Computer Vision

Spring 2006 15-385,-685

Instructor: S. Narasimhan

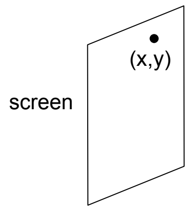
Wean 5403

T-R 3:00pm – 4:20pm

Image Sensing

Lecture #3

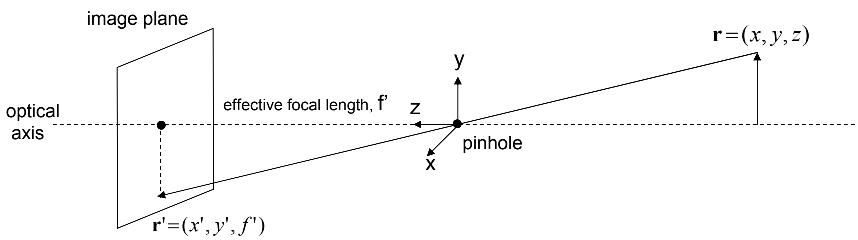
Recap: Pinhole and the Perspective Projection



scene

Is an image being formed on the screen?

YES! But, not a “clear” one.



$$\frac{\mathbf{r}'}{f'}=\frac{\mathbf{r}}{z} \quad \Rightarrow \quad \frac{x'}{f'}=\frac{x}{z} \qquad \frac{y'}{f'}=\frac{y}{z}$$

Vanishing Points

(NALWA)

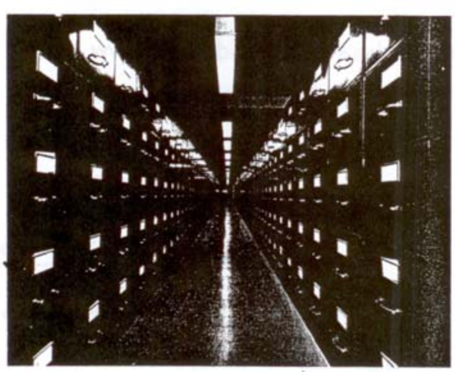


Figure 2.4 Photograph illustrating a vanishing point. Parallel straight lines converge at a single point under perspective projection. This point is called the *vanishing point* of the straight lines. (Photograph by Herbert Gehr, from the magazine *Life*, July 1947, © Time Warner, Inc.)

Vanishing Points

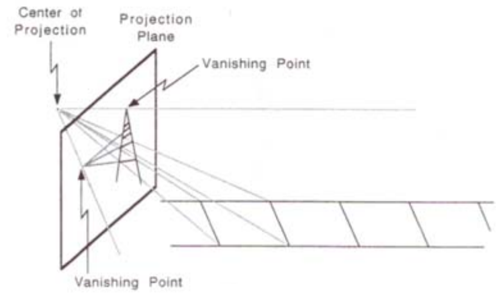
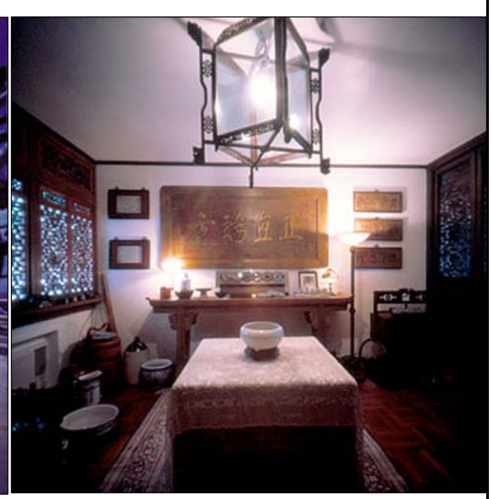


Figure 2.5 The vanishing point. The *vanishing point* of a straight line under perspective projection is that point on the projection surface at which the line would appear to "vanish" if the line were infinitely long in space. The location of the vanishing point of a straight line depends only on the orientation of the straight line in space, and not on the line's position: For any given spatial orientation, the vanishing point is located at that point on the projection surface where a straight line passing through the center of projection with the given orientation would intersect the projection surface.

Pinhole Images

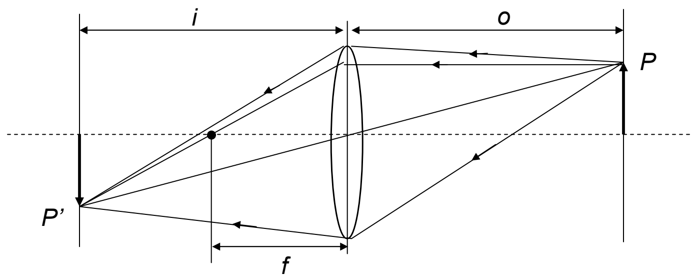
Exposure 4 seconds



Exposure 96 minutes

Image Formation using Lenses

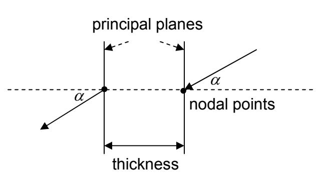
- Lenses are used to avoid problems with pinholes.
- Ideal Lens: Same projection as pinhole but gathers more light!



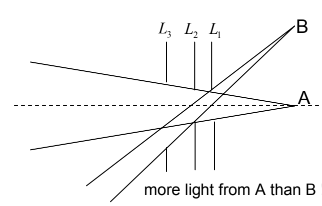
- Gaussian Thin Lens Formula: $\frac{1}{i} + \frac{1}{o} = \frac{1}{f}$
- *f* is the focal length of the lens – determines the lens's ability to refract light
- *f* different from the effective focal length ***f'*** discussed before!

Common Lens Related Issues - Summary

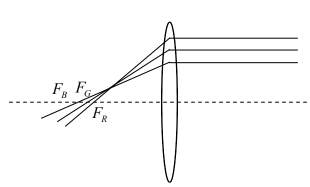
Compound (Thick) Lens



Vignetting



Chromatic Abberation



Lens has different refractive indices for different wavelengths.

Radial and Tangential Distortion

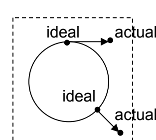


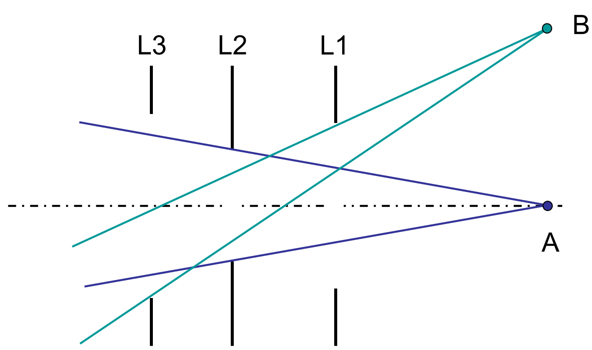
image plane

Lens Glare

- Stray interreflections of light within the optical lens system.
- Happens when very bright sources are present in the scene.

Reading: http://www.dpreview.com

Vignetting



More light passes through lens L3 for scene point A than scene point B

Results in spatially non-uniform brightness (in the periphery of the image)

Vignetting

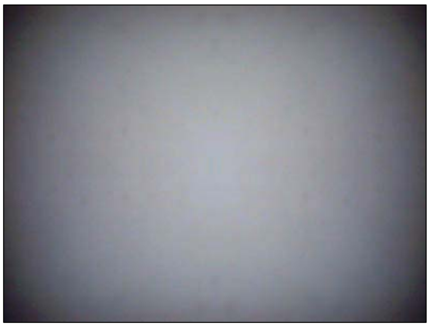
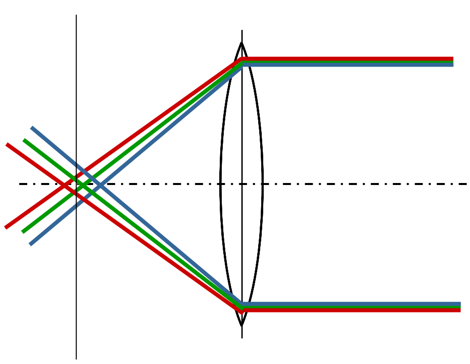
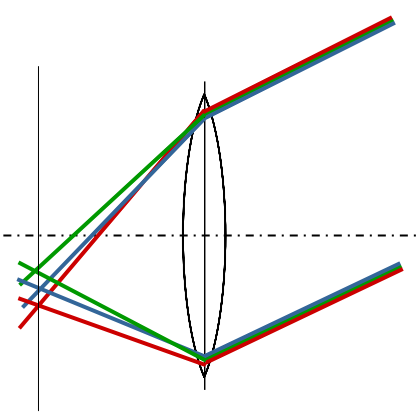


photo by Robert Johnes

Chromatic Aberration



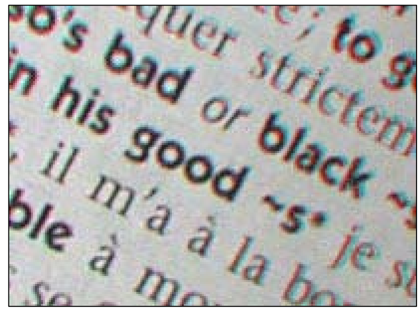
longitudinal chromatic aberration
(axial)



transverse chromatic aberration
(lateral)

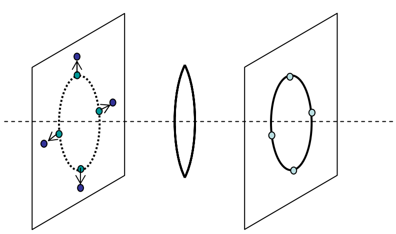
Chromatic Aberrations

longitudinal chromatic aberration
(axial)

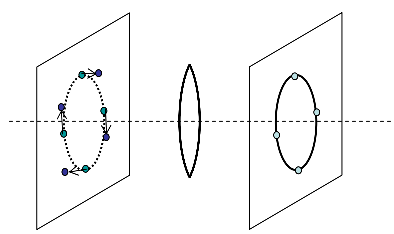


transverse chromatic aberration
(lateral)

Geometric Lens Distortions



Radial distortion

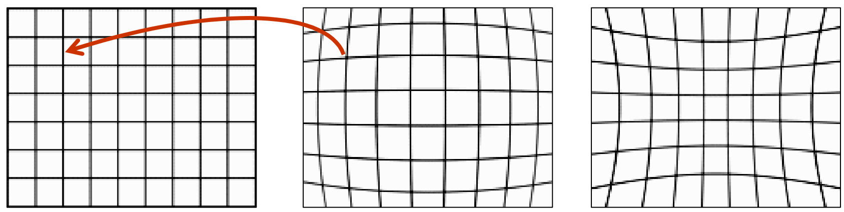


Tangential distortion

Photo by Helmut Dersch

Both due to lens imperfection
Rectify with geometric camera calibration

Radial Lens Distortions



No Distortion   Barrel Distortion   Pincushion Distortion

- Radial distance from Image Center:

$$r_u = r_d + k_1 r_d^3$$

Correcting Radial Lens Distortions

Before

After

http://www.grasshopperonline.com/barrel_distortion_correction_software.html

Topics to be Covered

- Image Sensors
- Sensing Brightness
- Sensing Color
- Our Eyes

Image Sensors

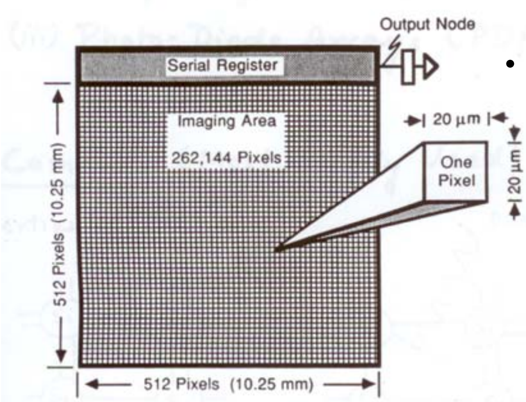
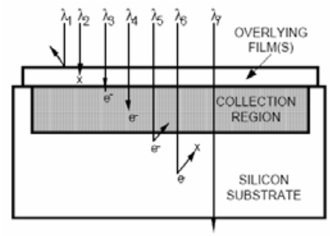


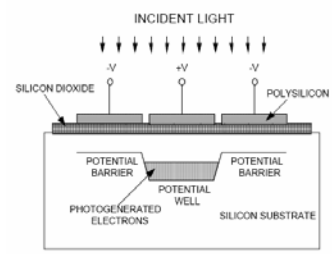
FIG. 4. Typical 512 × 512 CCD.

- Considerations
  - Speed
  - Resolution
  - Signal / Noise Ratio
  - Cost

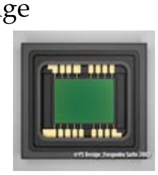
Image Sensors

- Convert light into electric charge

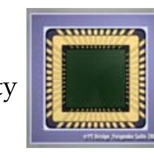




- CCD (charge coupled device)
  - Higher dynamic range
  - High uniformity
  - Lower noise

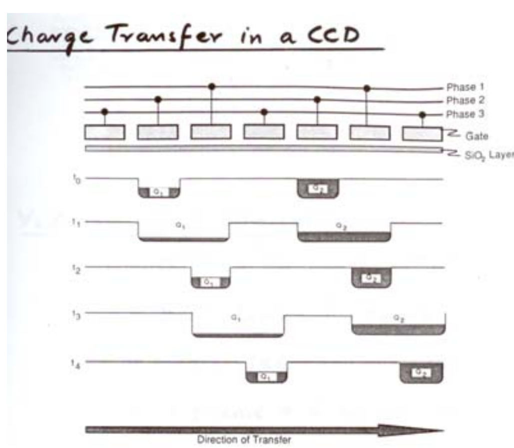


- CMOS (complementary metal Oxide semiconductor)
  - Lower voltage
  - Higher speed
  - Lower system complexity



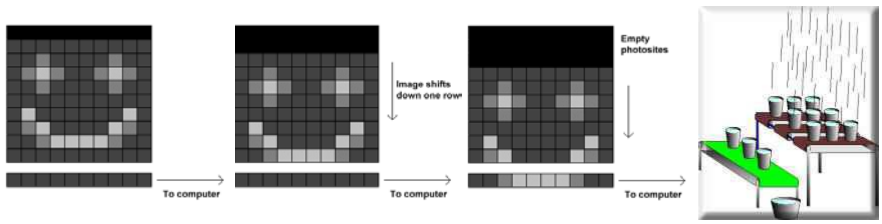
Sensor Readout

- CCD Bucket Brigade



Sensor Readout

- CCD Bucket Brigade



CCD Performance Characteristics

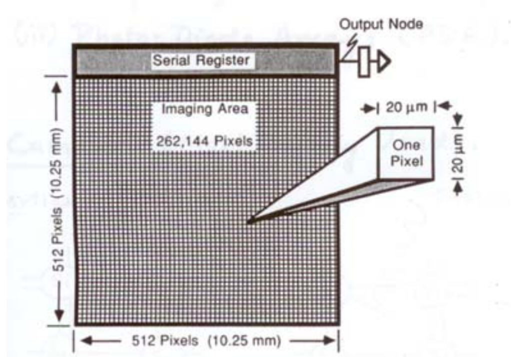


FIG. 4. Typical 512 × 512 CCD.

Resolution:

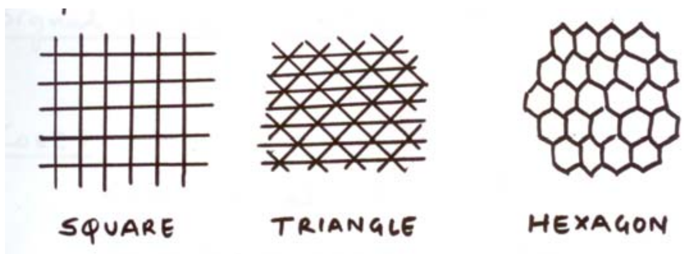
1k x 1k packed in 1-2 cm^2

No space between Pixels

No Photons wasted

CCD Performance Characteristics

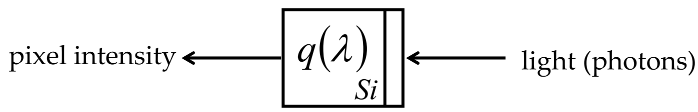
- Pixels must have same area
- Only 3 tessellations possible:



CCD Performance Characteristics

- Linearity Principle: Incoming photon flux vs. Output Signal
  - Sometimes cameras are made non-linear on purpose.
  - Calibration must be done (using reflectance charts)---covered later
- Dark Current Noise: Non-zero output signal when incoming light is zero
- Sensitivity: Minimum detectable signal produced by camera

Sensing Brightness



Quantum Efficiency

$$q(\lambda) = \frac{\text{generated electron flux}}{\text{photon flux of wavelength } \lambda}$$

Pixel intensity: $I = k(\text{generated electron flux})$

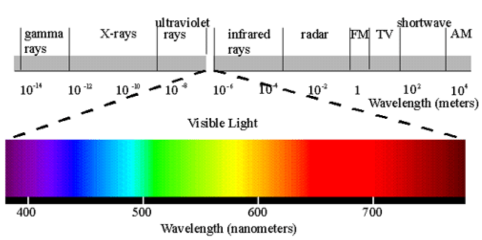
For monochromatic light $(\lambda = \lambda_i)$ with flux P_i :

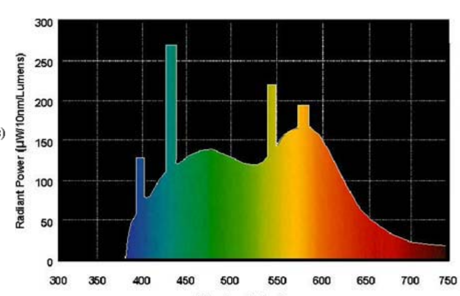
$$I = kq(\lambda_i)P_i$$

However, incoming light can vary in wavelength λ

Sensing Brightness

Incoming light has a **spectral distribution** $p(\lambda)$





So the pixel intensity becomes

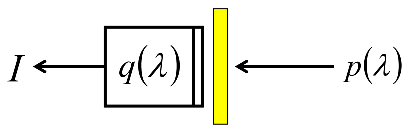
$$I = k\int_{-\infty}^{\infty} q(\lambda)p(\lambda)d\lambda$$

Sensing Color

- Assume we have an image
  - We know the pixel value I
  - We know our camera parameters $k, q(\lambda)$

$$I = k\int_{-\infty}^{\infty} q(\lambda)p(\lambda)d\lambda$$

Can we tell the color of the scene?
(Can we recover the spectral distribution $p(\lambda)$)

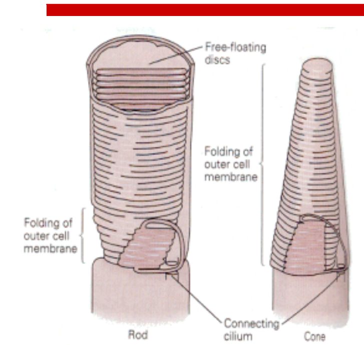


Use a filter $f_i(\lambda)$ Where $f_i(\lambda) = \delta(\lambda - \lambda_i) = \begin{cases} 1 & \lambda = \lambda_i \\ 0 & \text{otherwise} \end{cases}$

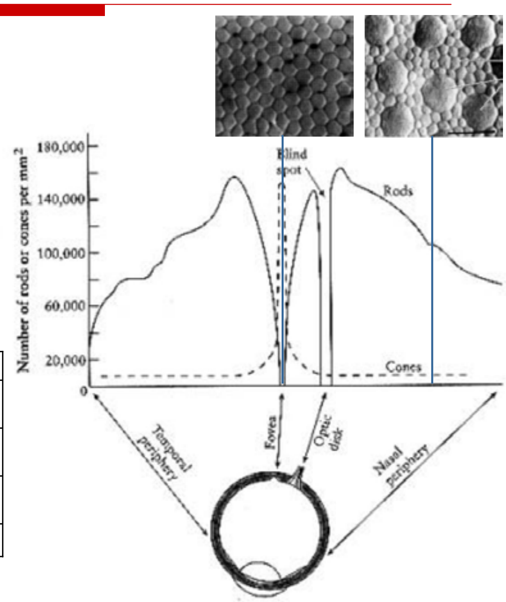
then

$$I = k\int_{-\infty}^{\infty} q(\lambda)p(\lambda)f(\lambda_i)d\lambda = kq(\lambda_i)\boxed{p(\lambda_i)}$$

Rods and Cones

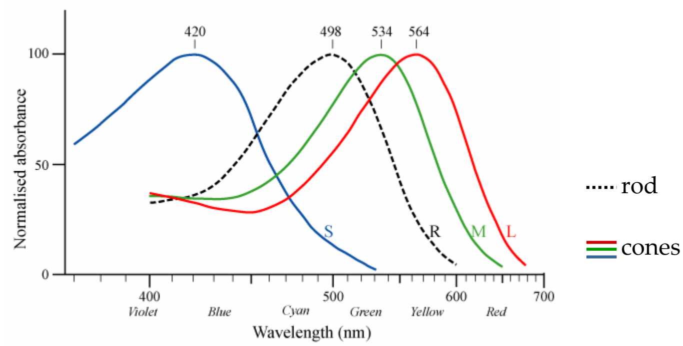


Rods	Cones
Achromatic: one type of pigment	Chromatic: three types of pigment
Slow response (long integration time)	Fast response (short integration time)
High amplification High sensitivity	Less amplification Lower absolute sensitivity
Low acuity	High acuity



How do we sense color?

- Do we have infinite number of filters?

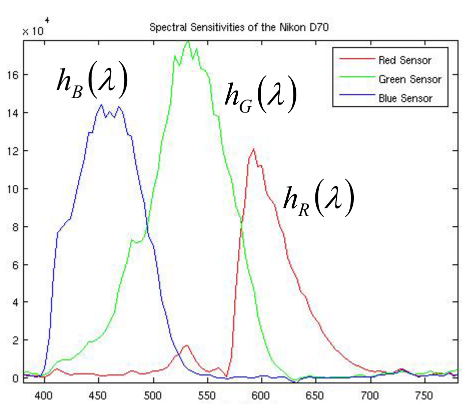


Three filters of different spectral responses

Sensing Color

- Tristimulus (trichromatic) values (I_R, I_G, I_B)

Camera's spectral response functions: $h_R(\lambda), h_G(\lambda), h_B(\lambda)$

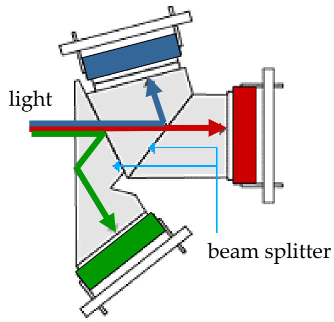


$$I_R = k\int_{-\infty}^{\infty} h_R(\lambda)p(\lambda)d\lambda$$

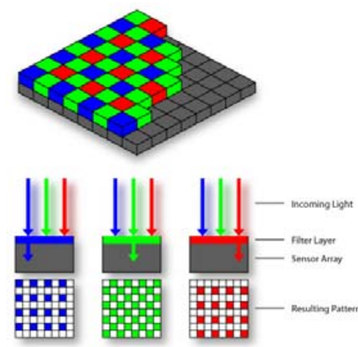
$$I_G = k\int_{-\infty}^{\infty} h_G(\lambda)p(\lambda)d\lambda$$

$$I_B = k\int_{-\infty}^{\infty} h_B(\lambda)p(\lambda)d\lambda$$

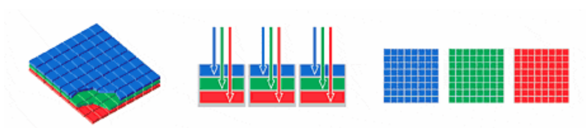
Sensing Color



3 CCD



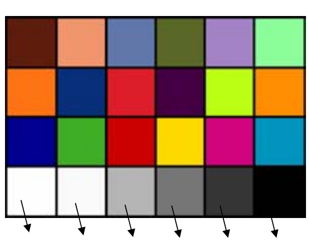
Bayer pattern

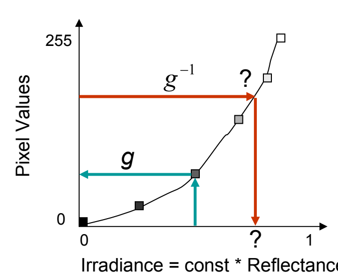


Foveon X3™

Color Chart Calibration

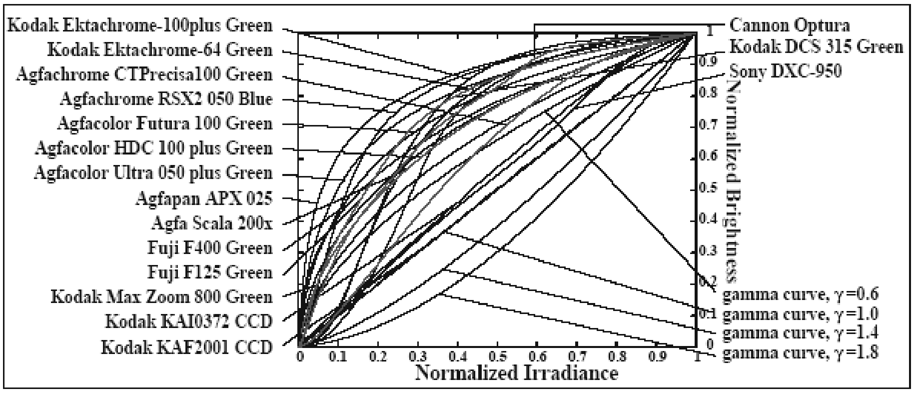
- Important preprocessing step for many vision and graphics algorithms
- Use a color chart with precisely known reflectances.





- Use more camera exposures to fill up the curve.
- Method assumes constant lighting on all patches and works best when source is far away (example sunlight).
- Unique inverse exists because g is monotonic and smooth for all cameras.

Measured Response Curves of Cameras

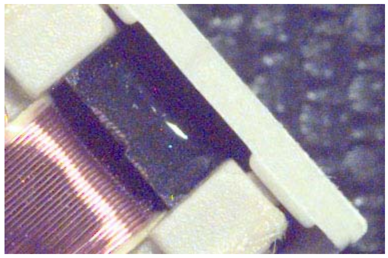


[Grossberg, Nayar]

Dark Current Noise Subtraction

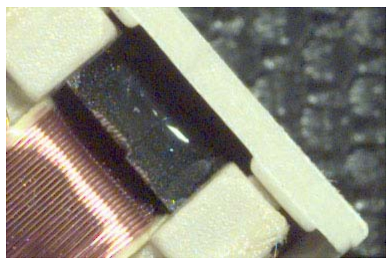
- Dark current noise is high for long exposure shots
- To remove (some) of it:
  - Calibrate the camera (make response linear)
  - Capture the image of the scene as usual
  - Cover the lens with the lens cap and take another picture
  - Subtract the second image from the first image

Dark Current Noise Subtraction



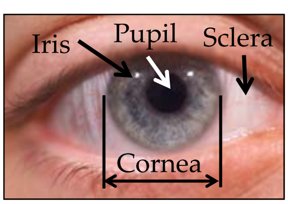
Original image + Dark Current Noise

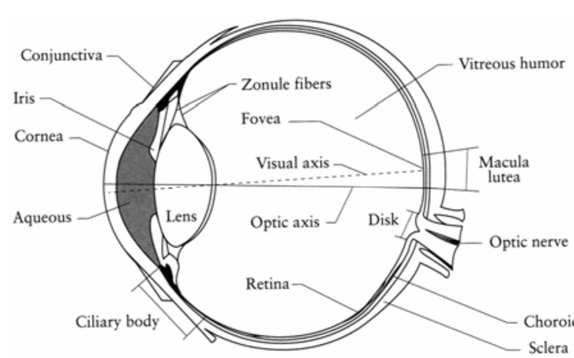
Image with lens cap on



Result of subtraction

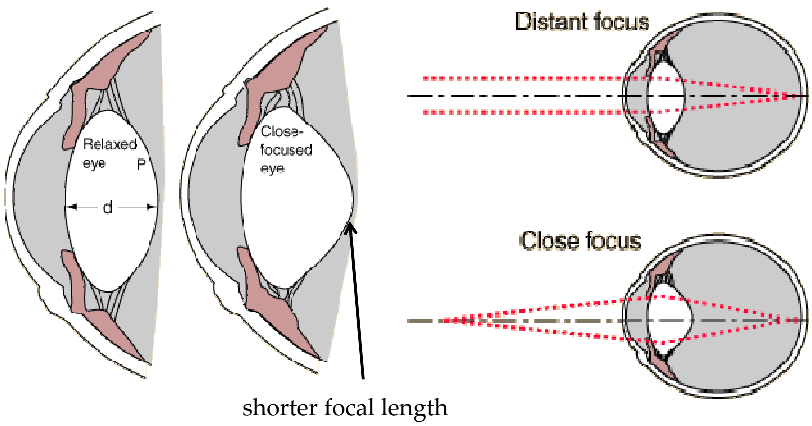
Our Eyes





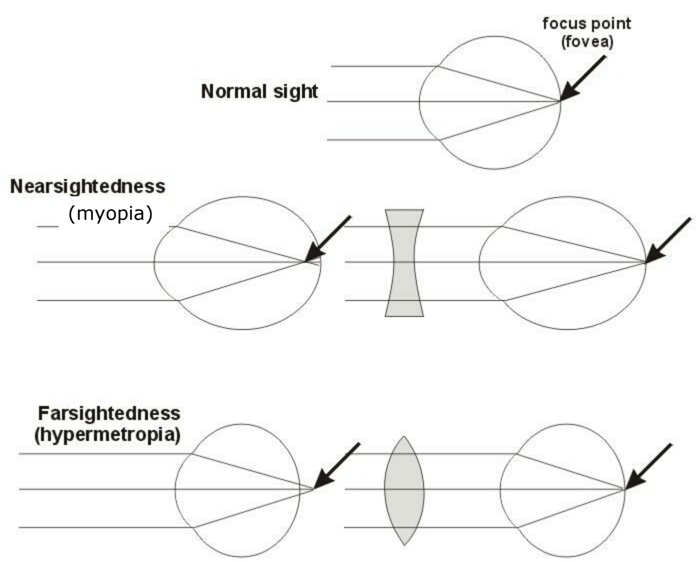
- Index of refraction: cornea 1.376, aqueous 1.336, lens 1.406-1.386
- Iris is the diaphragm that changes the aperture (pupil)
- Retina is the sensor where the fovea has the highest resolution

Accommodation

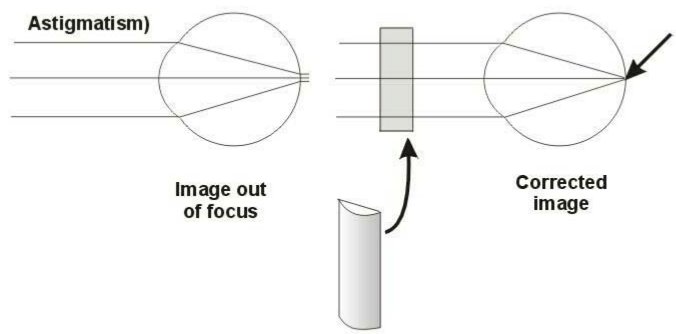


Changes the focal length of the lens

Myopia and Hyperopia



Astigmatism

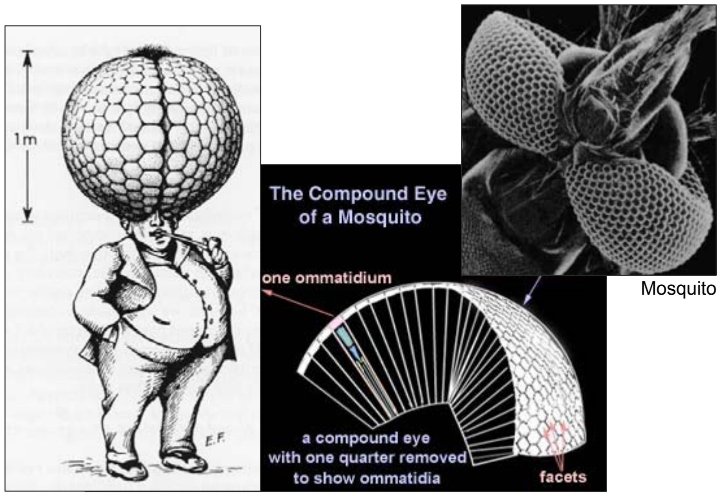


The cornea is distorted causing images to be un-focused on the retina.

Blind Spot in Eye

Close your right eye and look directly at the "+"

Eyes in Nature



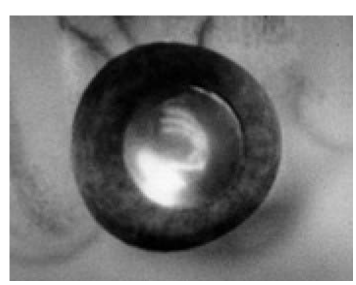
Mosquito

http://ebiomedia.com/gall/eyes/octopus-insect.html

Mosquitos have microscopic vision, but to focus at large distances their would need to be 1 m!

Curved Mirrors in Scallop Eyes

Telescopic Eye



(by Mike Land, Sussex)

… More in the last part of the course

Next Class

- Binary Image Processing
- Horn, Chapter 3