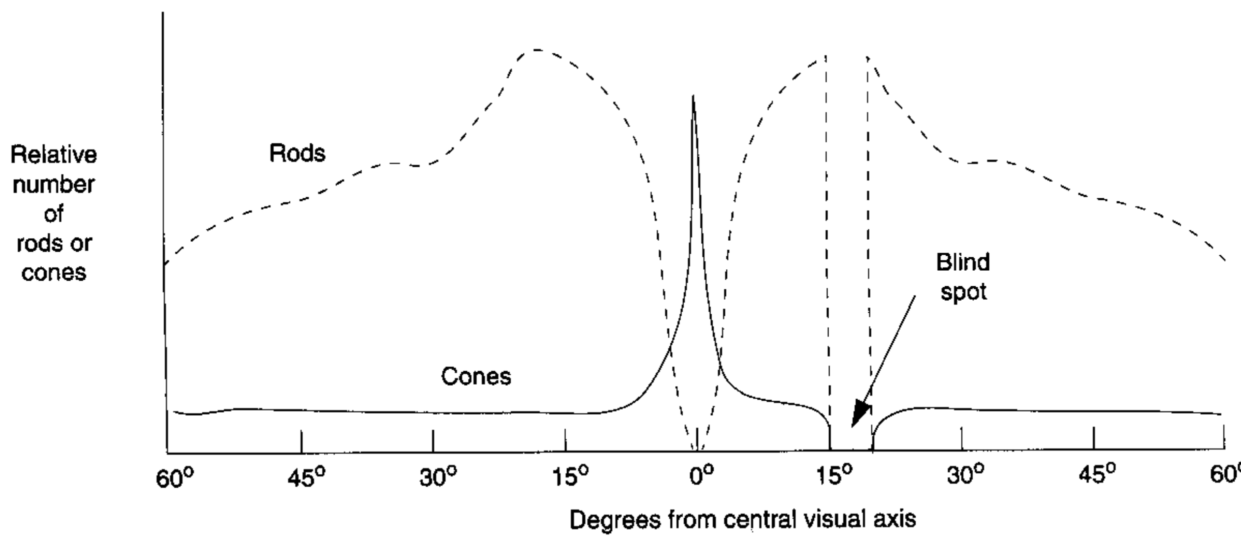
Color Measurement

- Let l denote wavelength
- Let E(l) denote the spectral power at a given wavelength
- Let r_k(l) denote the responsiveness of a sensor k to a given wavelength of light
- Then we can compute the "response" r_k of k as

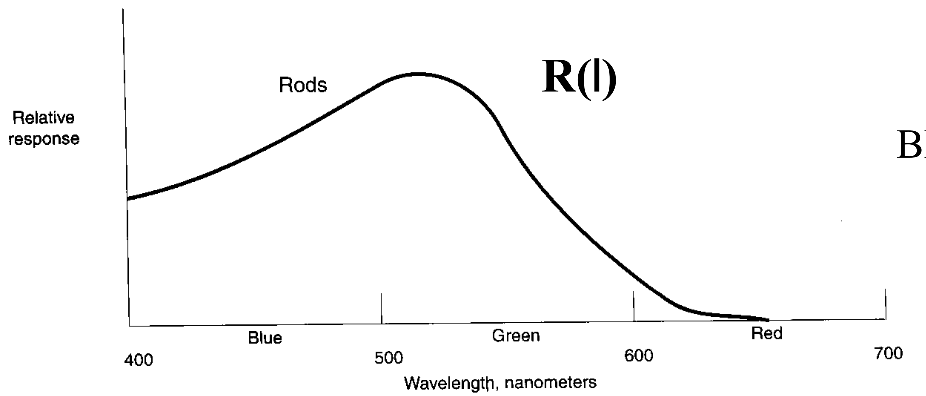
$$r_k = \int \rho(\lambda) E(\lambda) d\lambda$$

EXAMPLE: THE HUMAN EYE

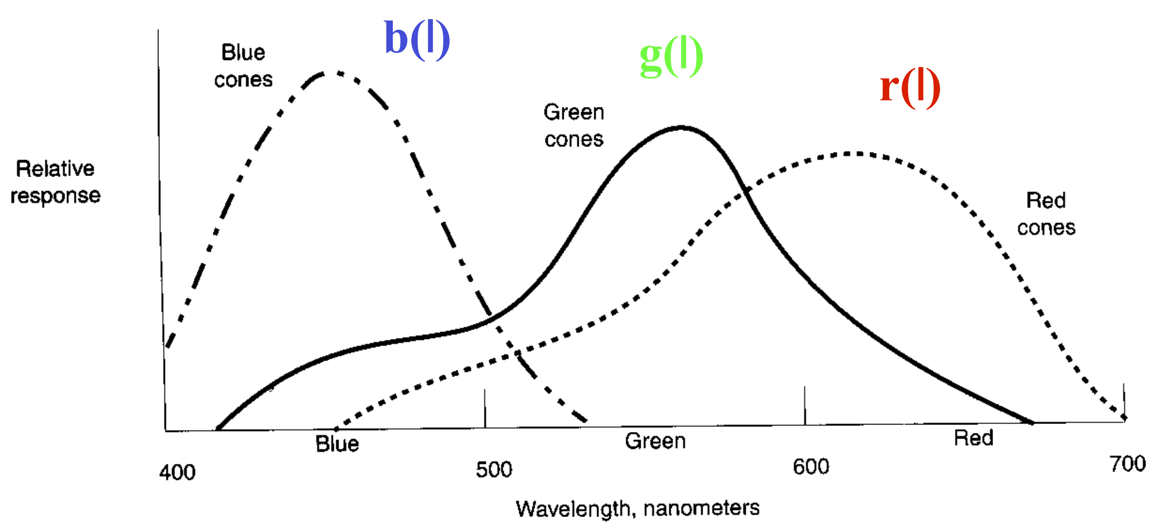




THE HUMAN EYE: RESPONSE



$$\text{BRIGHTNESS} = \int_{\lambda=400nm}^{\lambda=700nm} R(\lambda) I(\lambda) d\lambda$$

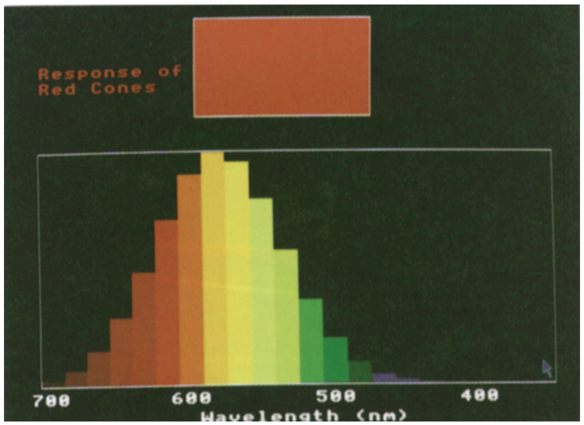


$$\text{RED} = \int_{\lambda=400nm}^{\lambda=700nm} r(\lambda) I(\lambda) d\lambda$$

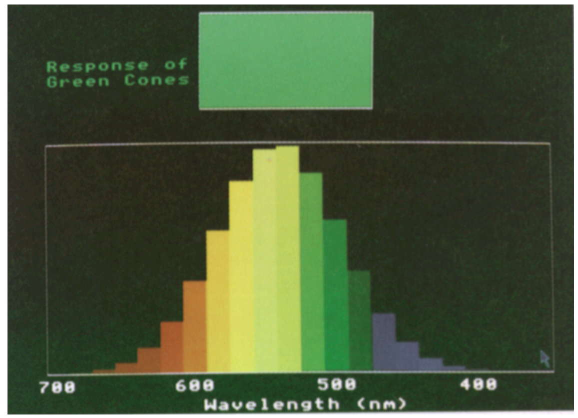
$$\text{GREEN} = \int_{\lambda=400nm}^{\lambda=700nm} g(\lambda) I(\lambda) d\lambda$$

$$\text{BLUE} = \int_{\lambda=400nm}^{\lambda=700nm} b(\lambda) I(\lambda) d\lambda$$

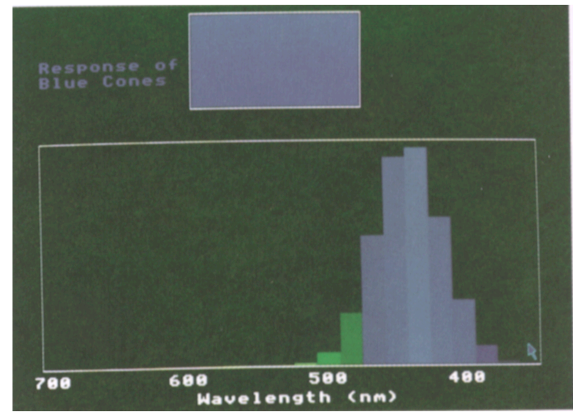
Color receptors



“Red” cone



“Green” cone

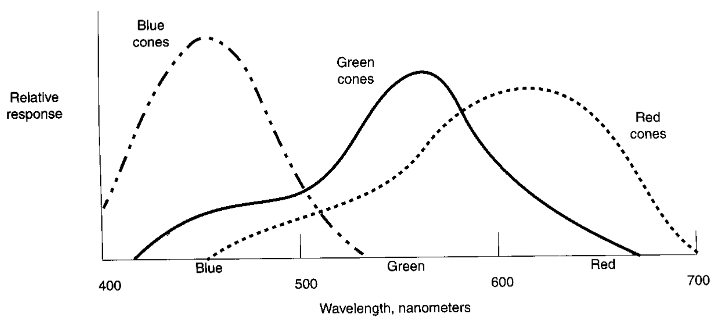


“Blue” cone

Principle of univariance: cones give the same amount of response to different wavelengths -- a single cone cannot distinguish color. Output of cone is obtained by summing probability of absorption over wavelengths.

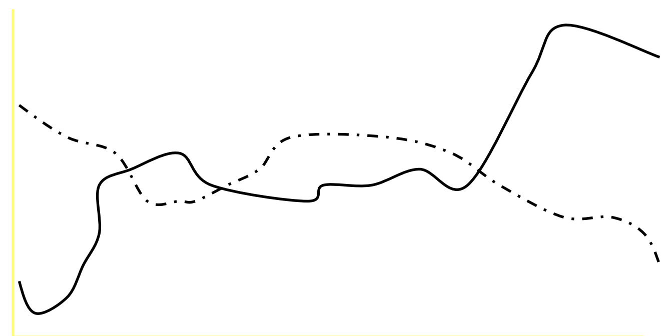
METAMERISM

- Two different Spectral Energy Distributions with the same RED, GREEN, BLUE response are termed ***metamers***.



b(l) g(l) r(l)

Radiance (Energy)



Wavelength
l

How Color Cameras Work

- 1 CCD cameras
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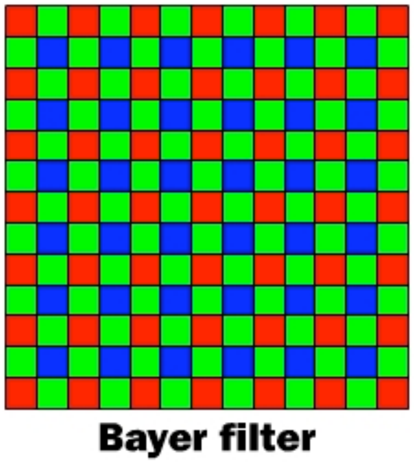
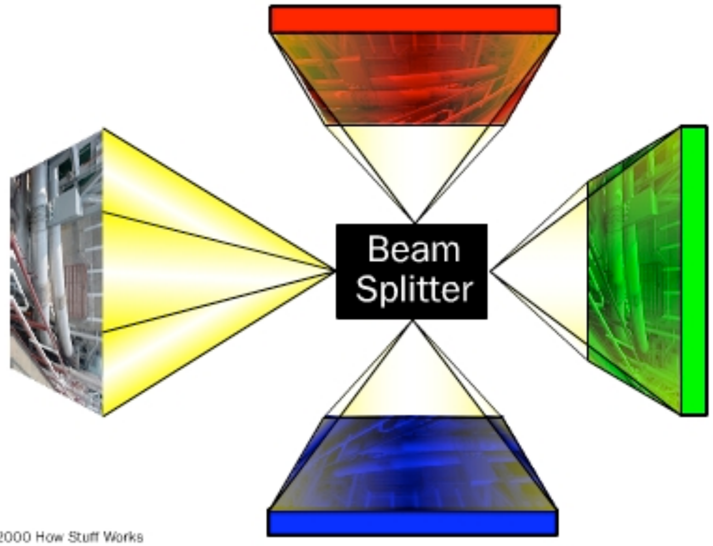
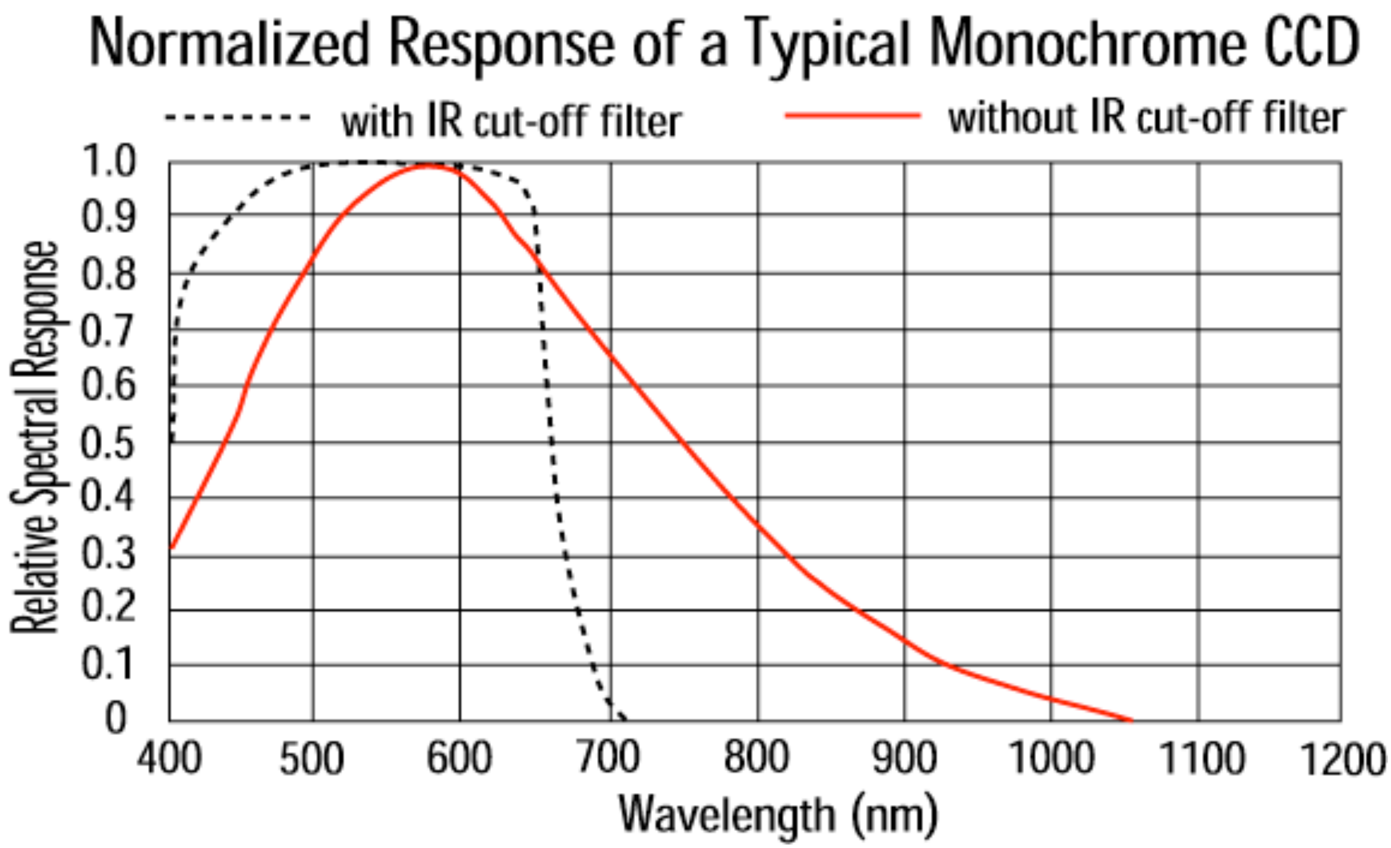
- 3 CCD camera use a beam splitter and 3 separate CCDs
  - higher color fidelity
  - needs lots of light
  - requires careful alignment of ccds

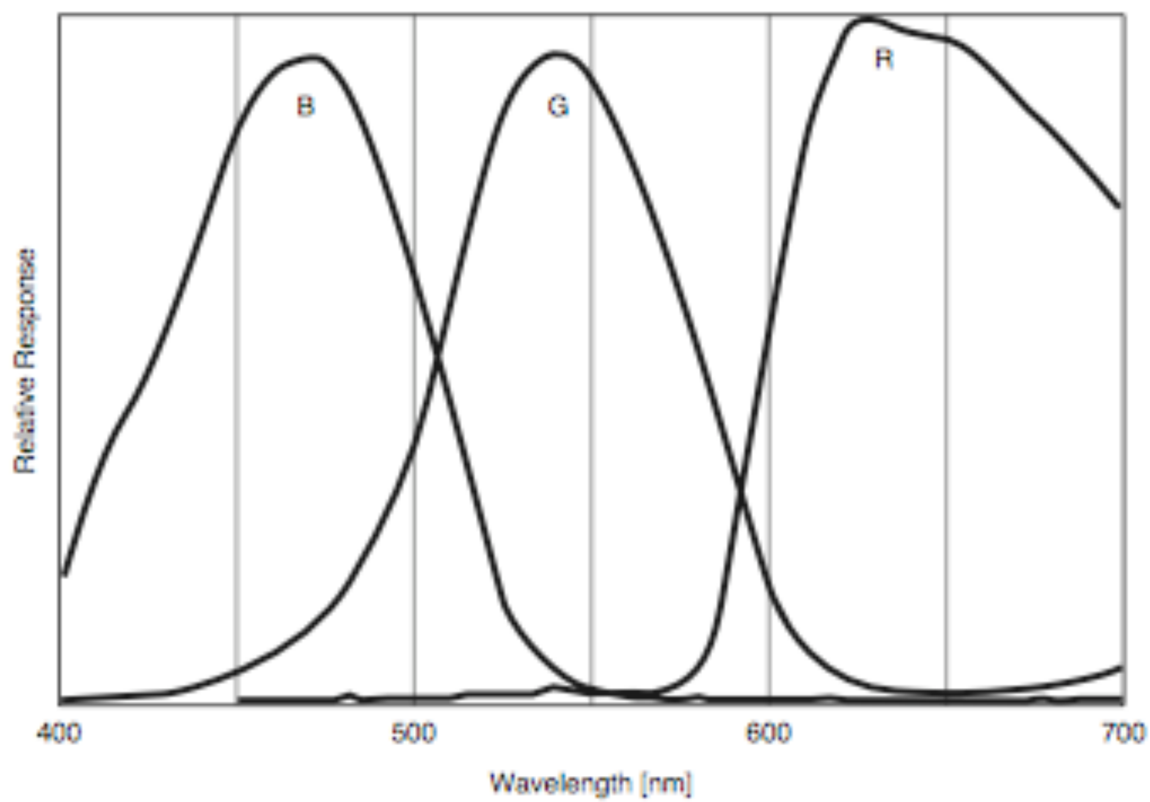




Unfiltered CCD Response



One Chip CCD Response (Sony DFW V500)

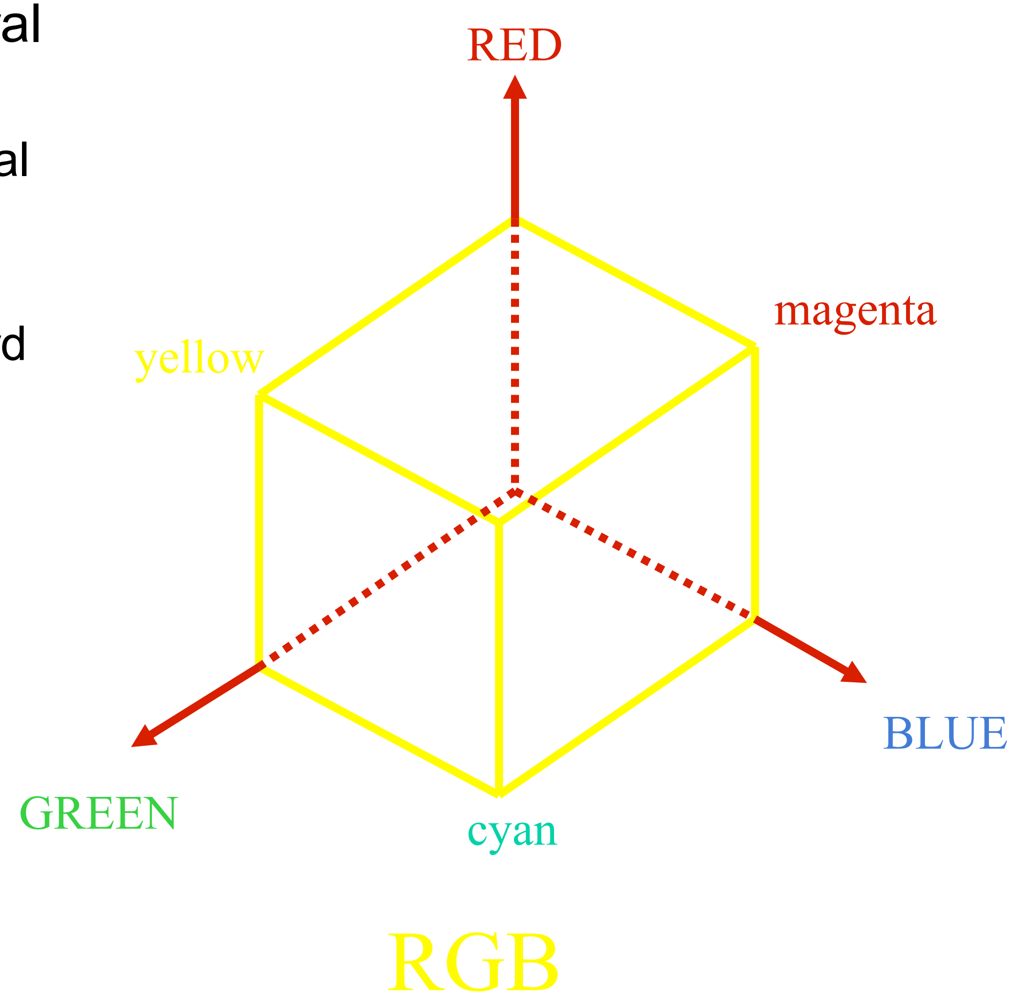


Filtering Colors

Green Red

Standard Linear Color Systems

- Several standards are used to define "color" based on spectral response functions
  - CIE (Commission International d'Eclairage) establishes standards
  - CIE XYZ is a popular standard with everywhere positive response
  - RGB requires a negative (subtractive) component in R response



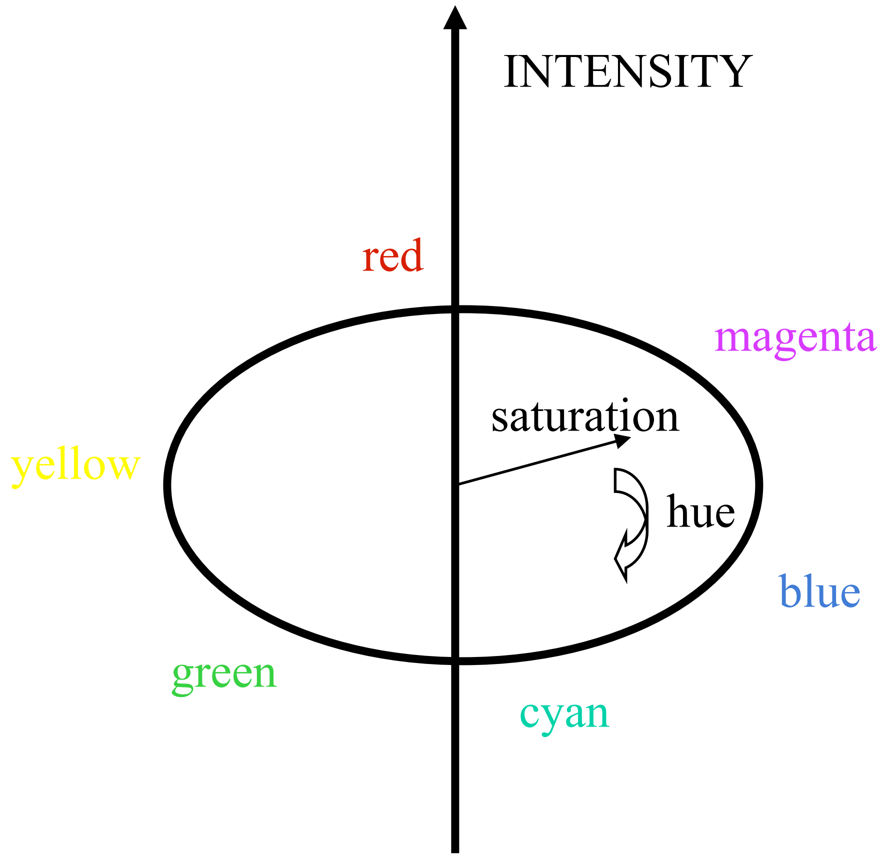
ANOTHER LINEAR SCHEME FOR REPRESENTING COLOR

- Invented for color television (NTSC)
- Backward compatible with B/W TV
- Y given higher bandwidth than I/Q

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} .3 & .59 & .11 \\ .6 & -.28 & -.32 \\ .21 & -.52 & .31 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

YIQ (also YUV); PAL vs. NTSC
YCbCr is YUV with a 0 reference level for Chromiance

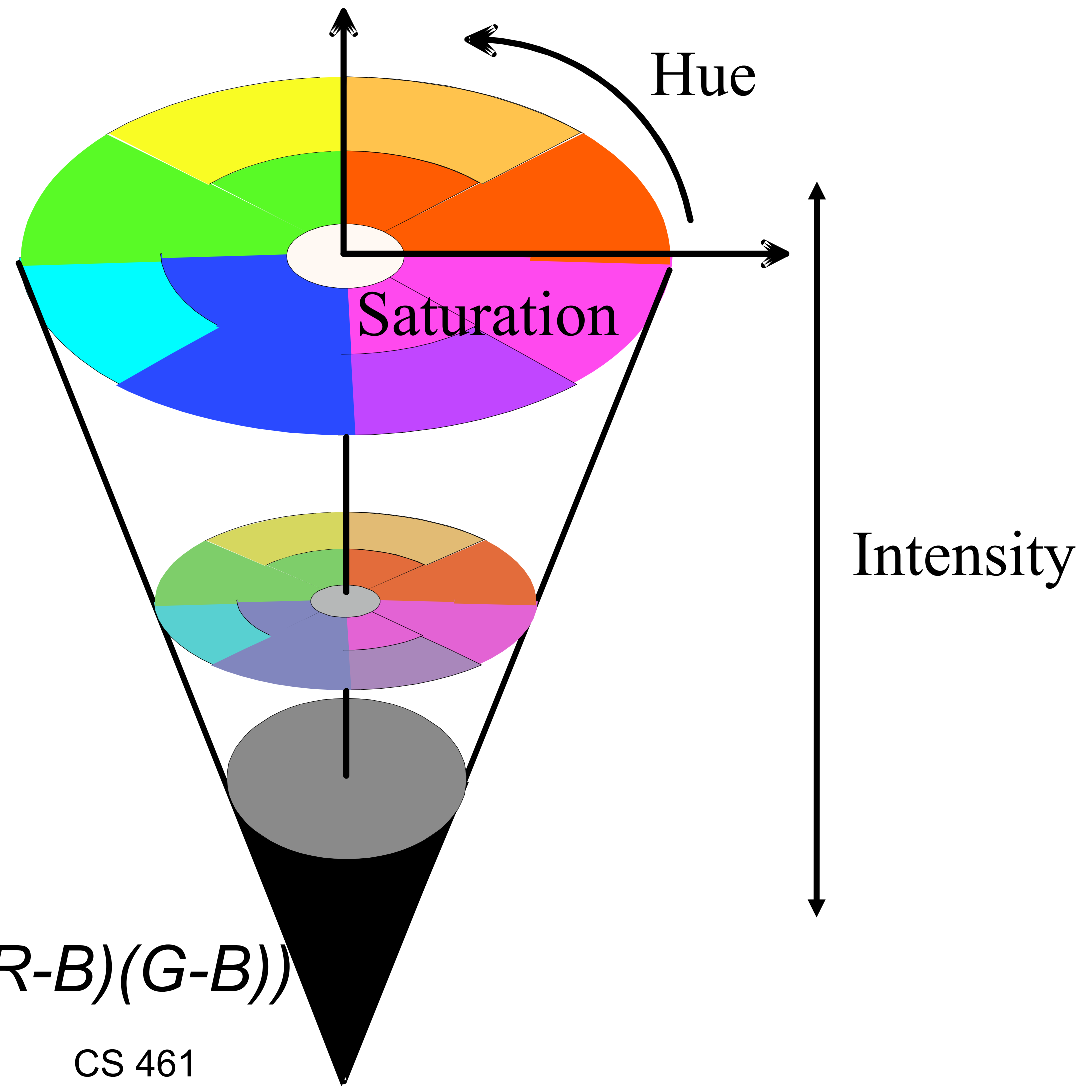
NONLINEAR SCHEMES FOR REPRESENTING COLOR



HSI

Dividing Up Color Space

HSI is a nonlinear representation of color space. Note the non-uniform treatment of color



$I = (R+G+B)/3$ or
$L = .3\,R + .6G + .1B$

$S = 1 - 3\min(R,G,B)/I$

$$H = \begin{cases} \cos^{-1}(x) & \text{if } G > B \\ p - \cos^{-1}(x) & \text{if } G < B \end{cases}$$

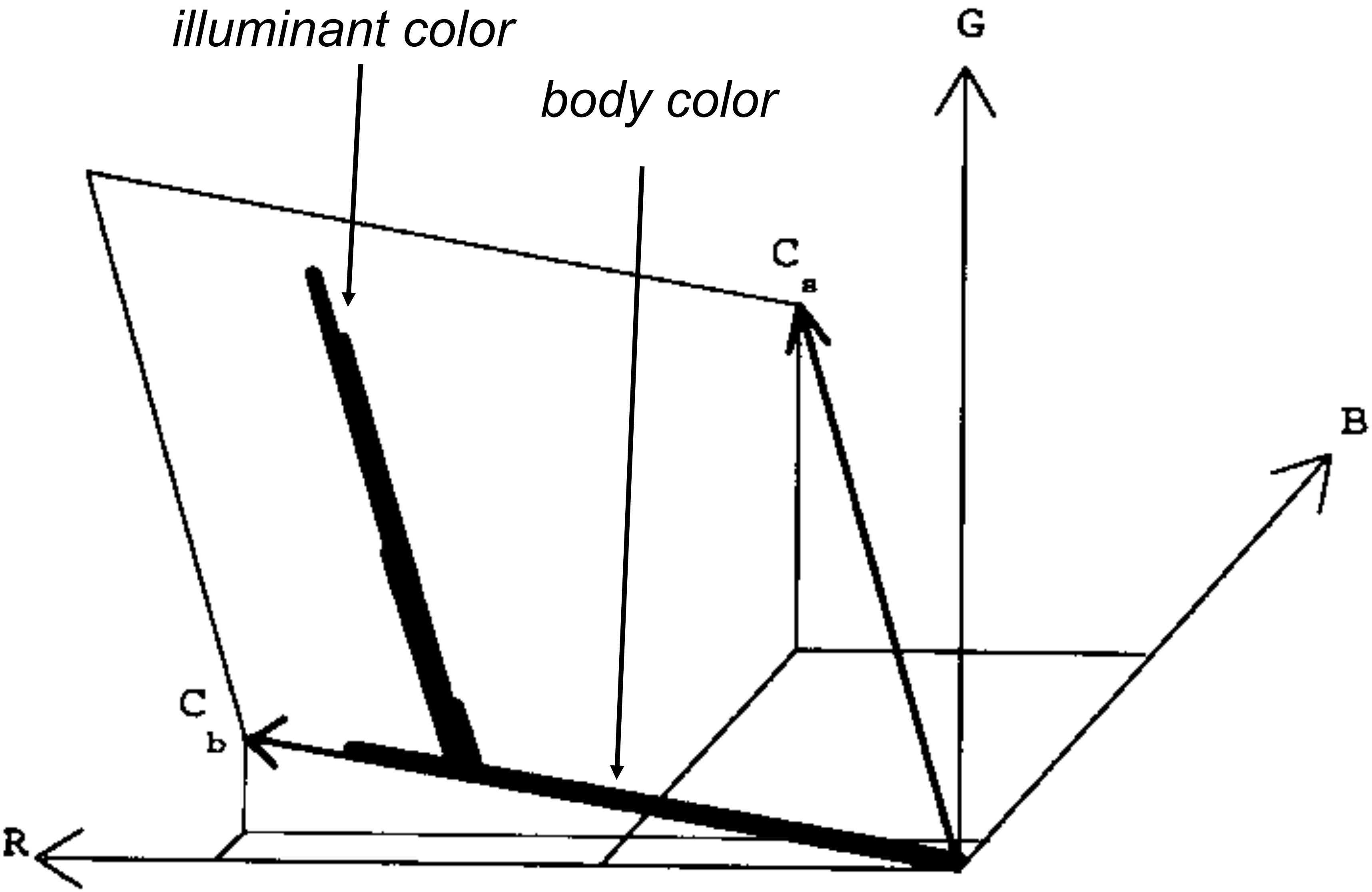
$x = (R-G) + (R-B)/((R-G)^2 + (R-B)(G-B))$

Tieing Things Together: Color Imaging

- Color imaging is a complex process involving the intrinsic color of the object, in color of the illumination, inter-reflection of surfaces ....
- As a result, what we might perceive as “constant” color is in fact widely varying depending on the vantage point
- There are several extant theories of color constancy, but this is still an open problem: there is no algorithm that comes close to human performance

Example Use: Finding Specularities

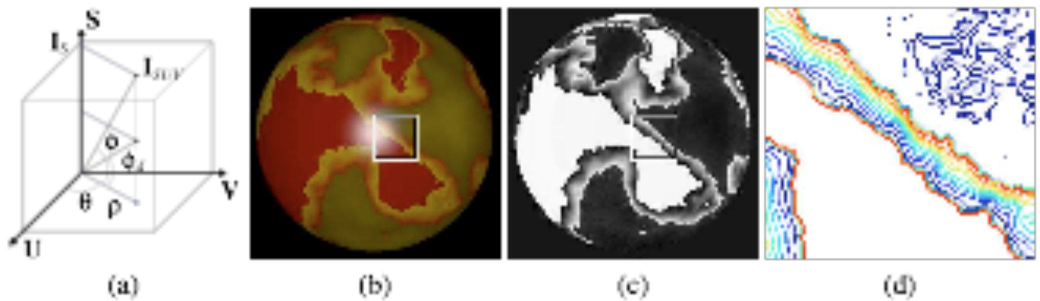
- Assume we are dealing with dielectrics
  - specularly reflected light is the same colour as the source
- Reflected light has two components
  - diffuse
  - specular
  - and we see a weighted sum of these two


illuminant color
body color
G
B
R
C_s
C_b

Initial Image

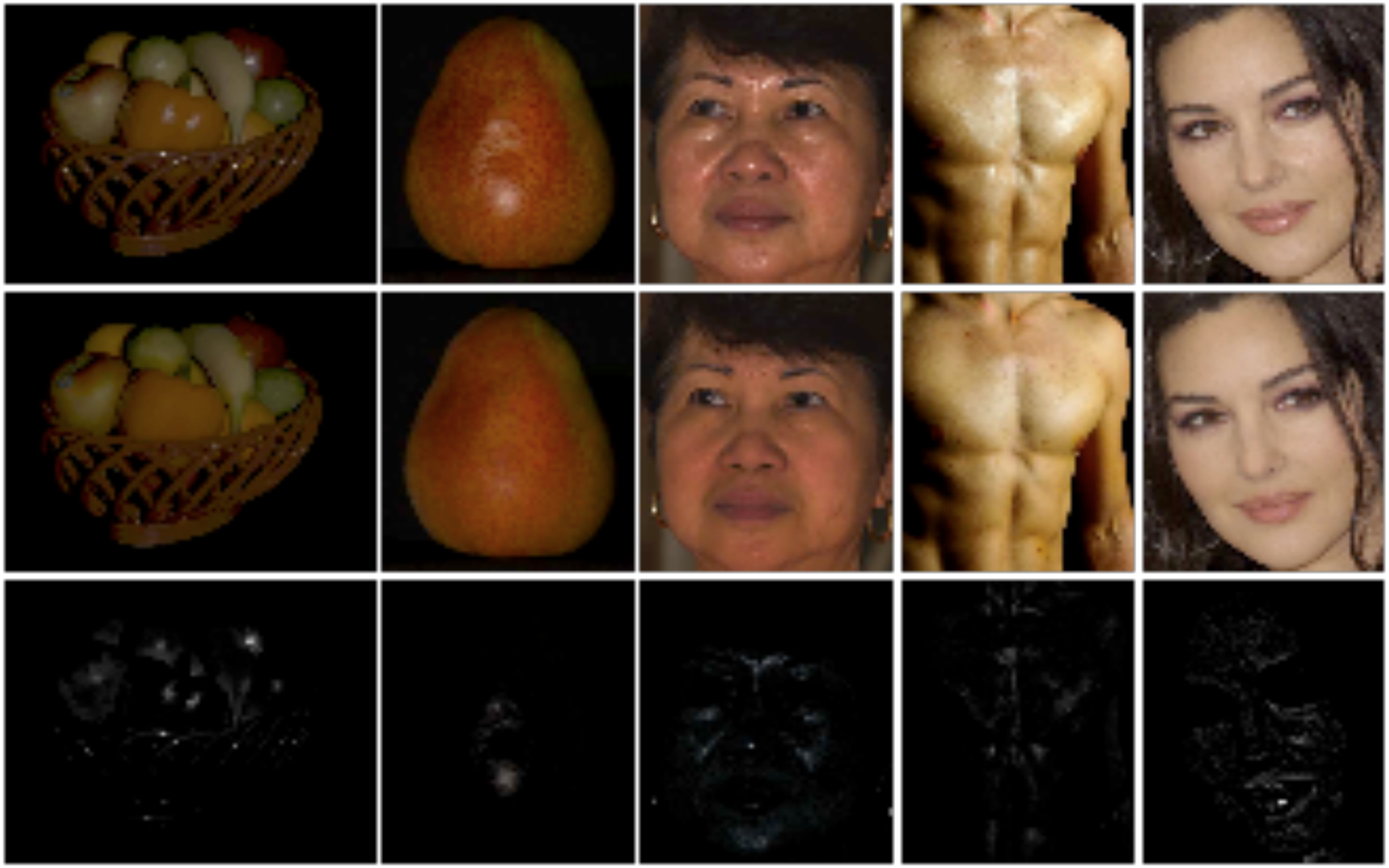
A “Color Space” For Specularities

(Mallick et al. CVPR, 2006)



- Create an YUV-like “color space” where the central axis points in the direction of the source: SUV
- The S axis measures the illumination brightness; off-axis are the remaining color components
- Now, run a diffusion process to “smooth” the S component throughout the image (this is tricky!)

Specularity Removal Result



Check out taaz.com

Summary

- Cameras and how they work --> plusses and pitfalls
- Radiance/irradiance and BRDF --> photometric stereo
- Color imaging --> color systems and color constancy
- Images and storage ---> how matlab handles things