Cameras and Imaging

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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/....

A Word On Computer-Imaging

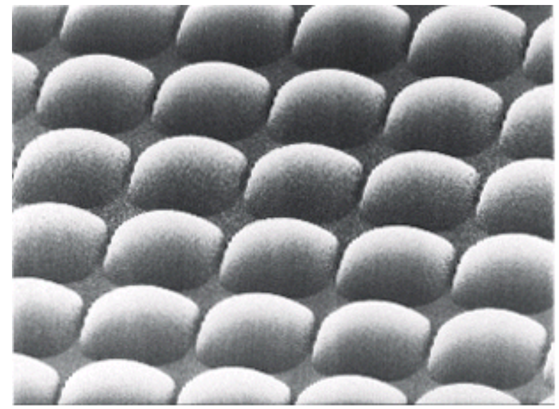
- Video imaging has gone from an exotic technology to everyday commodity.

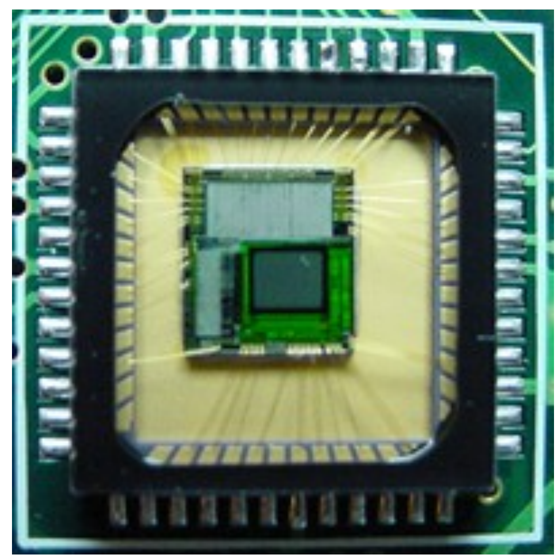
- Originally (since ~1930) NTSC standard
  - 480 x 640 YUV
  - Interlaced

- Now, a wide variety of resolutions and quality
  - VGA (= NTSC)
  - SVGA (= 600x800)
  - XVGA (= 768x1024)
  - SXGA (=1024x1280)
  - UGA (= 1200x1600)
  - HD (= 1080x1960)
  - SHD (=1080x1960x2)

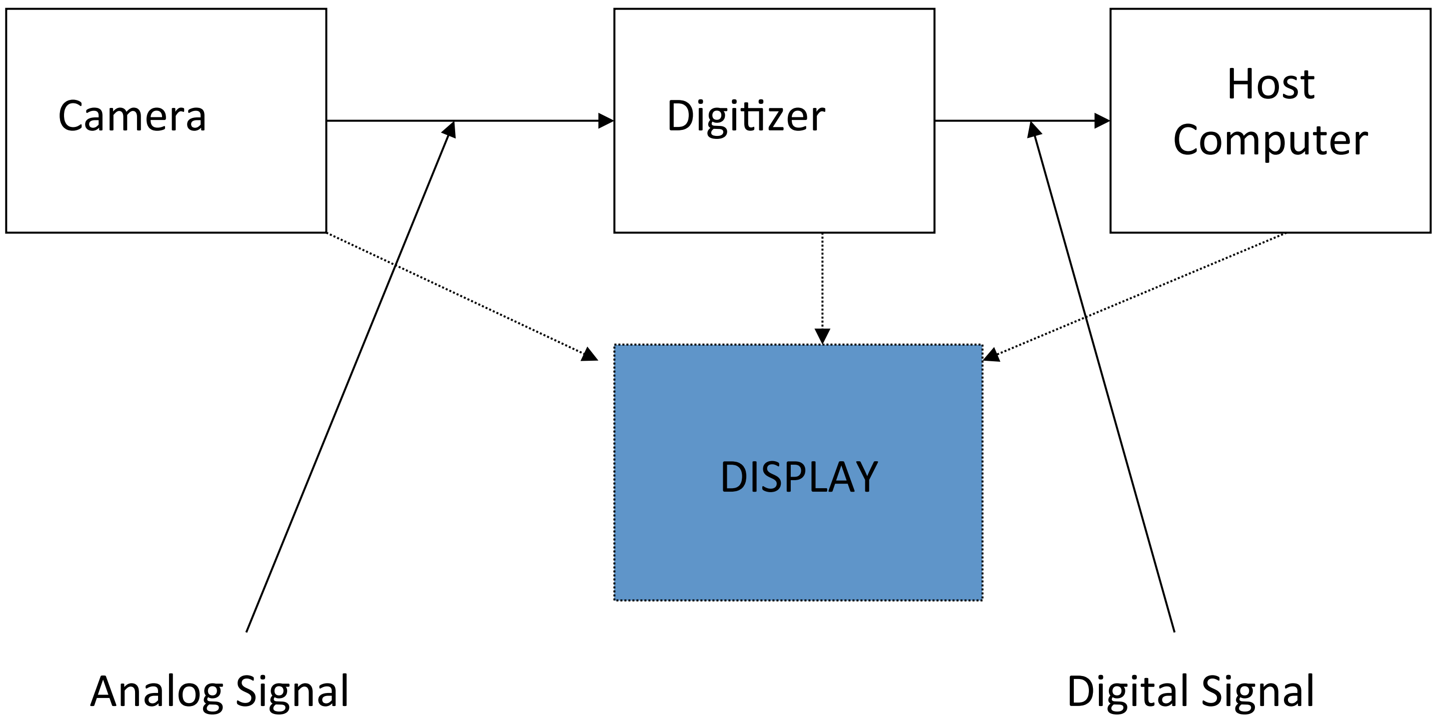
How Cameras Produce Images

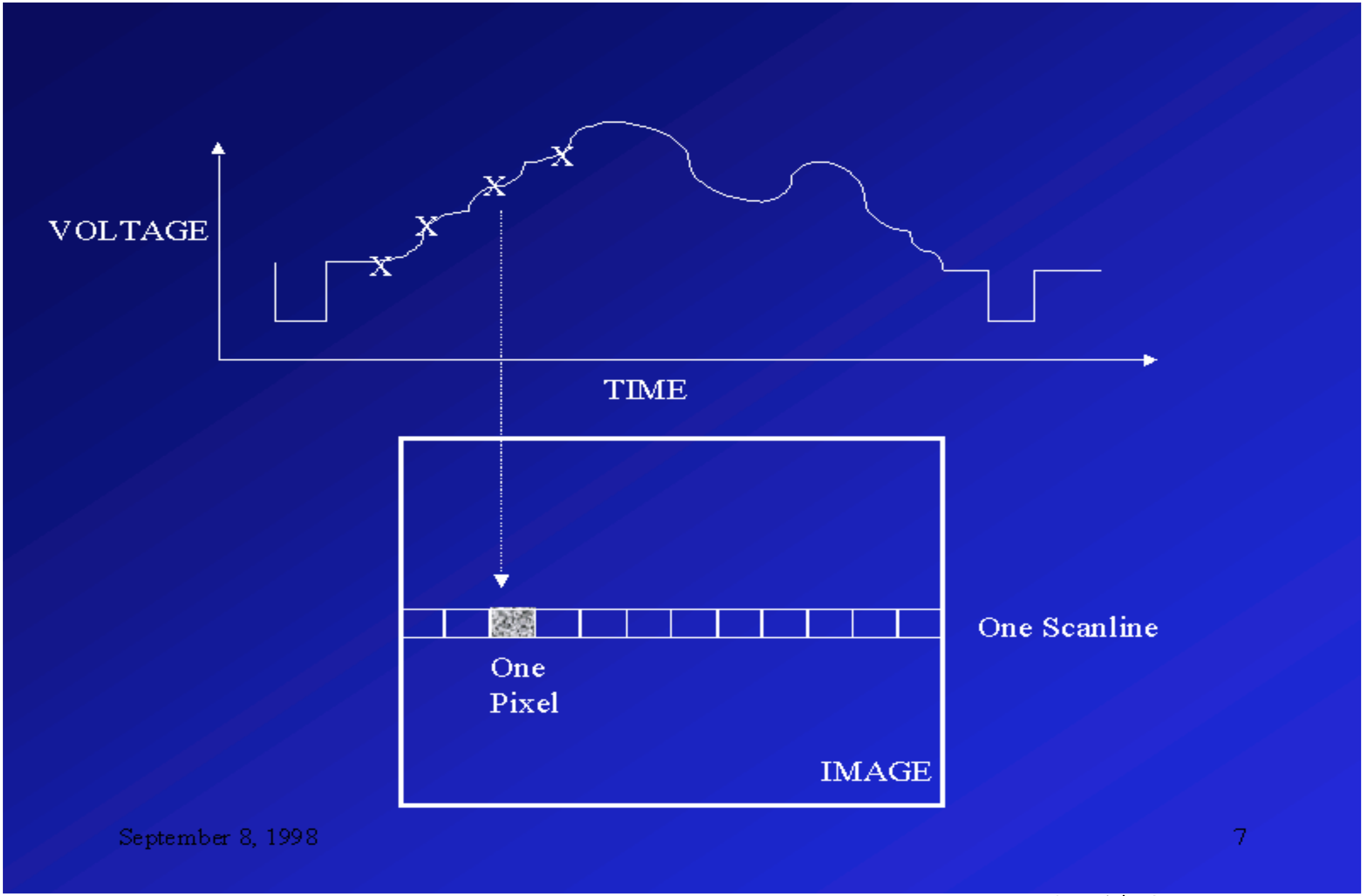
- Basic process:
  - photons hit a detector
  - the detector becomes charged
  - the charge is read out as brightness
- Sensor types:
  - CCD (charge-coupled device)
    - most common
    - high sensitivity
    - high power
    - cannot be individually addressed
    - blooming
  - CMOS
    - simple to fabricate (cheap)
    - lower sensitivity, lower power
    - can be individually addressed



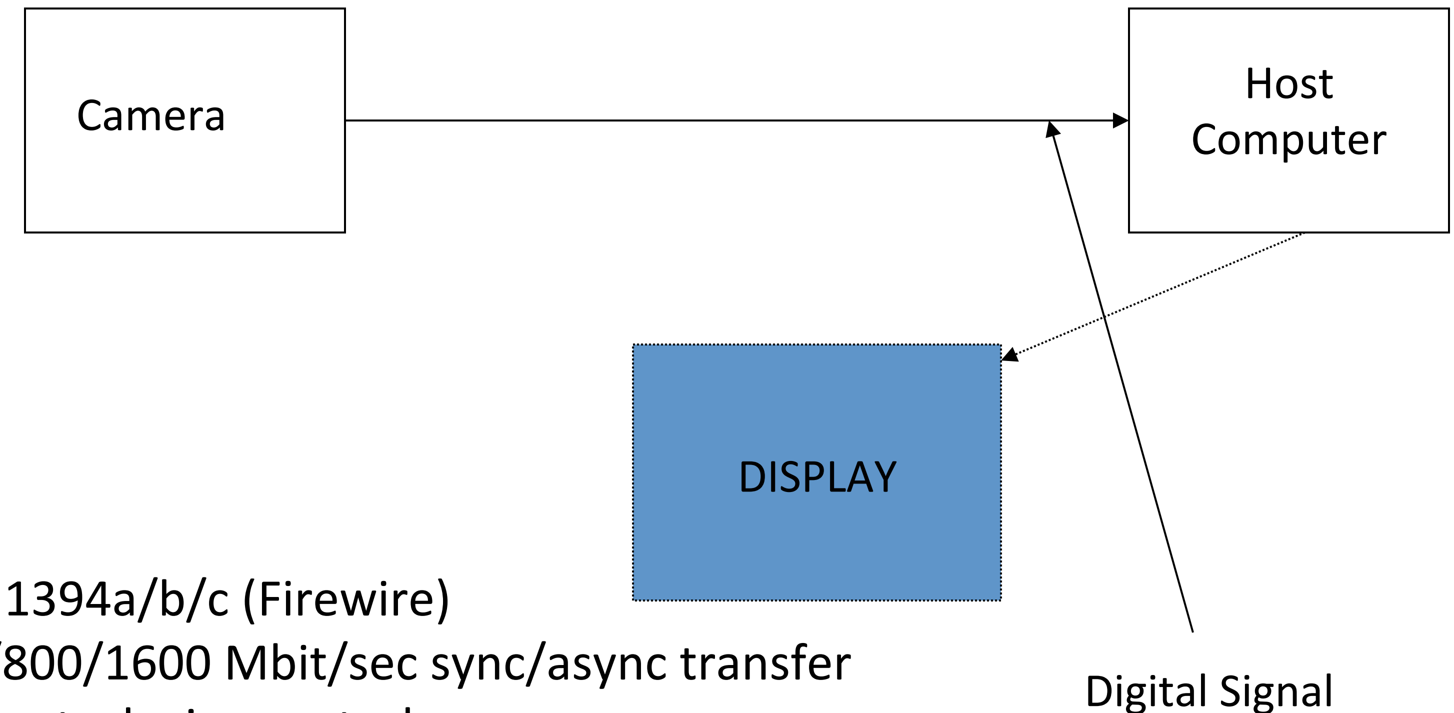


A "Traditional" Camera




VOLTAGE
TIME
One Scanline
One
Pixel
IMAGE
September 8, 1998
7

A Modern Digital Camera



IEEE 1394a/b/c (Firewire)
400/800/1600 Mbit/sec sync/async transfer
Supports device control

USB 2.0
480 Mbit/sec (~280Mbit/sec in practice)
USB 3.0 – 5 Gb
Less flexible, but simpler to implement

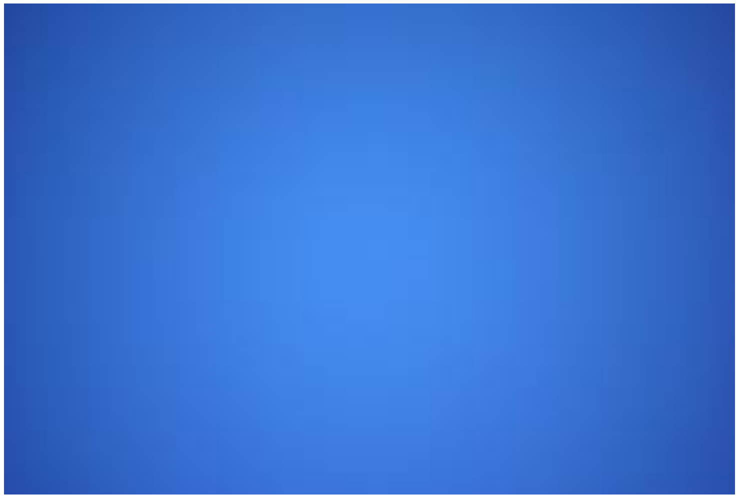
Other Issues

- 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).

What's going on here?

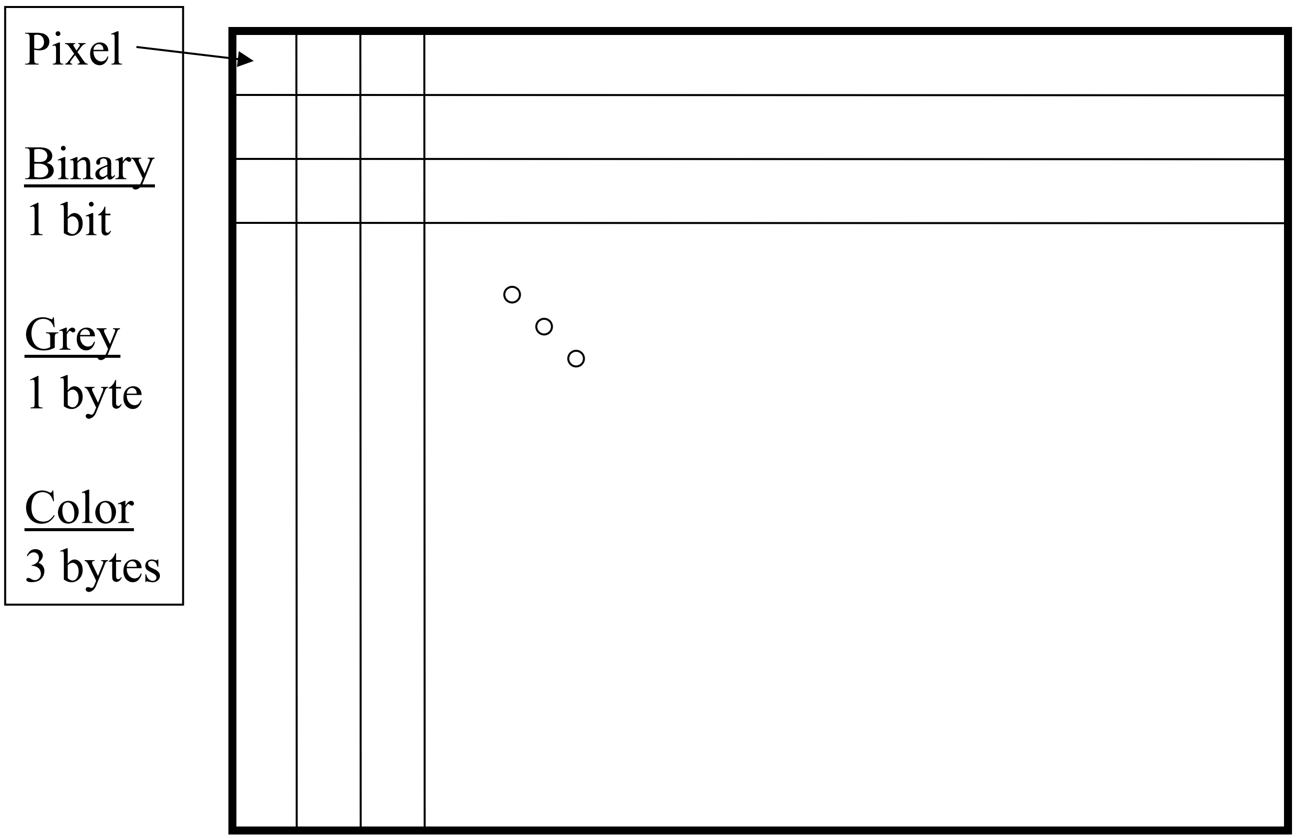
Other Issues

- Vignetting: limitations of finite lens systems and off-axis capture of lighting



What's going on here?

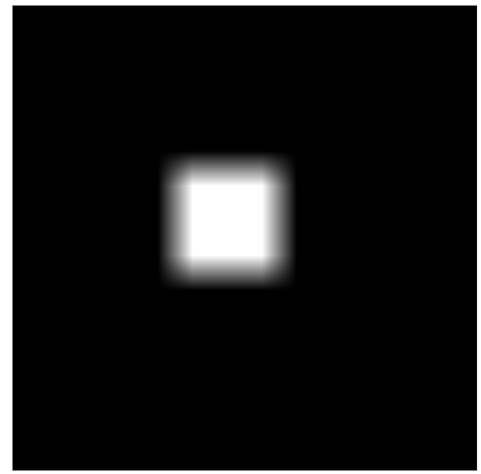
THE ORGANIZATION OF A 2D IMAGE

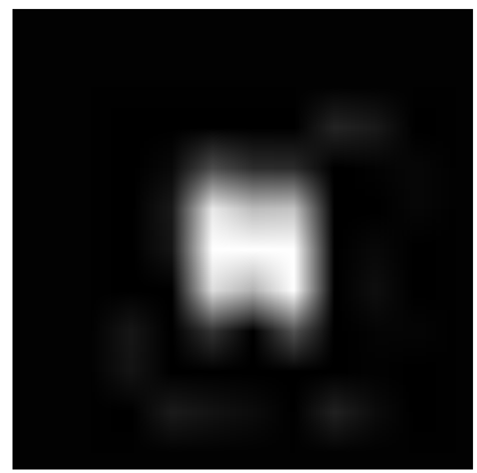


Storing Images

- Non-lossy schemes
  - pbm/pgm/ppm/pnm
    - code for file type, size, number of bands, and maximum brightness
  - tiff (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





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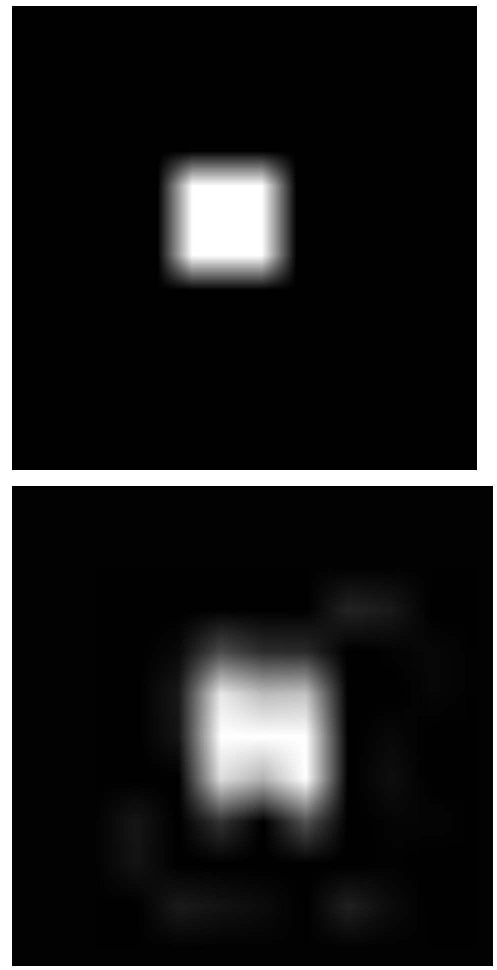


GIF IMAGE FORMAT

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

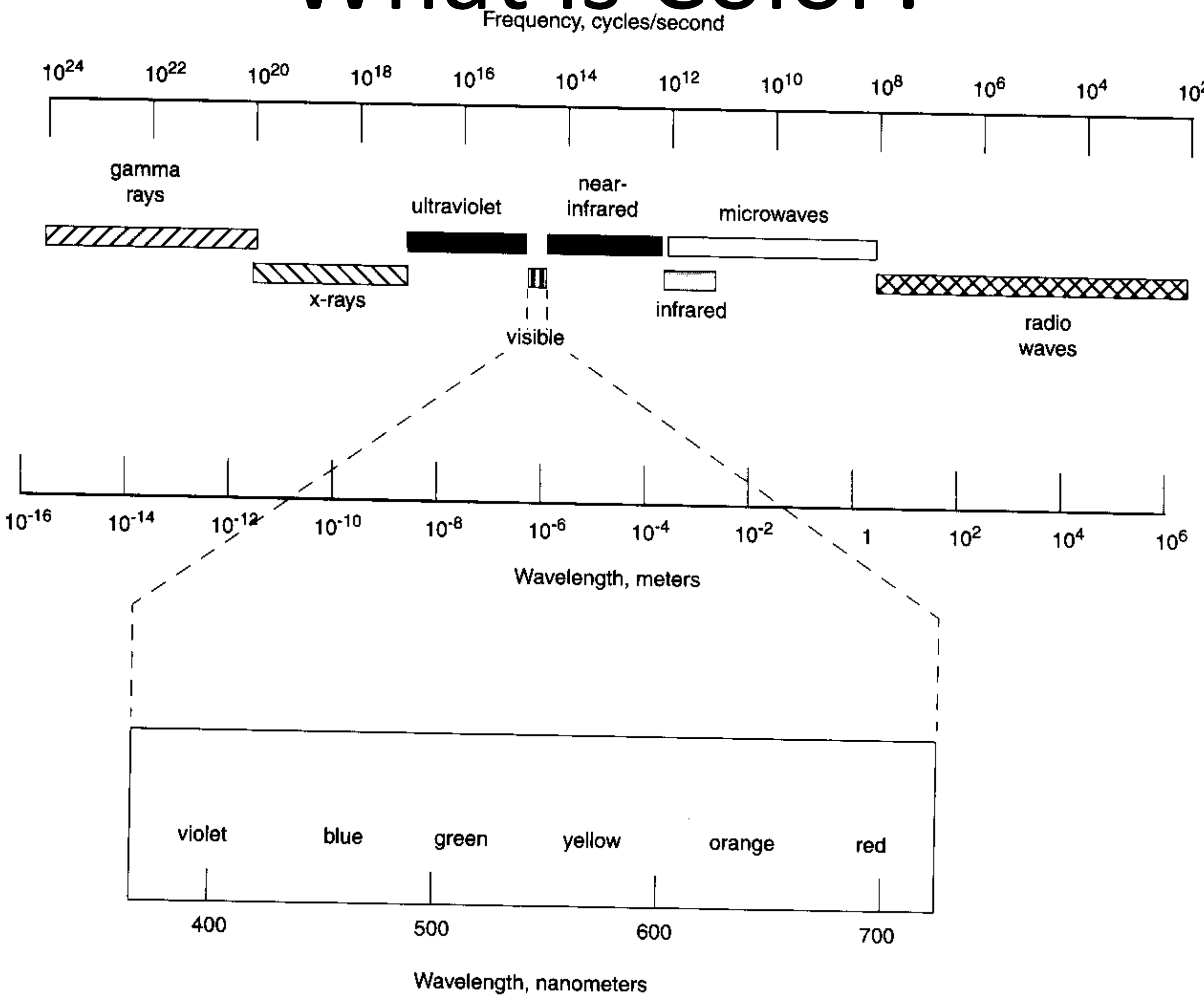
8-bit index	RED	GREEN	BLUE
0	R0	G0	B0
1	R1	G1	B1
2	R2	G2	B2
	⋮	⋮	⋮
254	R254	G254	B254
255	R255	G255	B255

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)

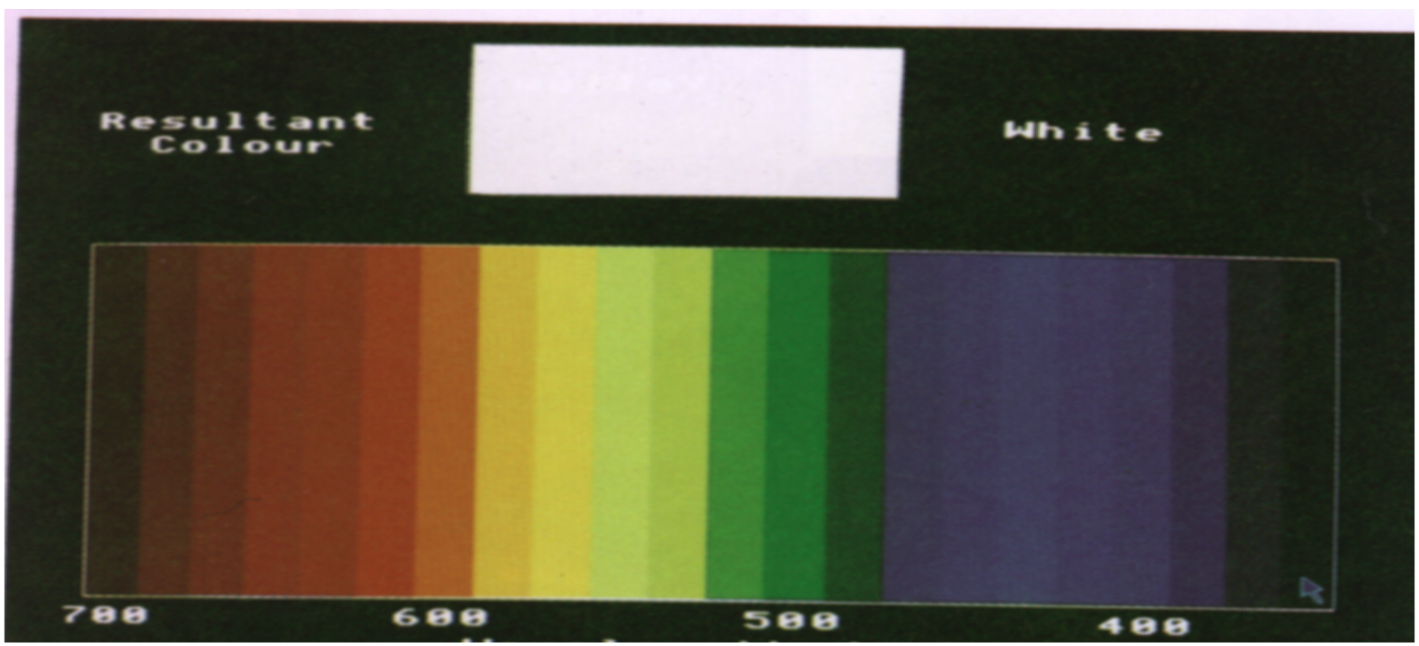
Color

What is Color?

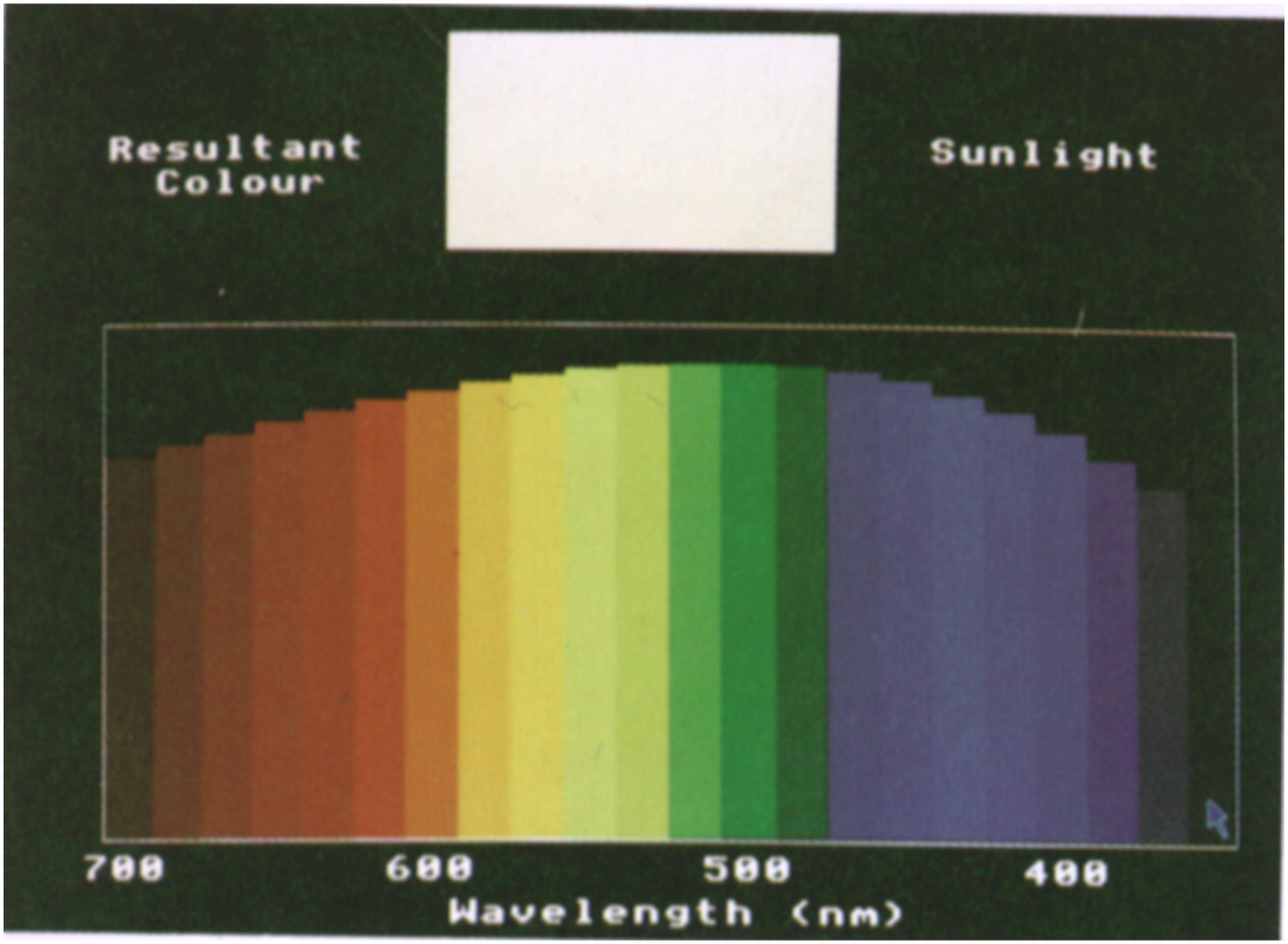


What is Color?

- 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



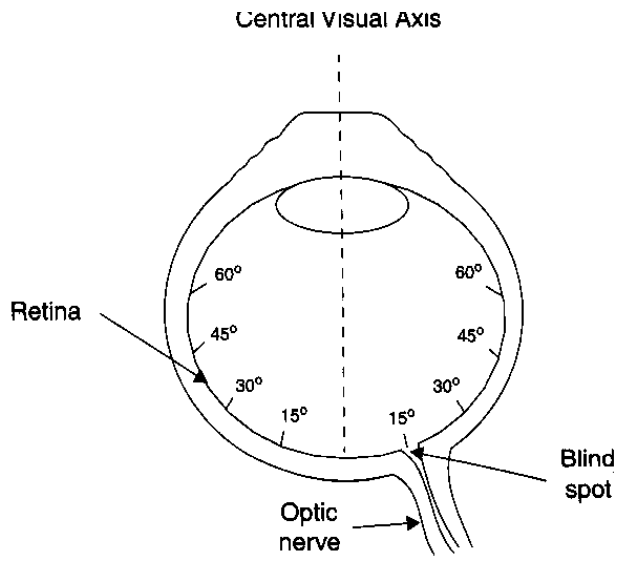
Thermal Imaging for Tracking Humans

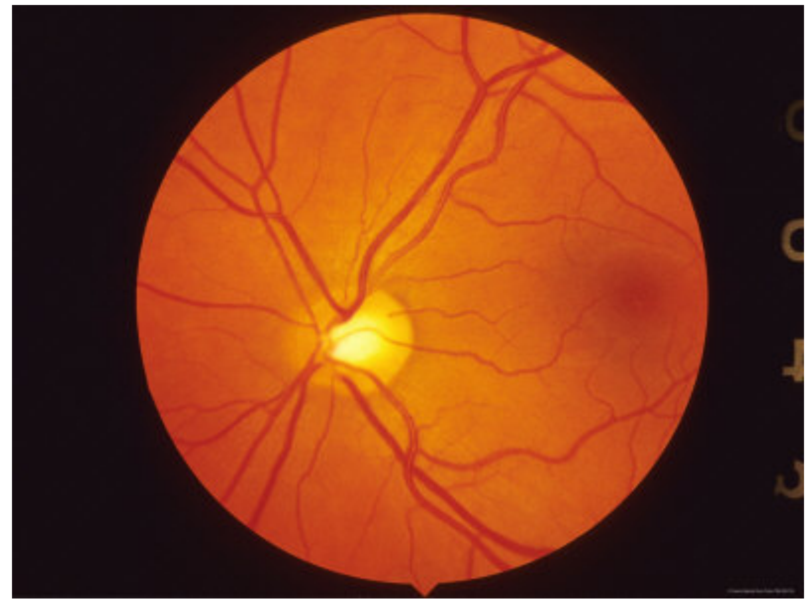
Color Measurement

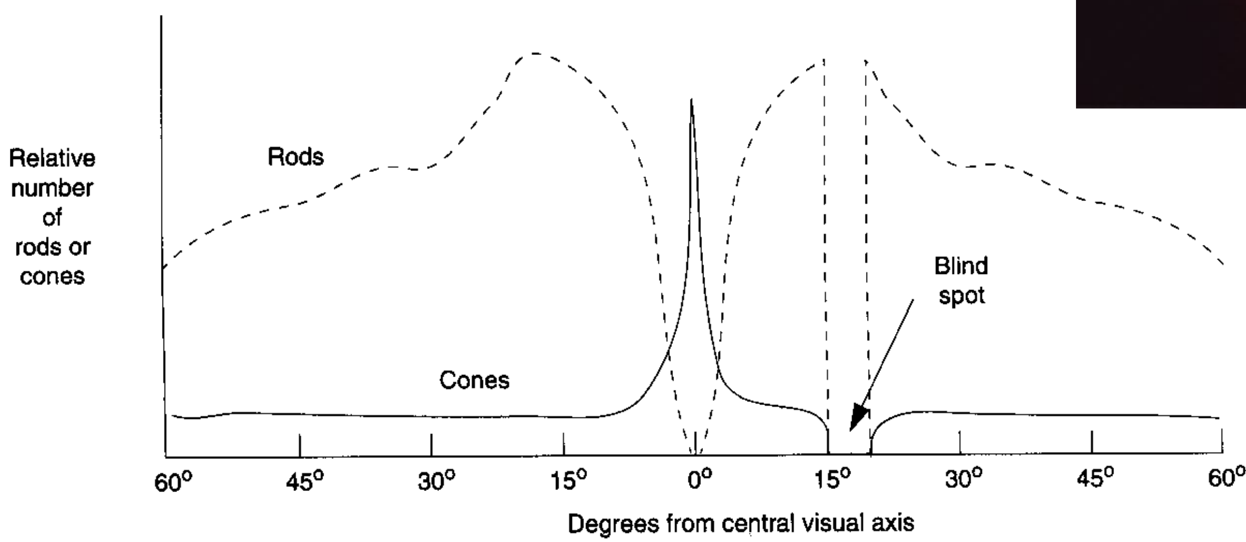
- Let λ denote wavelength
- Let $E(\lambda)$ denote the spectral power at a given wavelength
- Let $\rho_k(\lambda)$ denote the responsiveness of a sensor k to a given wavelength of light
- Then we can compute the "response" r_k of k as

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

Example: The Human Eye







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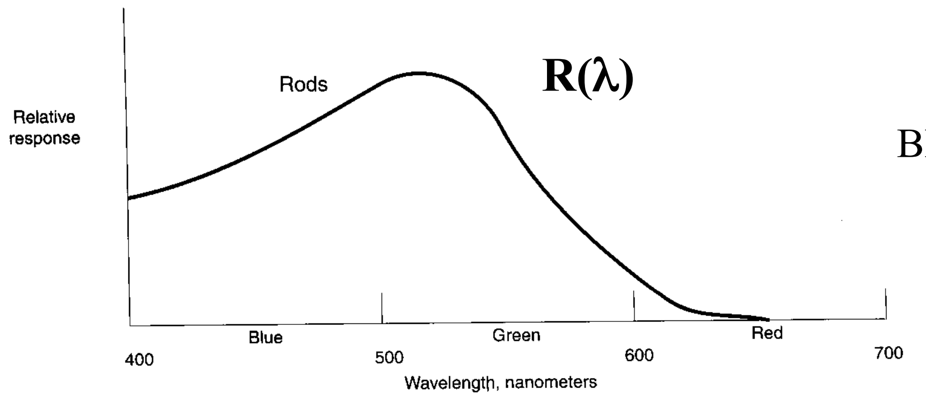
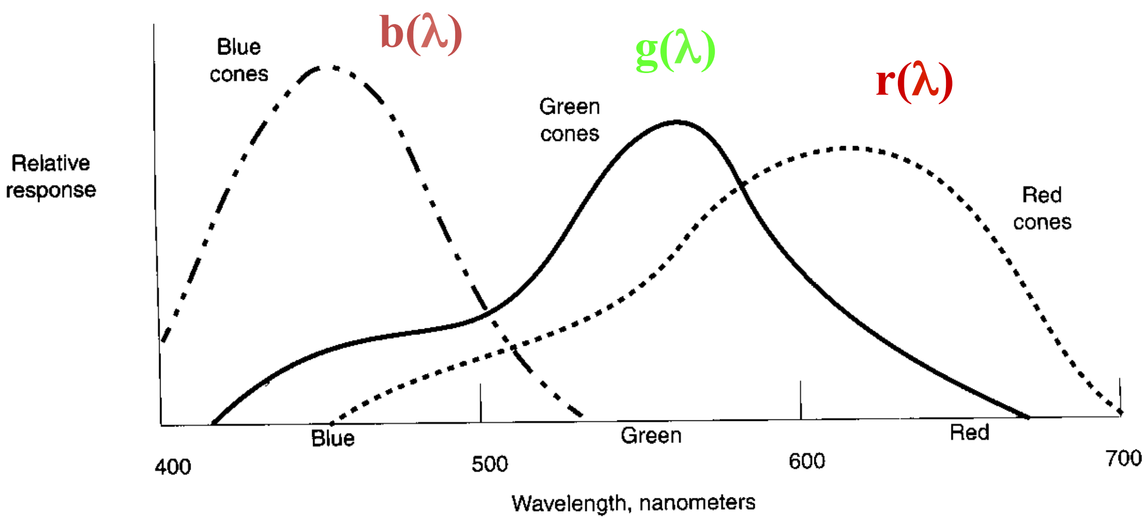
THE HUMAN EYE: RESPONSE



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

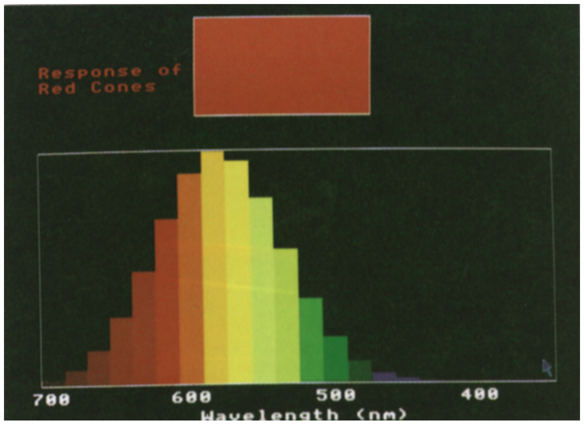


$$\text{RED} = \int_{\lambda=400nm}^{\lambda=700nm} r(\lambda) I(\lambda) d\lambda$$

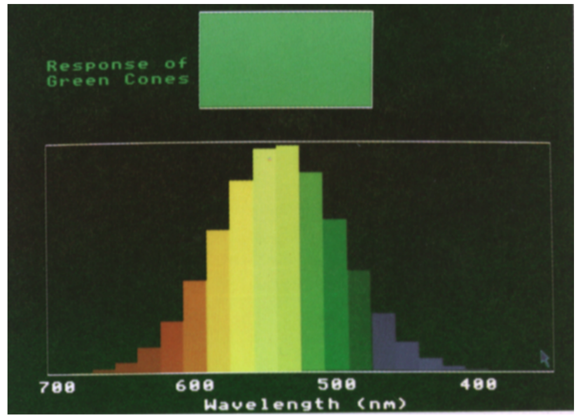
$$\text{GREEN} = \int_{\lambda=400nm}^{\lambda=700nm} g(\lambda) I(\lambda) d\lambda$$

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

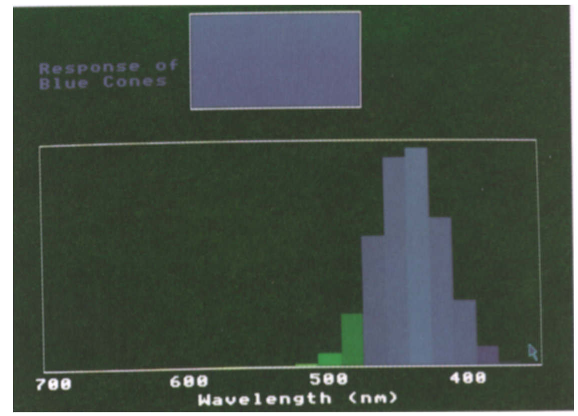
Color receptors



"Red" cone

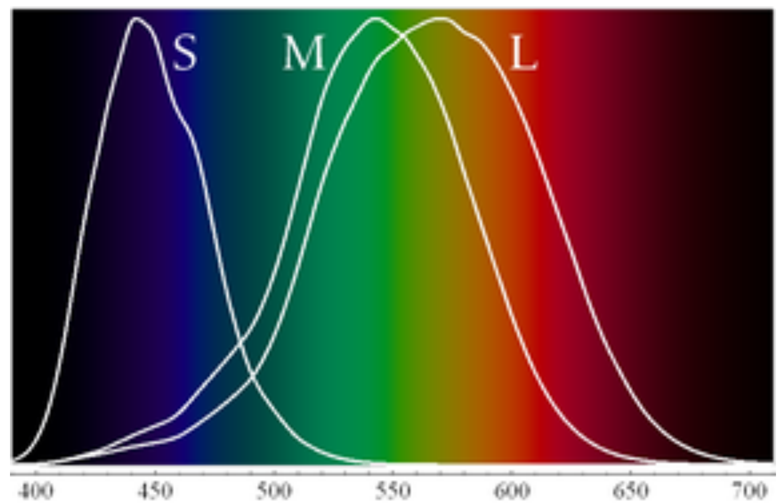


"Green" cone



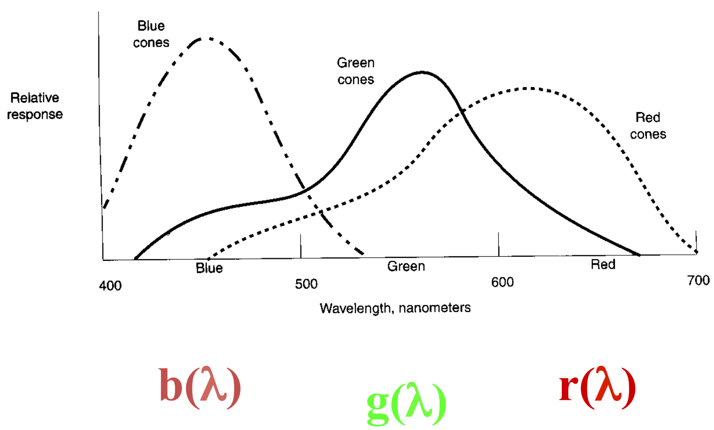
"Blue" cone

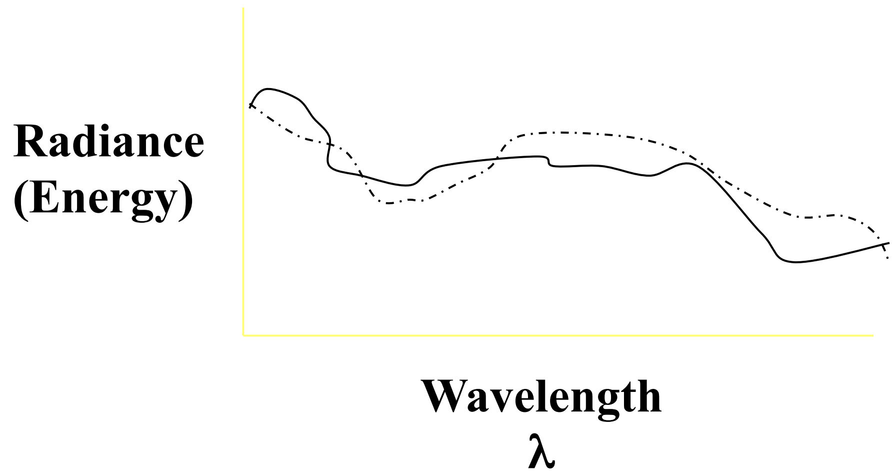
Principle of univariance: cones give the same amount of response to different wavelengths -- a single cone cannot distinguish color. Output of cone is obtained by summing probability of absorption over wavelengths.



Metamerism

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

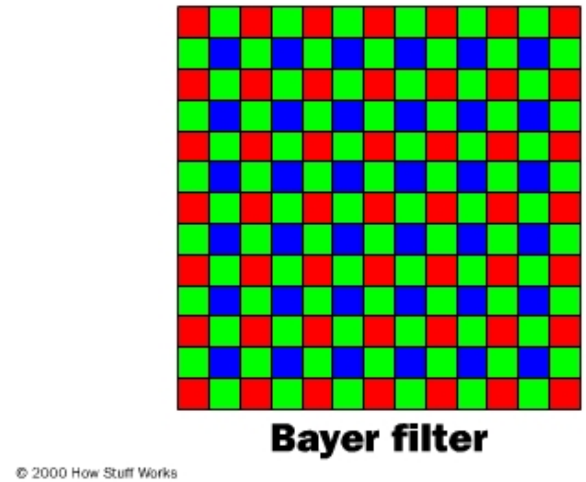


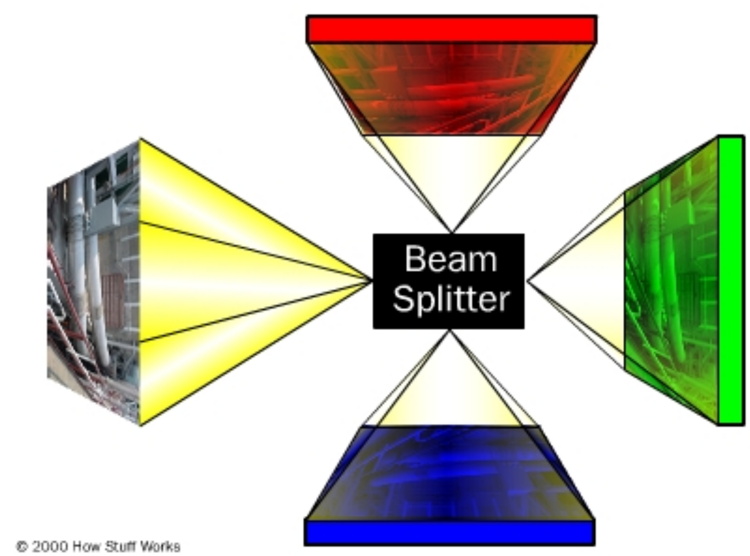


Metamerism is important to many industries, but is fickle; it can vary person to person and lighting situation to lighting situation. Metameric **failure** can be a large problem.

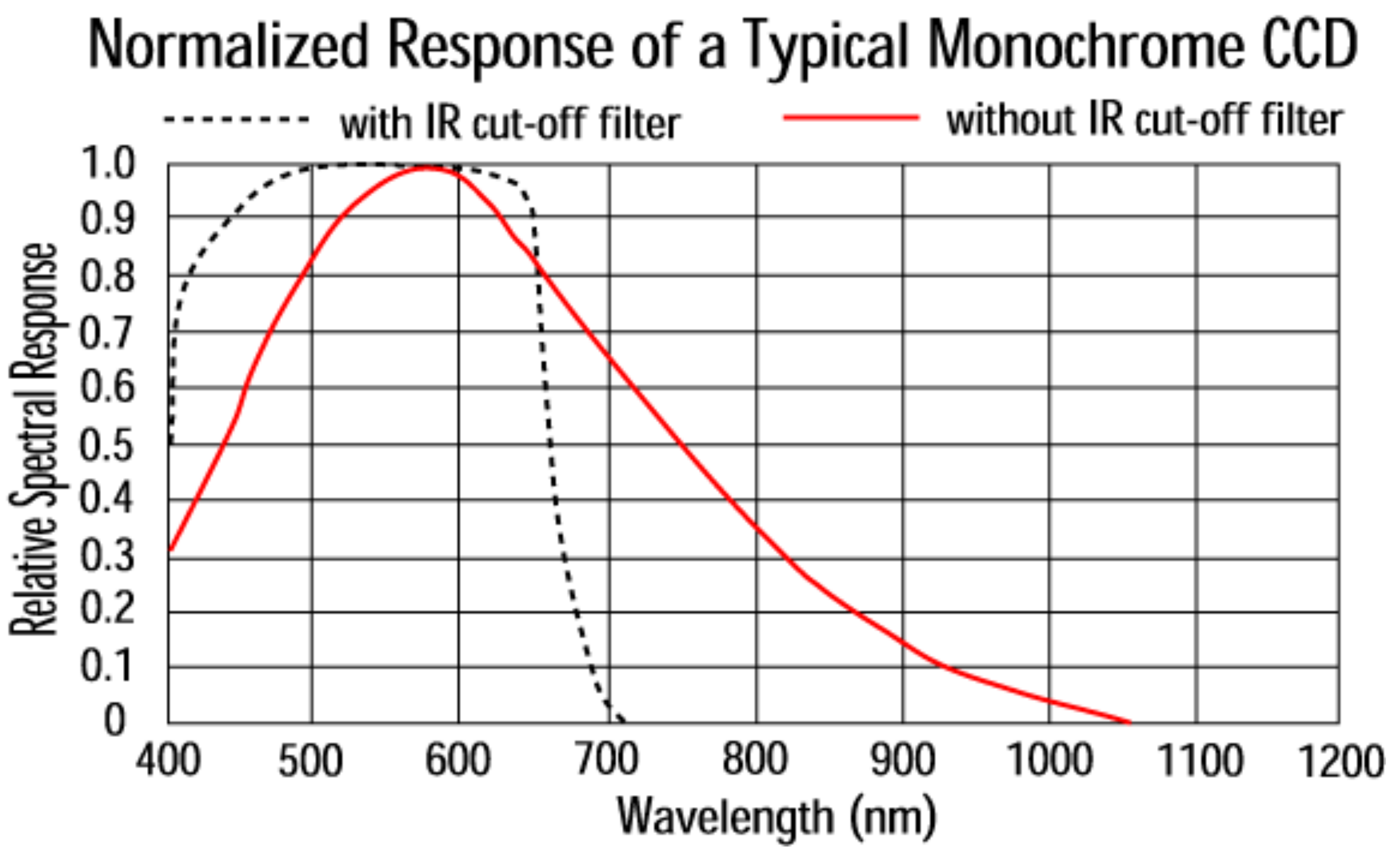
How Color Cameras Work

- 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 color separation beam splitter and 3 separate CCDs
  - higher color fidelity
  - needs lots of light
  - requires careful alignment of ccds

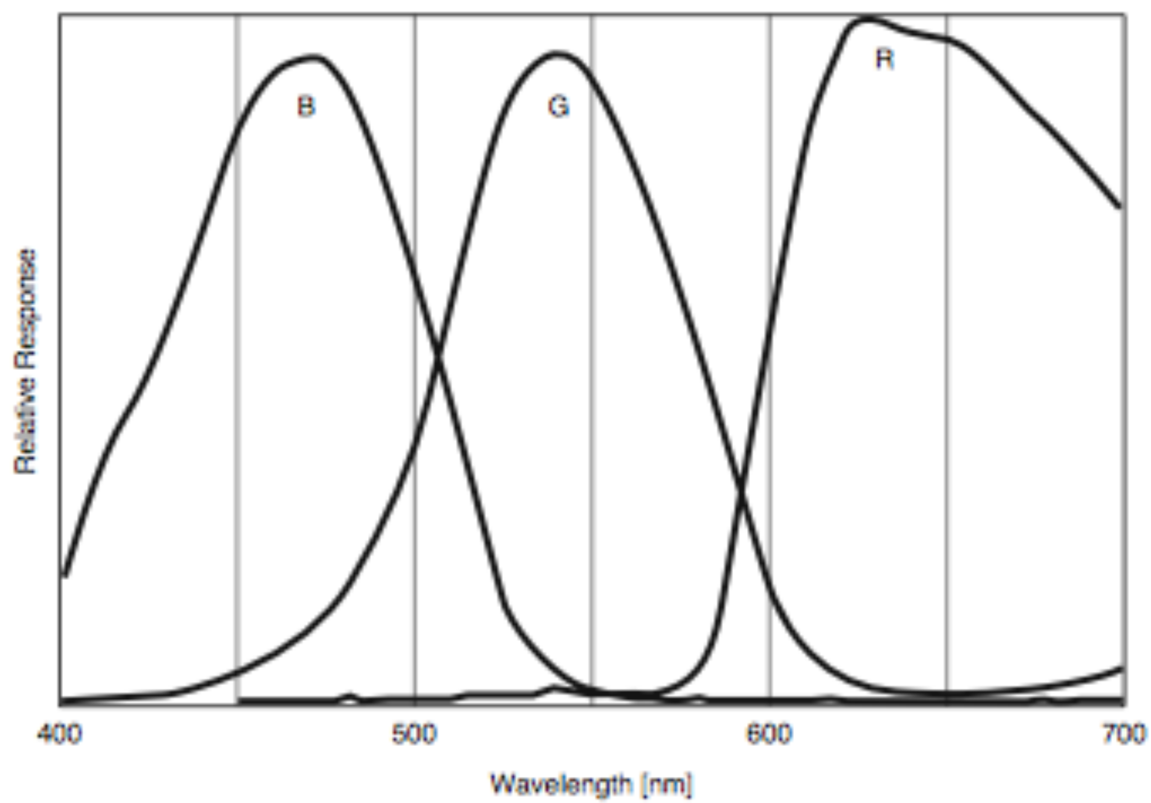




Unfiltered CCD Response



One Chip CCD Response
(Sony DFW V500)



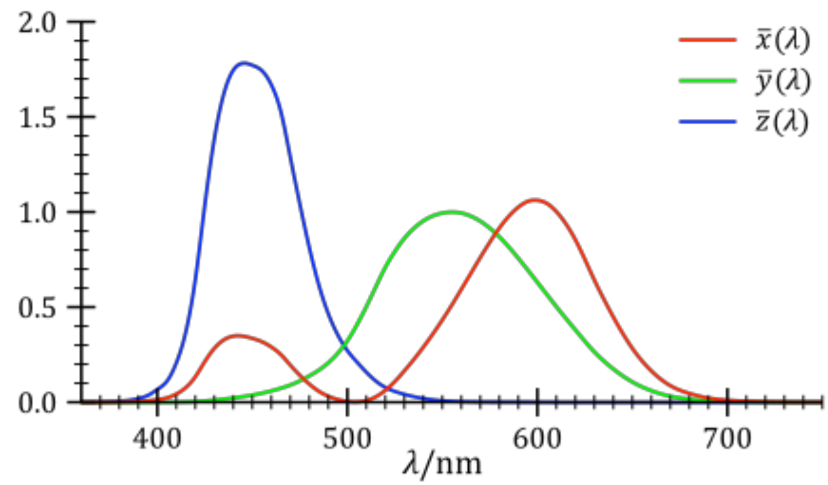
Filtering Colors

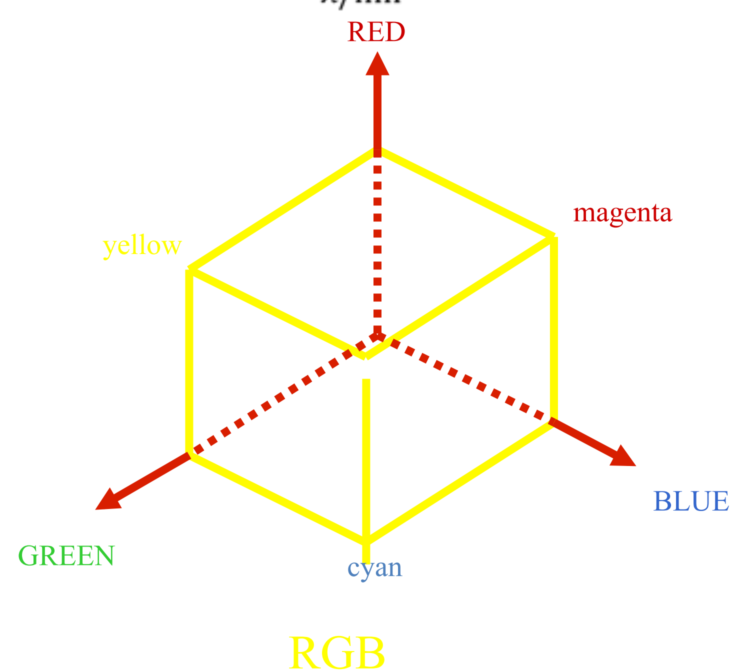
Blue

Red

Standard Linear Color Systems

- Several standards are used to define "color" based on specific 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 to render the complete color gamut of CIE XYZ





YUV-YIQ

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

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

- YUV is similar to YIQ; PAL vs. NTSC
- YCbCr is YUV but with a different
- reference level for Chrominance

HSI

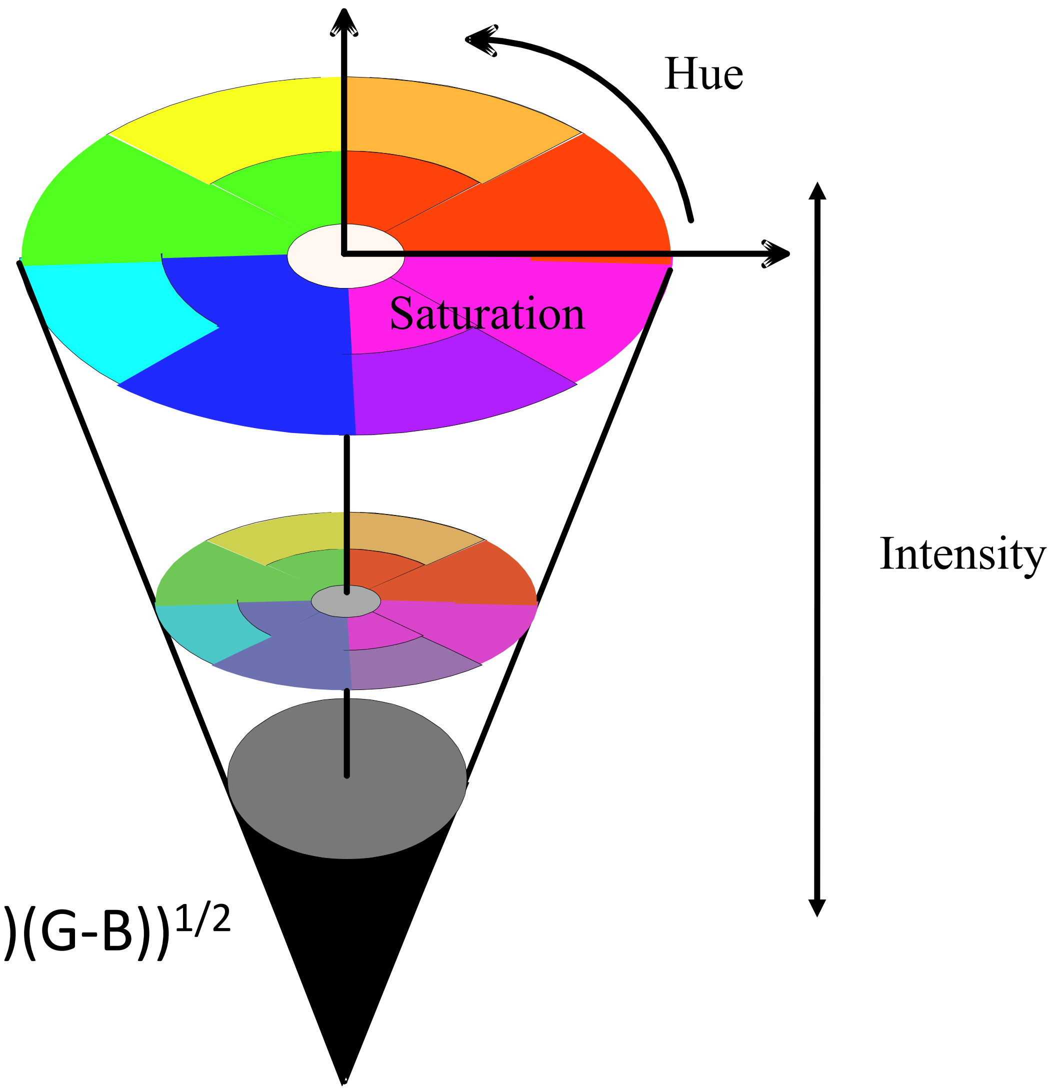
HSI is a nonlinear representation of color space.

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

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

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

$$x = (R-G) + (R-B)/((R-G)^2 + (R-B)(G-B))^{1/2}$$



RG Chromaticity

- r = R/(R+B+G)   g = G/(R+B+G)

- The implied third variable, $b = B / (R + G + B)$, can be omitted from the representation since $r + g + b = 1$, so the blue portion of the color can also be recovered from just r and g.

- The lighting model under which invariance is achieved assumes that changes in the lighting of an object will result in multiplication of its RGB values by a constant.

Summary

- Basics of Camera operation
- Image representation
- Basics of color and color representation