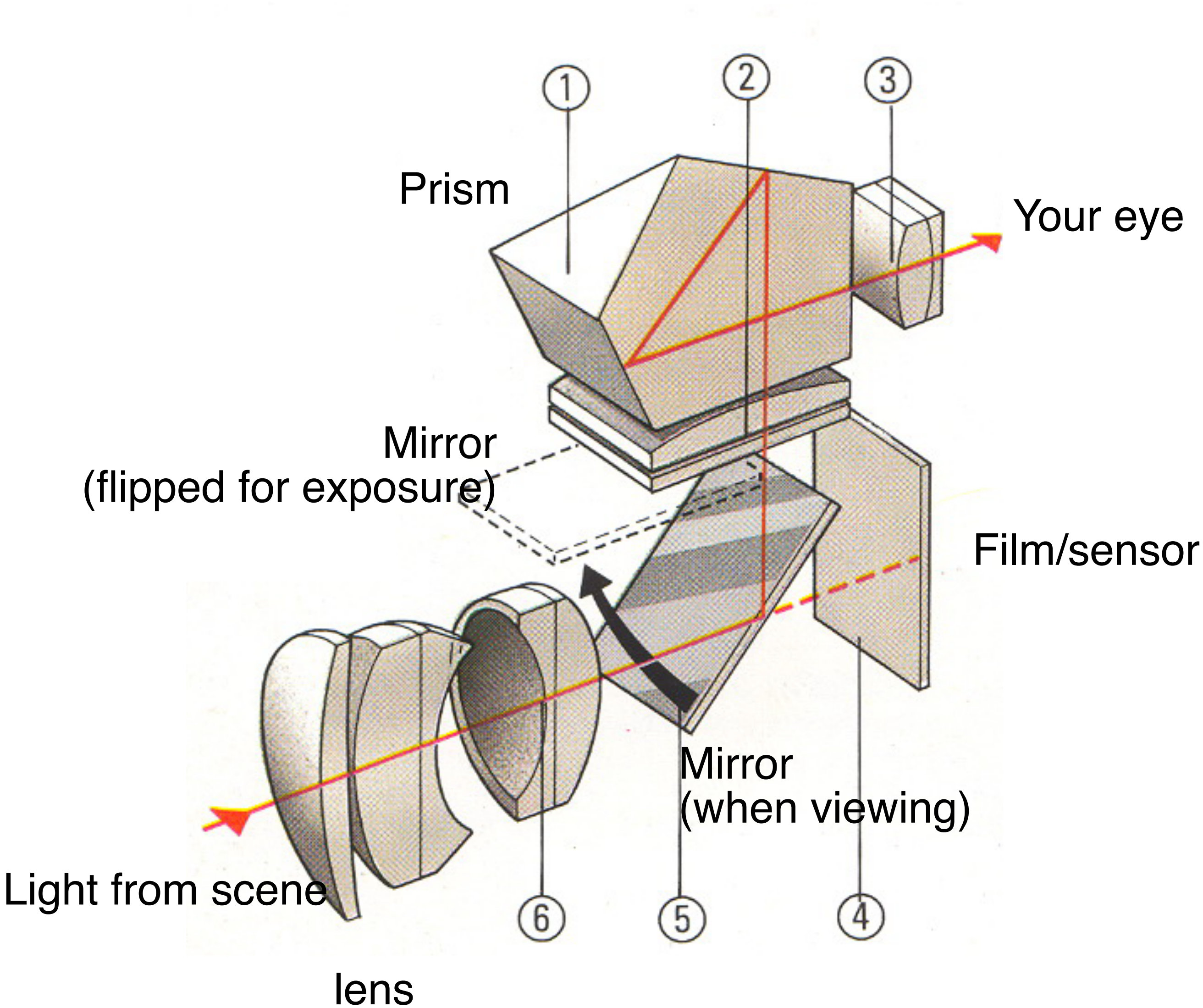
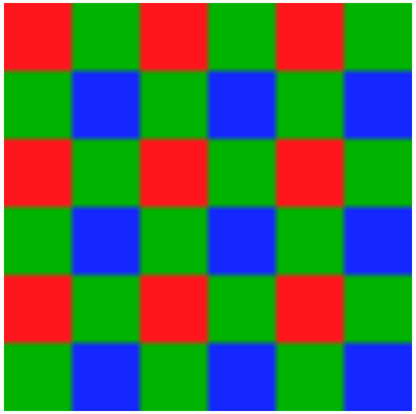
Last Lecture



- Focal Length
- F-stop
- Depth of Field
- Color Capture



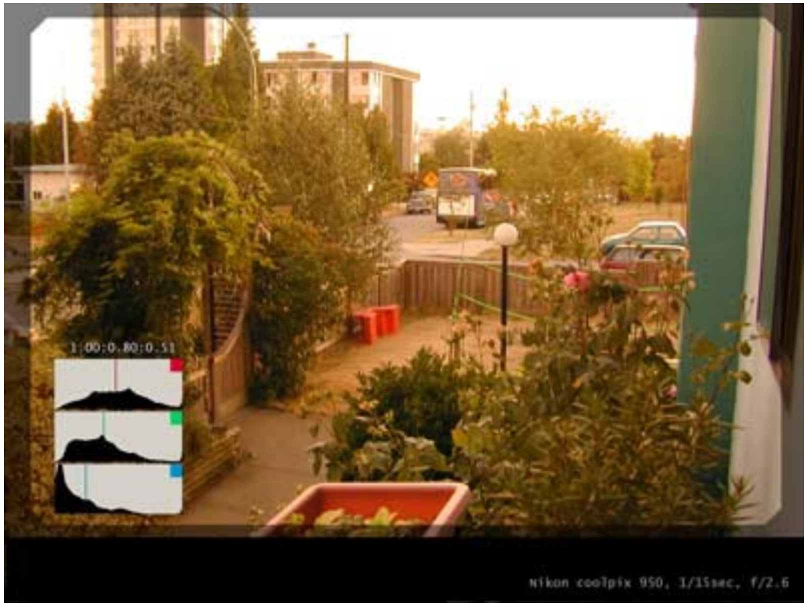
Bayer pattern

YungYu Chuang's slide

Color processing

- After color values are recorded, more color processing usually happens:
  - White balance
  - Non-linearity to approximate film response or match TV monitor gamma

Auto White Balance



warmer

automatic white balance

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 255/R'_w & 0 & 0 \\ 0 & 255/G'_w & 0 \\ 0 & 0 & 255/B'_w \end{bmatrix} \begin{bmatrix} R' \\ G' \\ B' \end{bmatrix}$$

YungYu Chuang's slide

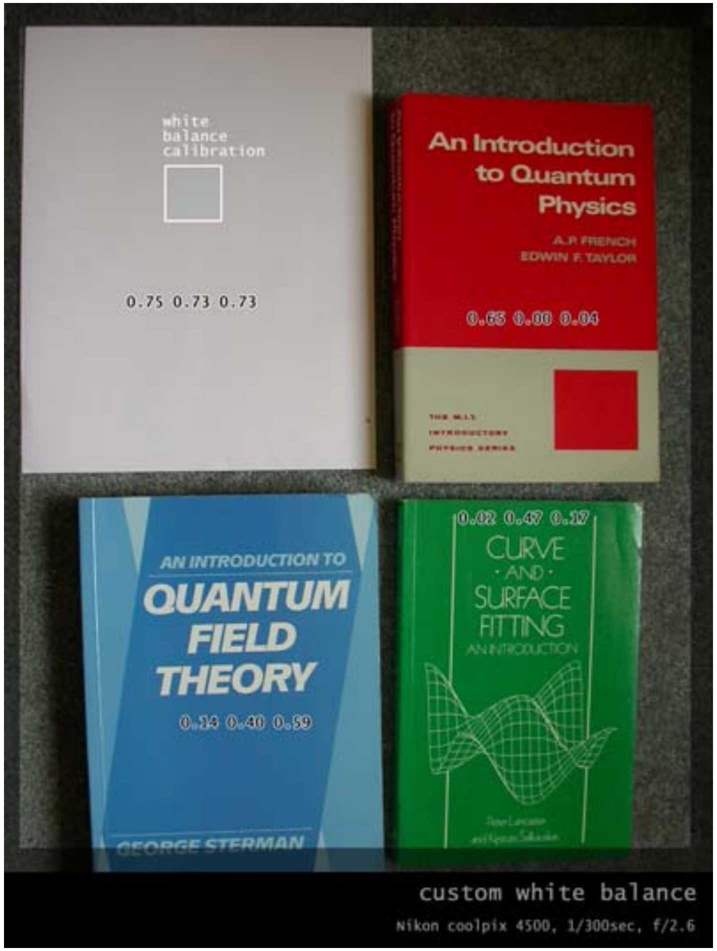
Auto White Balance

The auto white balance was unable to find a white reference, resulting in dull and artificial colors.

The auto white balance got it right this time in a very similar scene because it could use the clouds as its white reference.

http://www.dpreview.com/learn/?/Glossary/Digital_Imaging/White_Balance_01.htm

Manual white balance

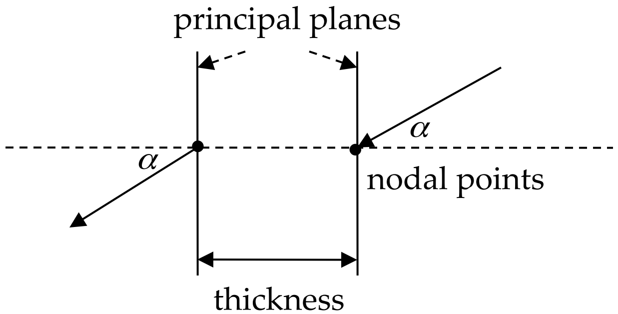


white balance with
the white book

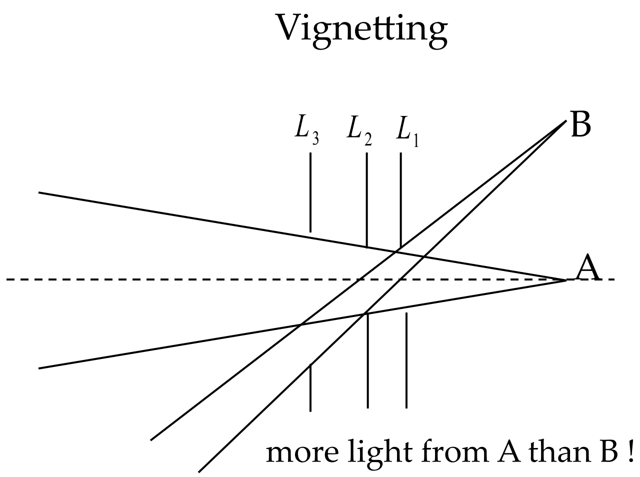
white balance with
the red book

YungYu Chuang's slide

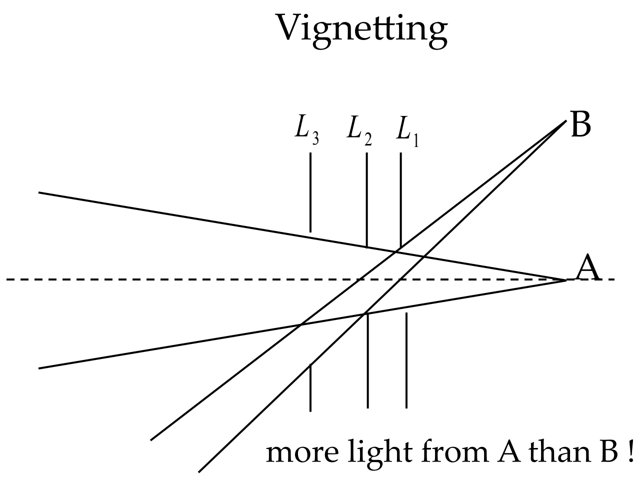
Lens related issues: Coumpound Thick Lens



Lens related issues: Vignetting



Lens related issues: Vignetting

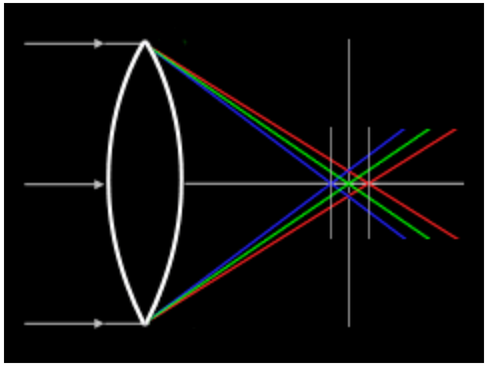


original

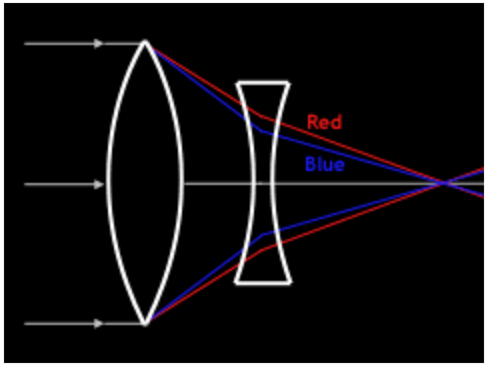
corrected

Goldman & Seitz ICCV 2005

Lens related issues: Chromatic Abberation



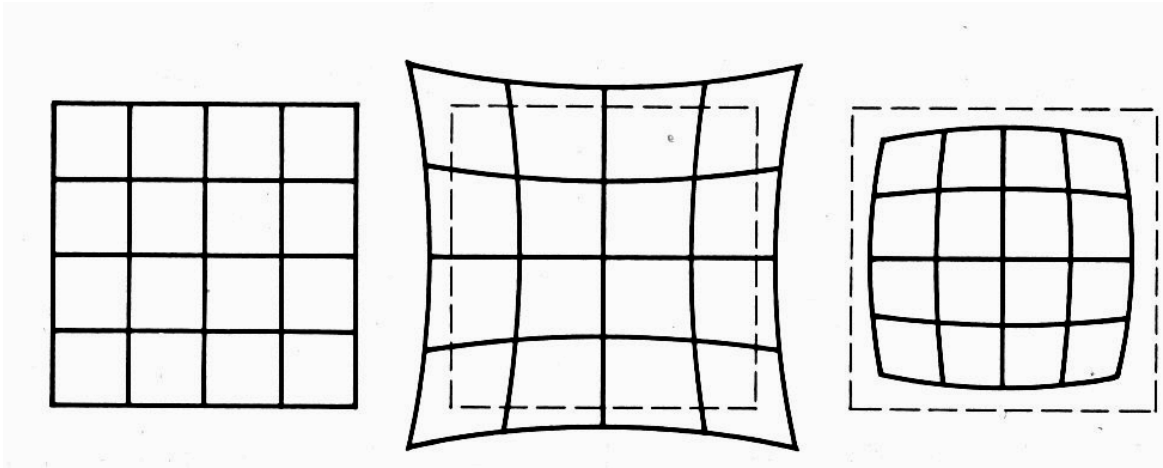
Lens has different refractive indices for different wavelengths.



Special lens systems using two or more pieces of glass with different refractive indexes can reduce or eliminate this problem.

http://www.dpreview.com/learn/?/Glossary/Optical/chromatic_aberration_01.htm

Lens related issues: Distortion



No distortion   Pin cushion   Barrel

- Radial distortion of the image
  - Caused by imperfect lenses
  - Deviations are most noticeable for rays that pass through the edge of the lens

Steve Seitz's slide

Correcting radial distortion

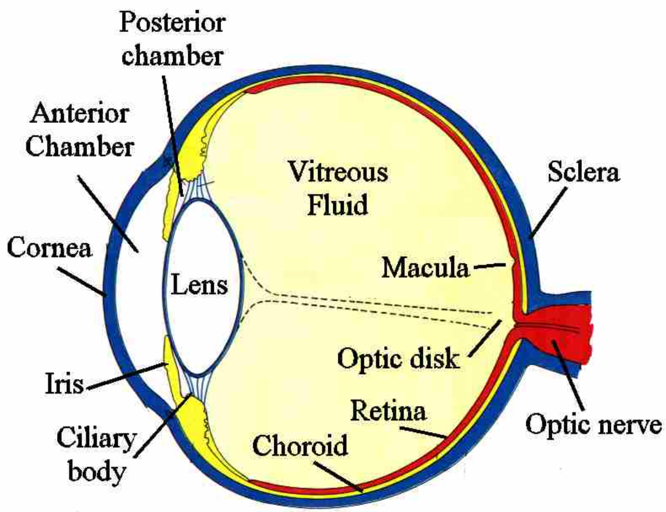
from Helmut Dersch

Steve Seitz's slide

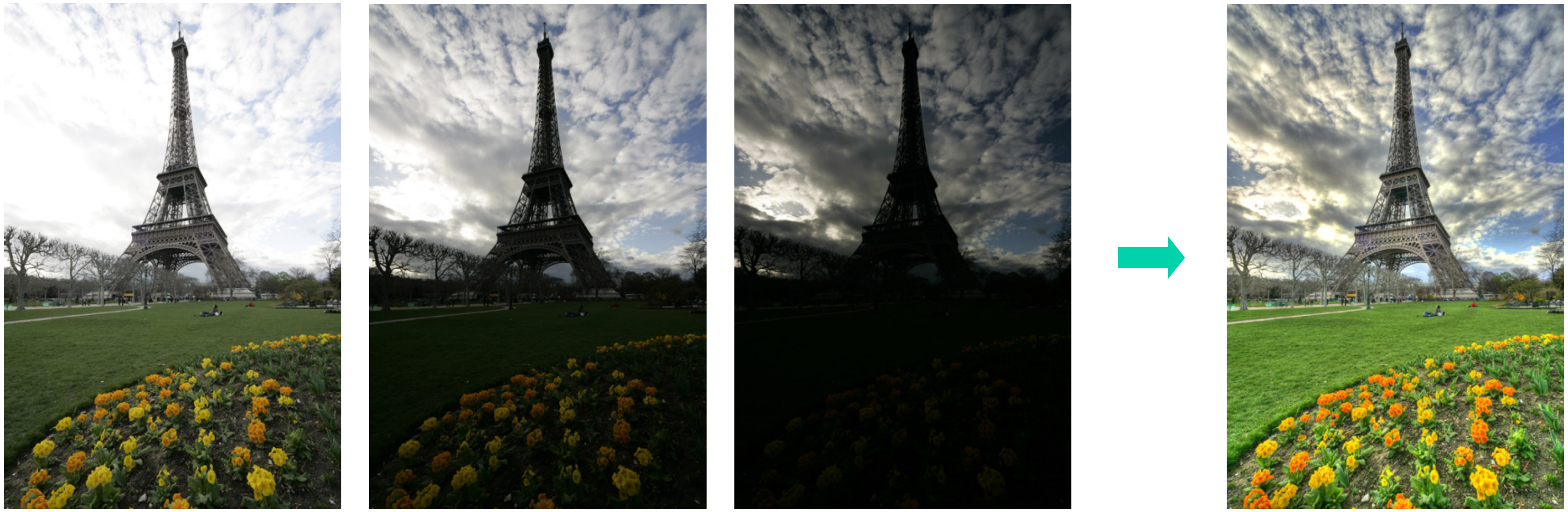
Digital camera review website

- http://www.dpreview.com/
- http://www.imaging-resource.com/
- http://www.steves-digicams.com/

Today

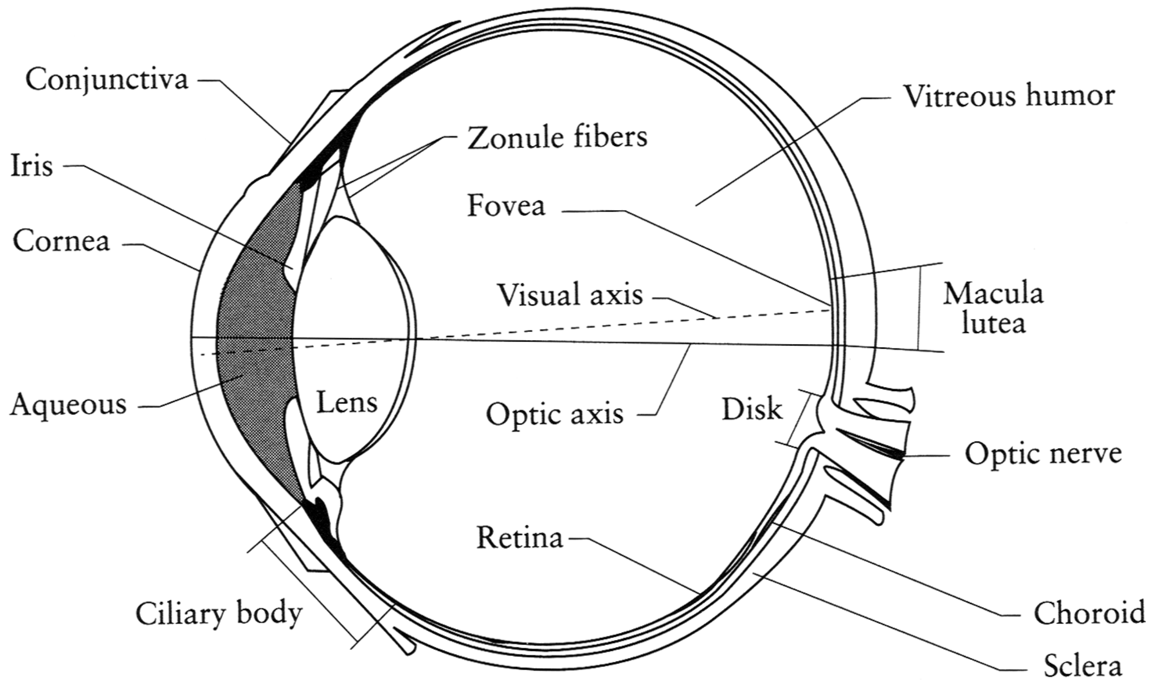


Kimber, D.C.; C.E. Gray, and C.E. Stackpole. (1966). *Anatomy and Physiology*. MacMillan Co., NY. pg 335.



photomatix.com

The Eye



- The human eye is a camera!
  - **Iris** - colored annulus with radial muscles
  - **Pupil** - the hole (aperture) whose size is controlled by the iris
  - What's the "film"?

    - photoreceptor cells (rods and cones) in the **retina**

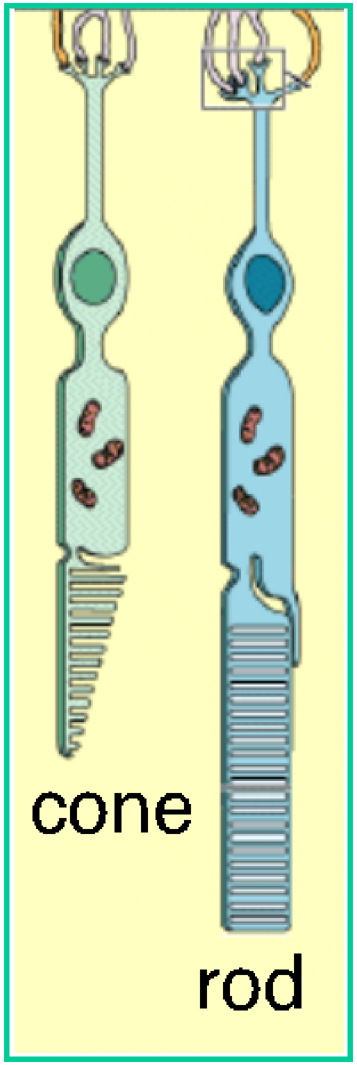
Two types of light-sensitive receptors

Rods

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

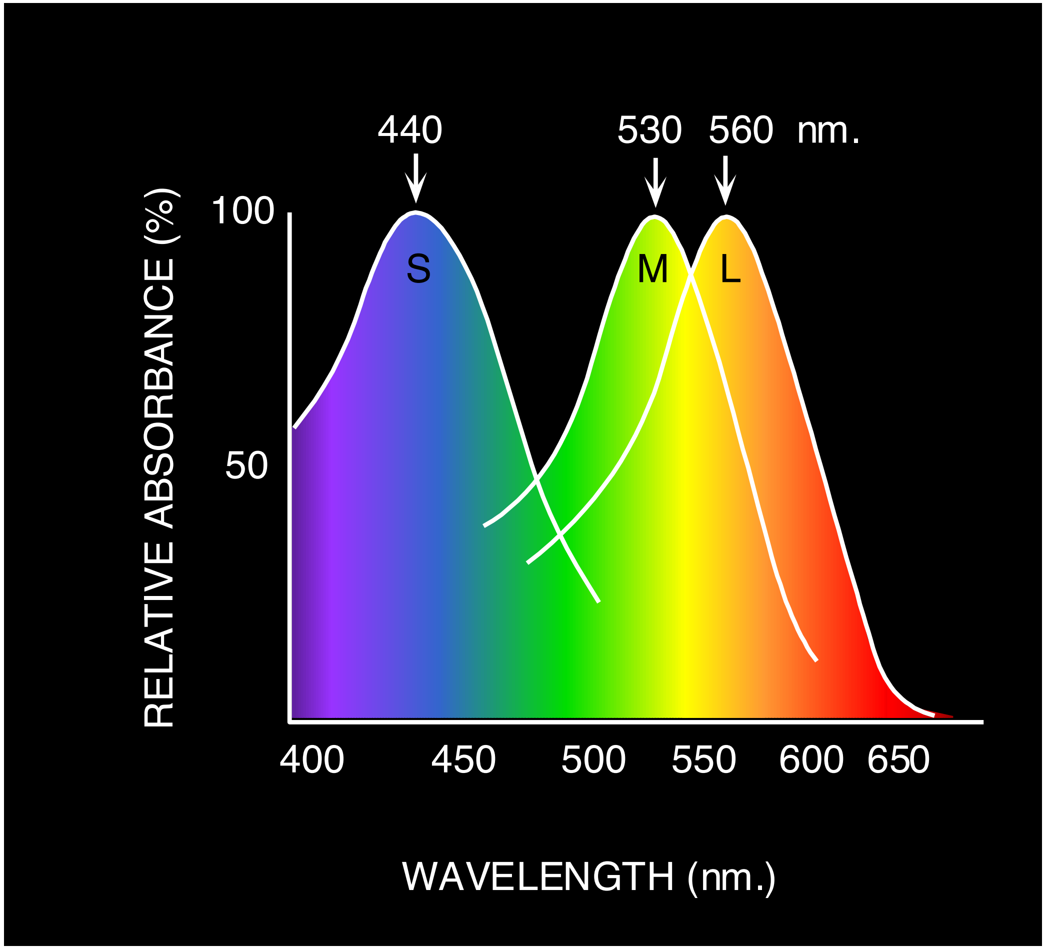
Cones

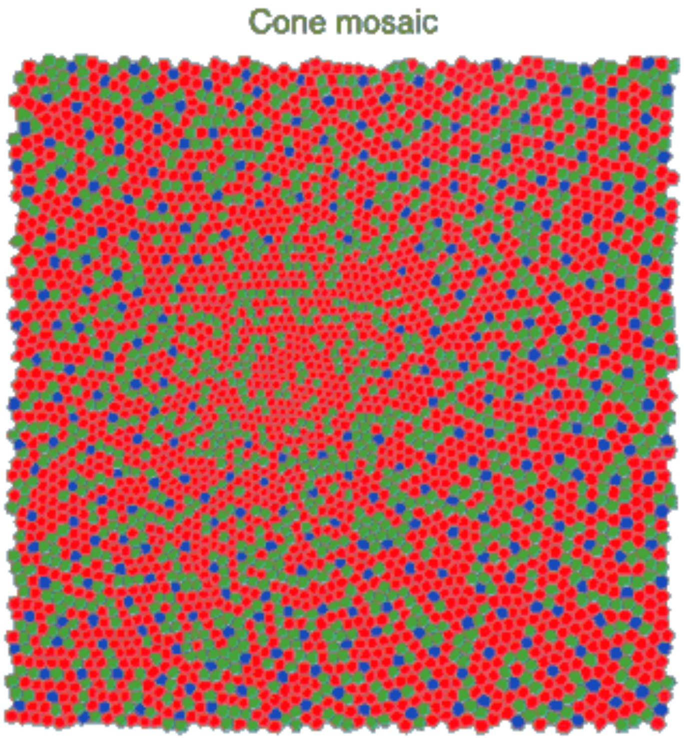
cone-shaped
less sensitive
operate in high light
color vision



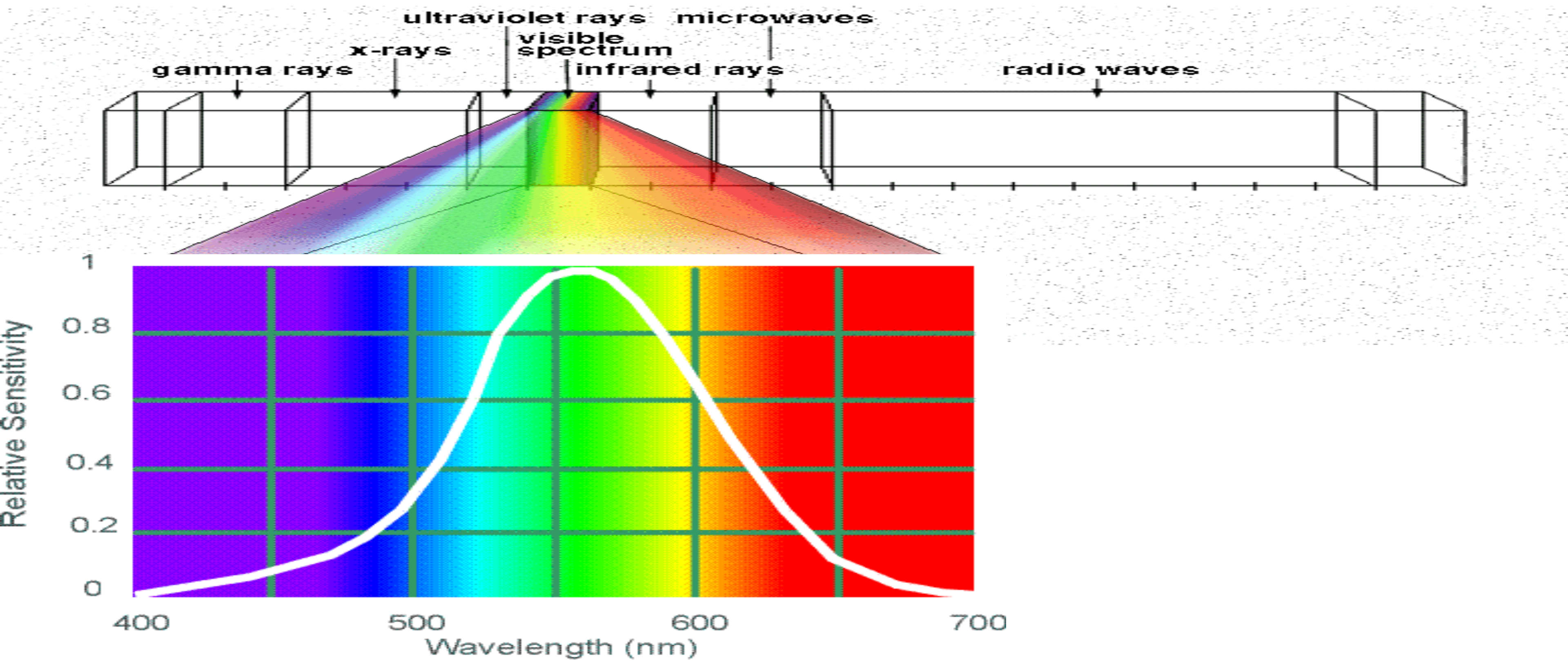
Physiology of Color Vision

Three kinds of cones:





Electromagnetic Spectrum



Human Luminance Sensitivity Function

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

References

- http://www.howstuffworks.com/digital-camera.htm
- http://electronics.howstuffworks.com/autofocus.htm
- Ramanath, Snyder, Bilbro, and Sander. Demosaicking Methods for Bayer Color Arrays, Journal of Electronic Imaging, 11(3), pp306-315.
- Rajeev Ramanath, Wesley E. Snyder, Youngjun Yoo, Mark S. Drew, Color Image Processing Pipeline in Digital Still Cameras, IEEE Signal Processing Magazine Special Issue on Color Image Processing, vol. 22, no. 1, pp. 34-43, 2005.
- http://www.worldatwar.org/photos/whitebalance/index.mhtml
- http://www.100fps.com/

The World in an Eye

Ko Nishino Shree K. Nayar

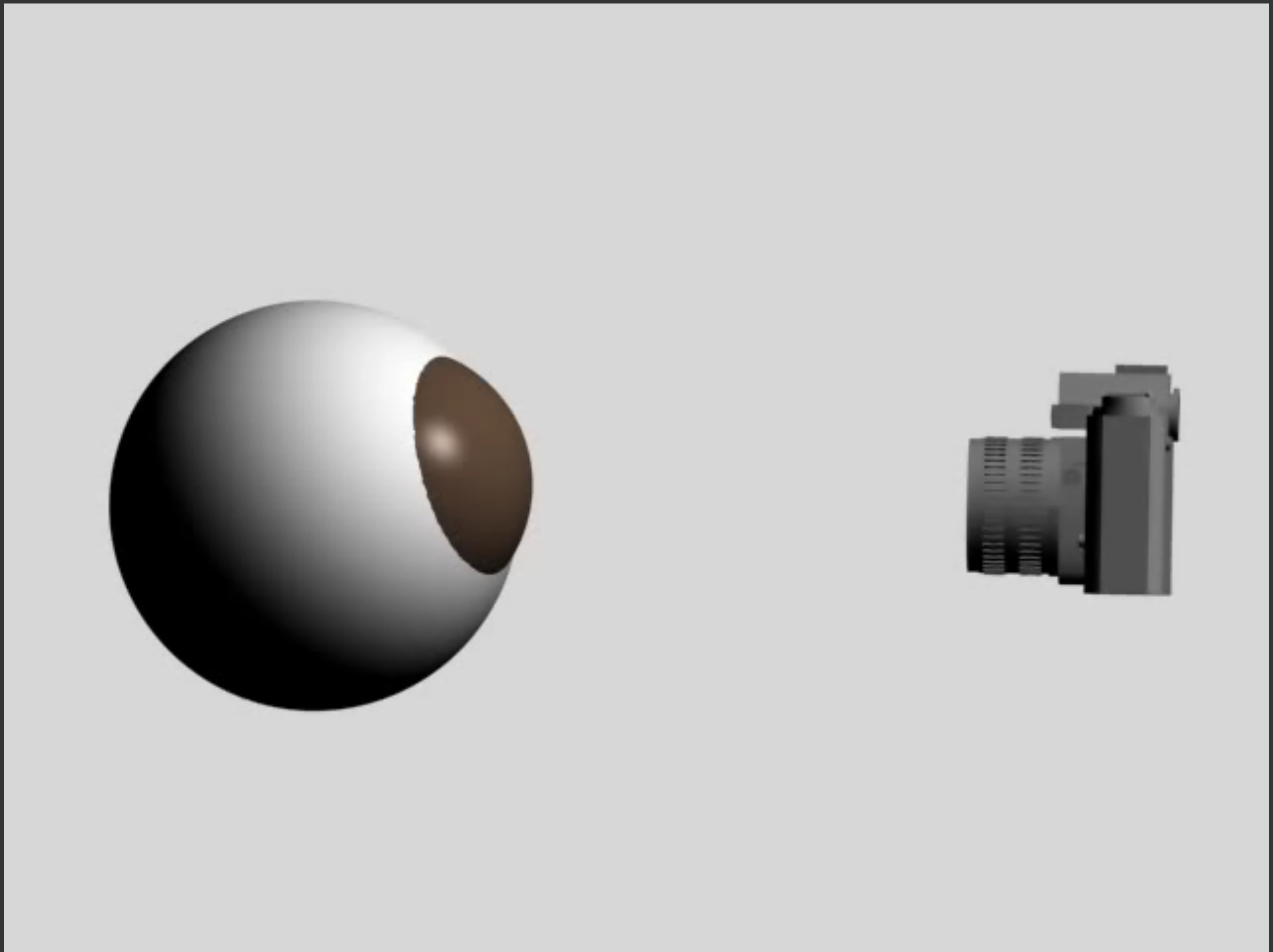
Columbia University

http://www1.cs.columbia.edu/CAVE/projects/world_eye/world_eye.php

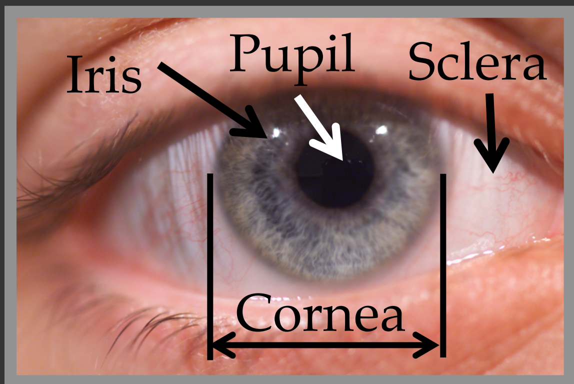
IEEE CVPR Conference
June 2004, Washington DC, USA

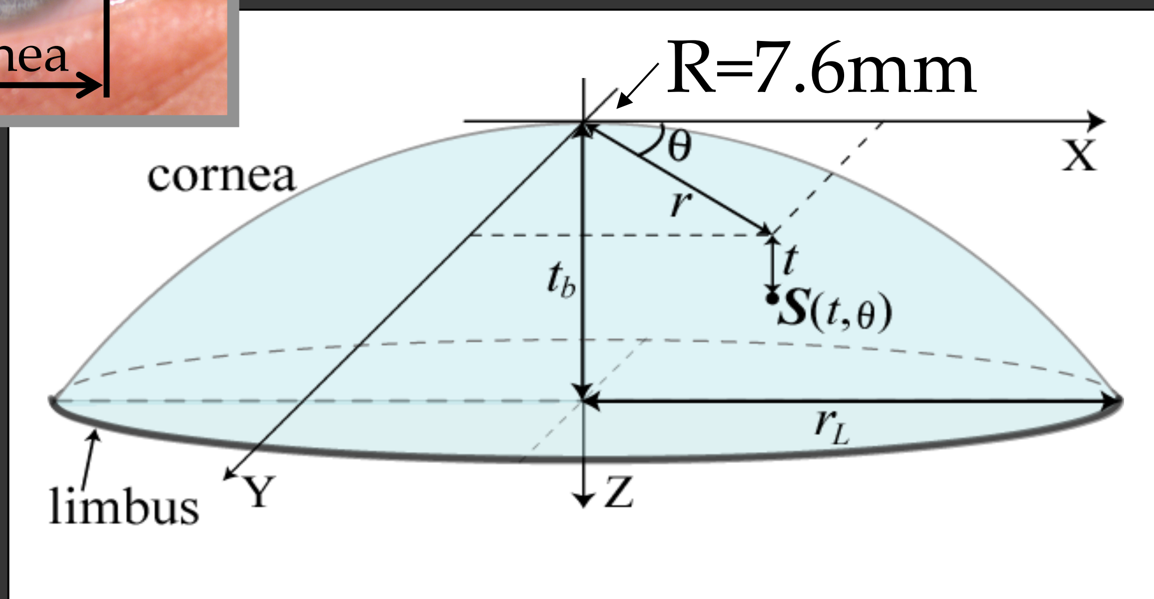
Supported by NSF

Corneal Imaging System



Geometric Model of the Cornea





$$t_b = 2.18\text{mm} \qquad r_L = 5.5\text{mm}$$

Finding the Limbus

limbus parameters e : radii (r_x, r_y) center (c_x, c_y) tilt θ

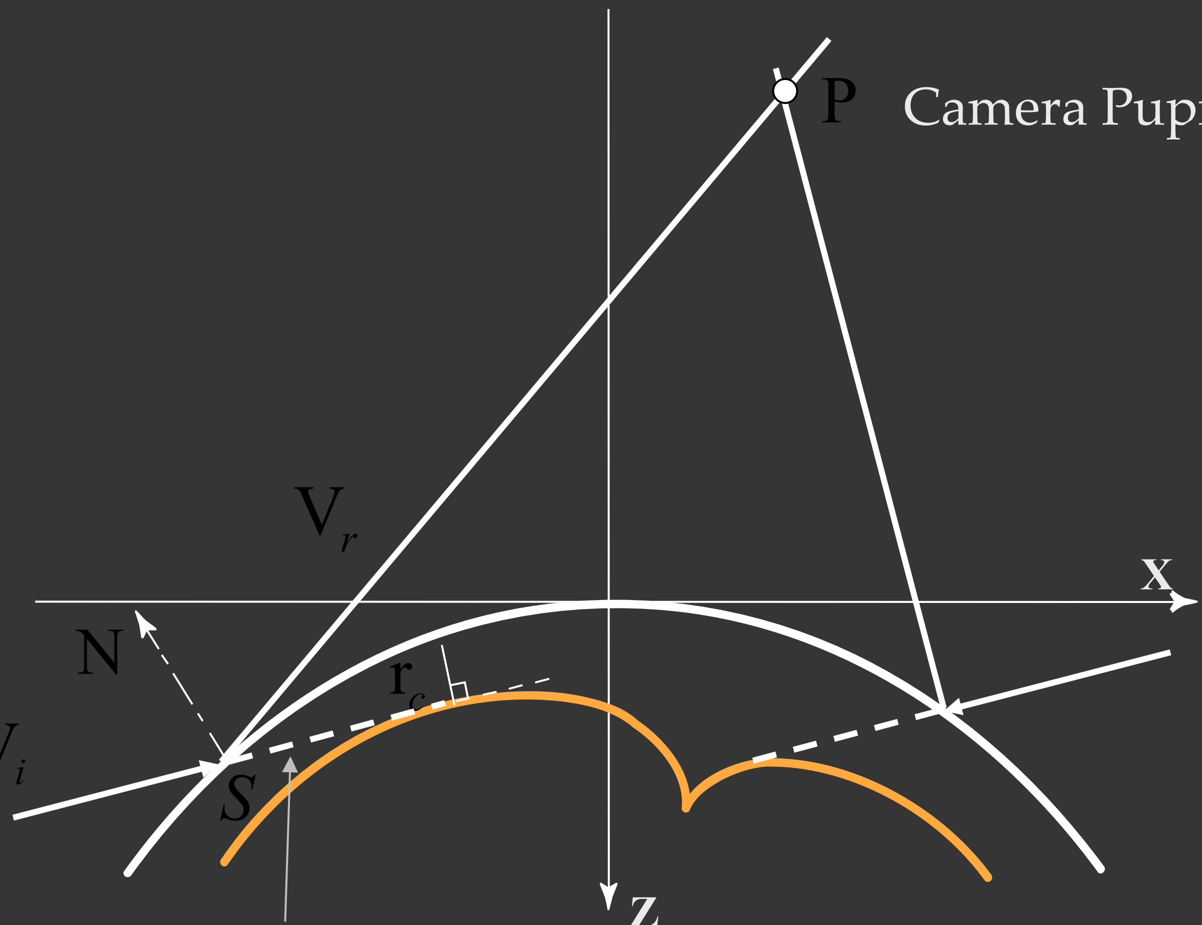
$$\max_e \left| \underbrace{g_\sigma(r_x)}_{\text{Gaussian}} * \frac{\partial}{\partial r_x} \oint_e \underbrace{I(x,y)}_{\text{intensity value}} ds + g_\sigma(r_y) * \frac{\partial}{\partial r_y} \oint_e I(x,y)\, ds \right|$$

Self-calibration:

3D Coordinates, 3D Orientation

How does the World Appear in an Eye?

Imaging Characteristics: Viewpoint Locus

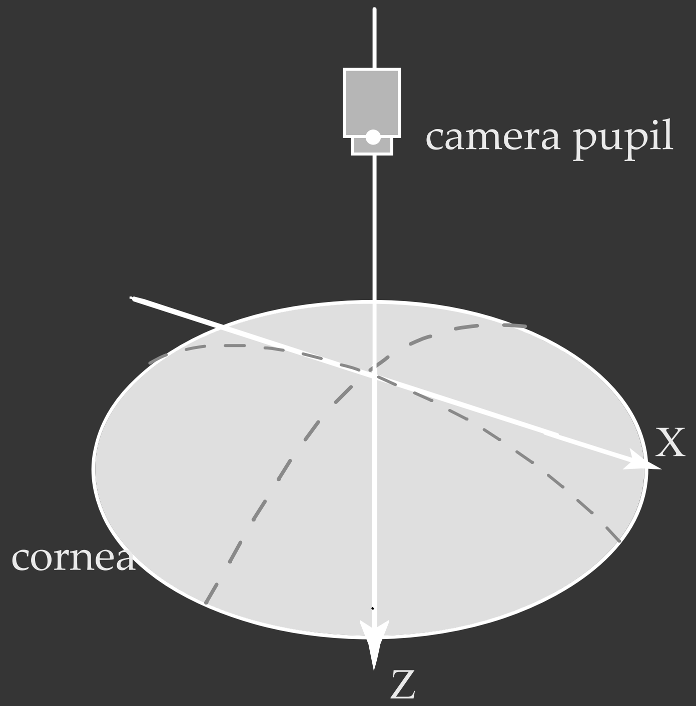


$$\mathbf{V}(t,\theta,r) = \mathbf{S}(t,\theta) + r\mathbf{V}_i(t,\theta)$$

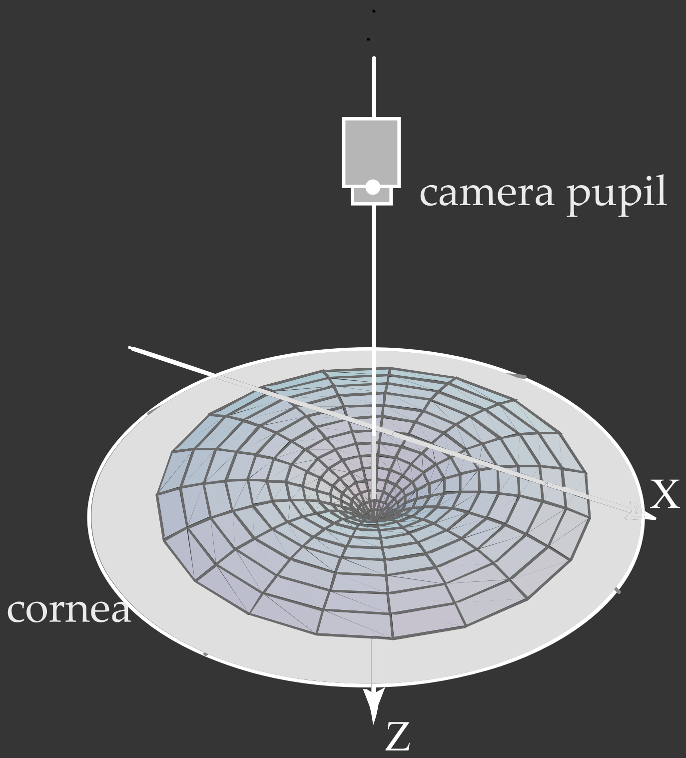
$$\det J(\mathbf{V}(t,\theta,r_c)) = 0$$

[Burkhard and Shealy 73; Swaminathan et al. 01]

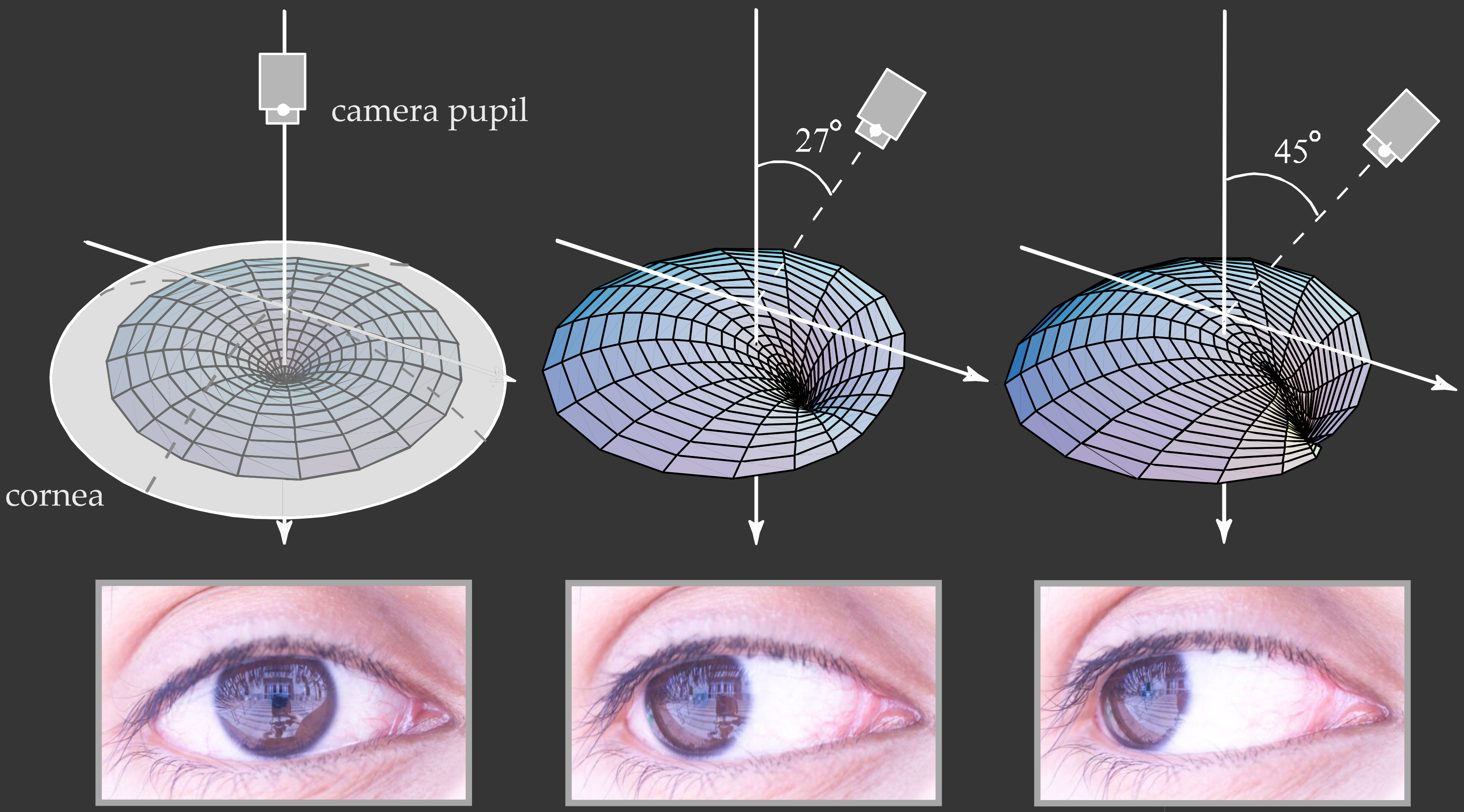
Viewpoint Loci



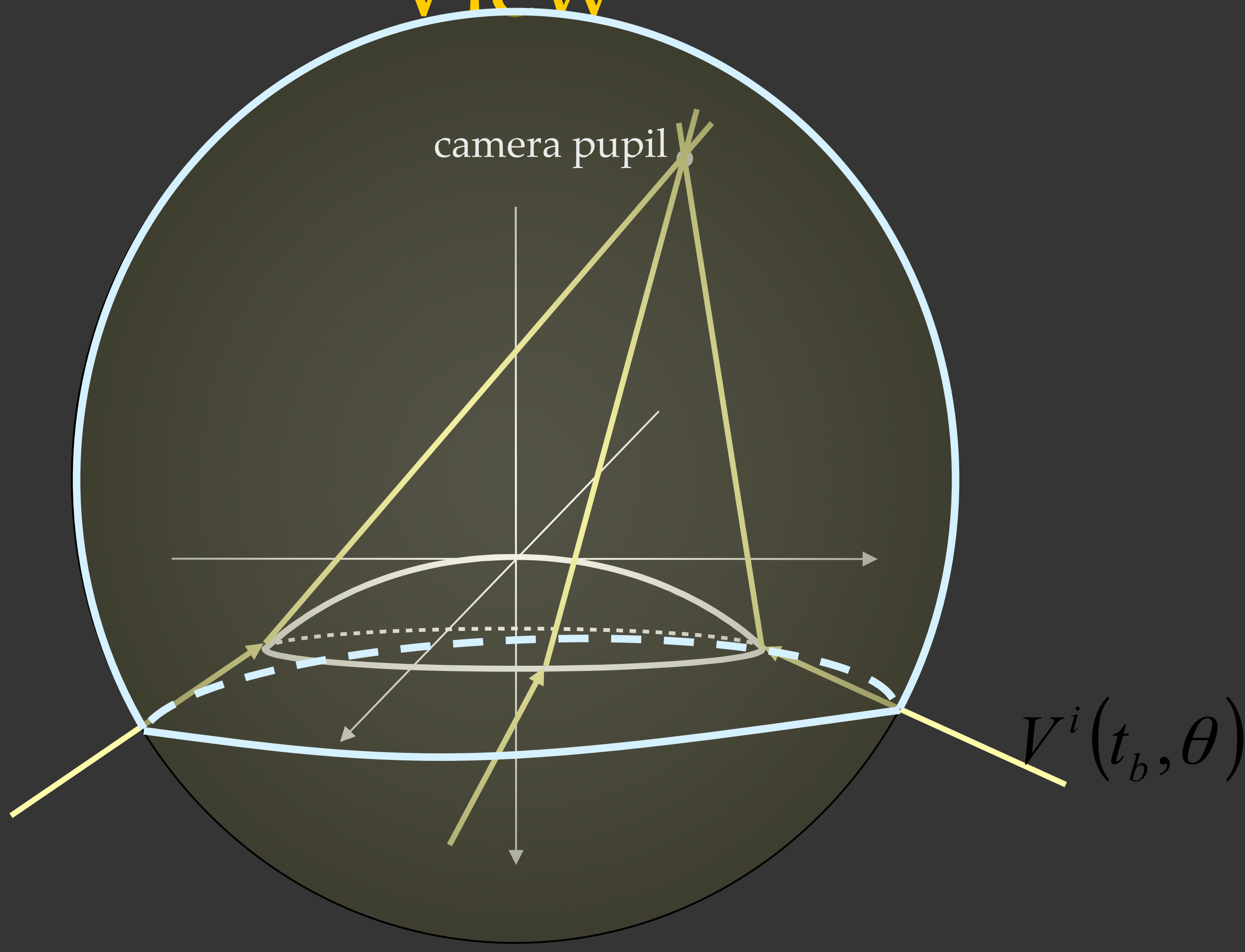
Viewpoint Loci



Viewpoint Loci



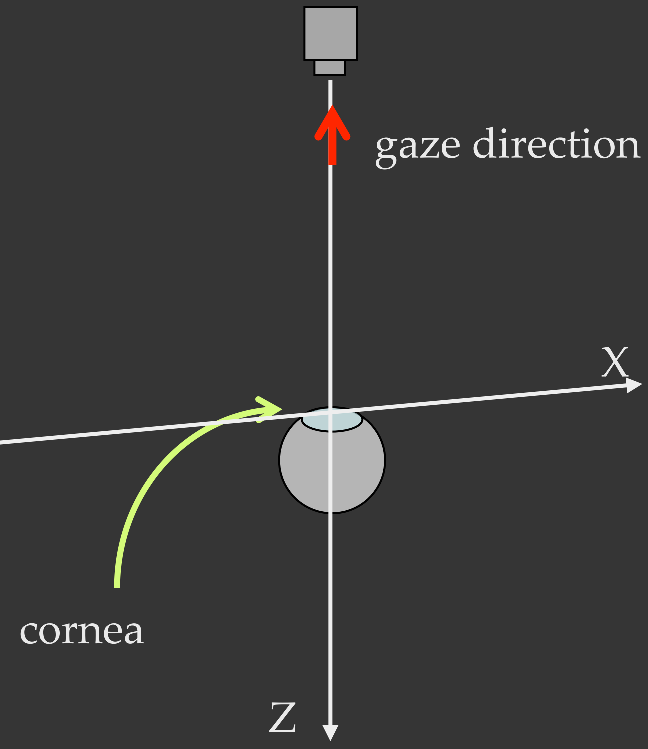
Imaging Characteristics: Field of View

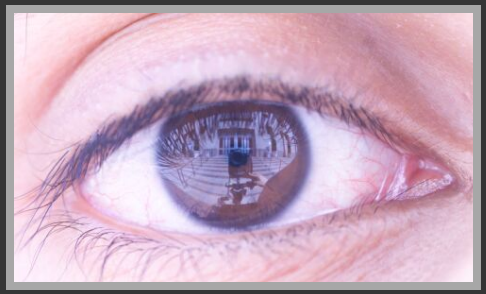


$$\text{FOV} = \int_0^{2\pi} \left(-V_z^i(t_b, \theta) + 1 \right) d\theta$$

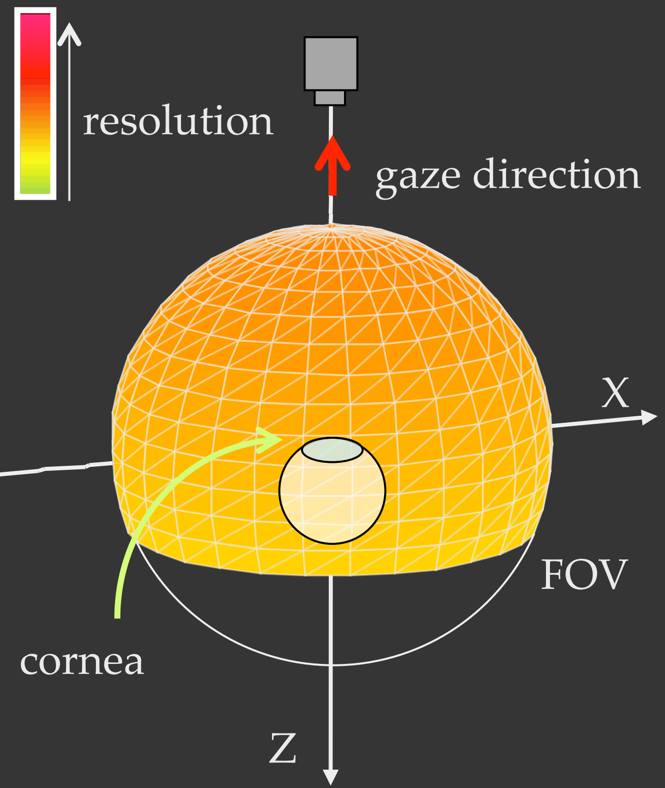
closed loop of limbus incident light rays

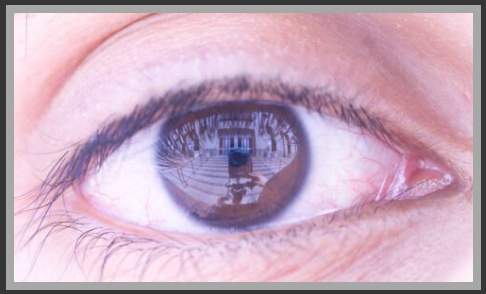
Gaze and Field of View



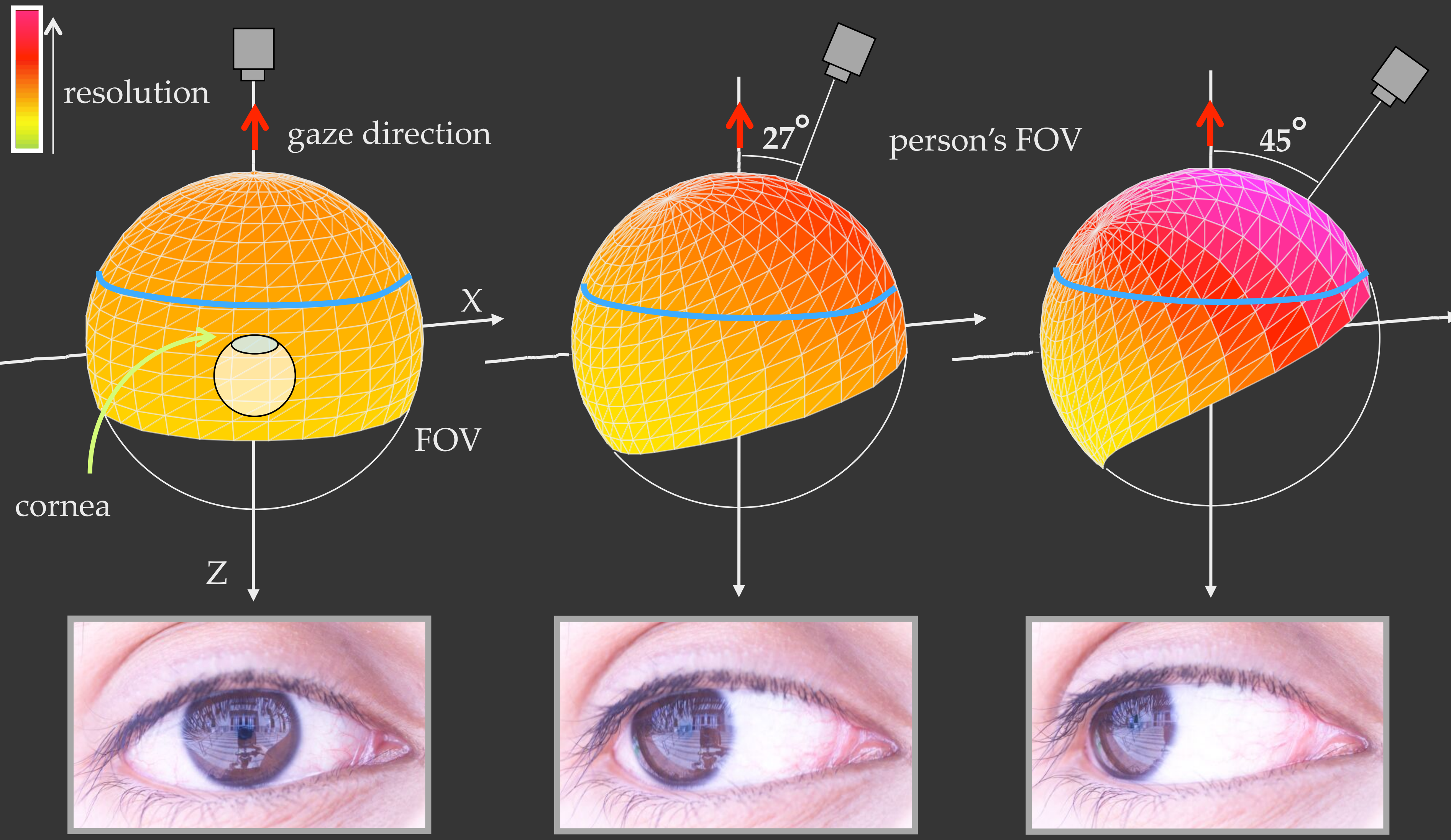


Gaze and Field of View

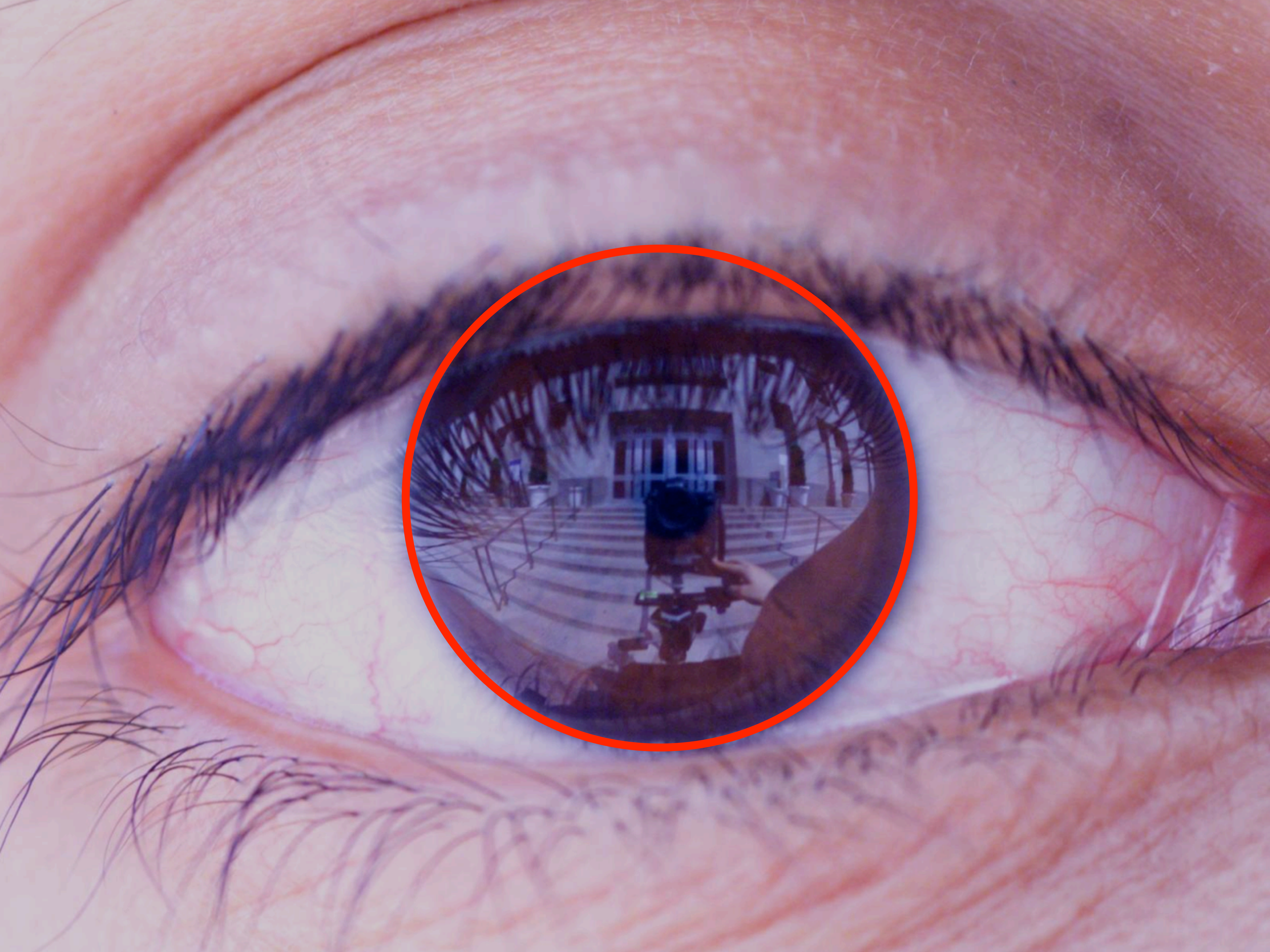




Gaze and Field of View



What does the Eye Reveal?

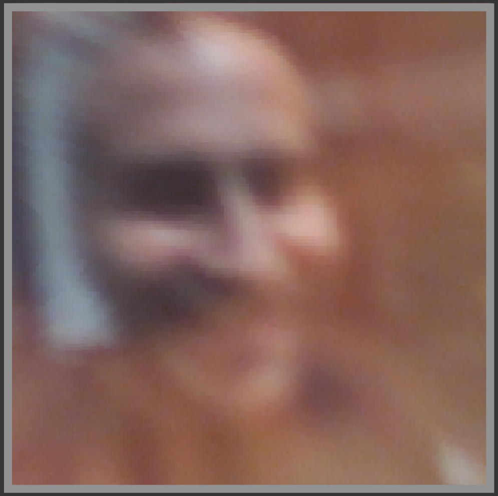


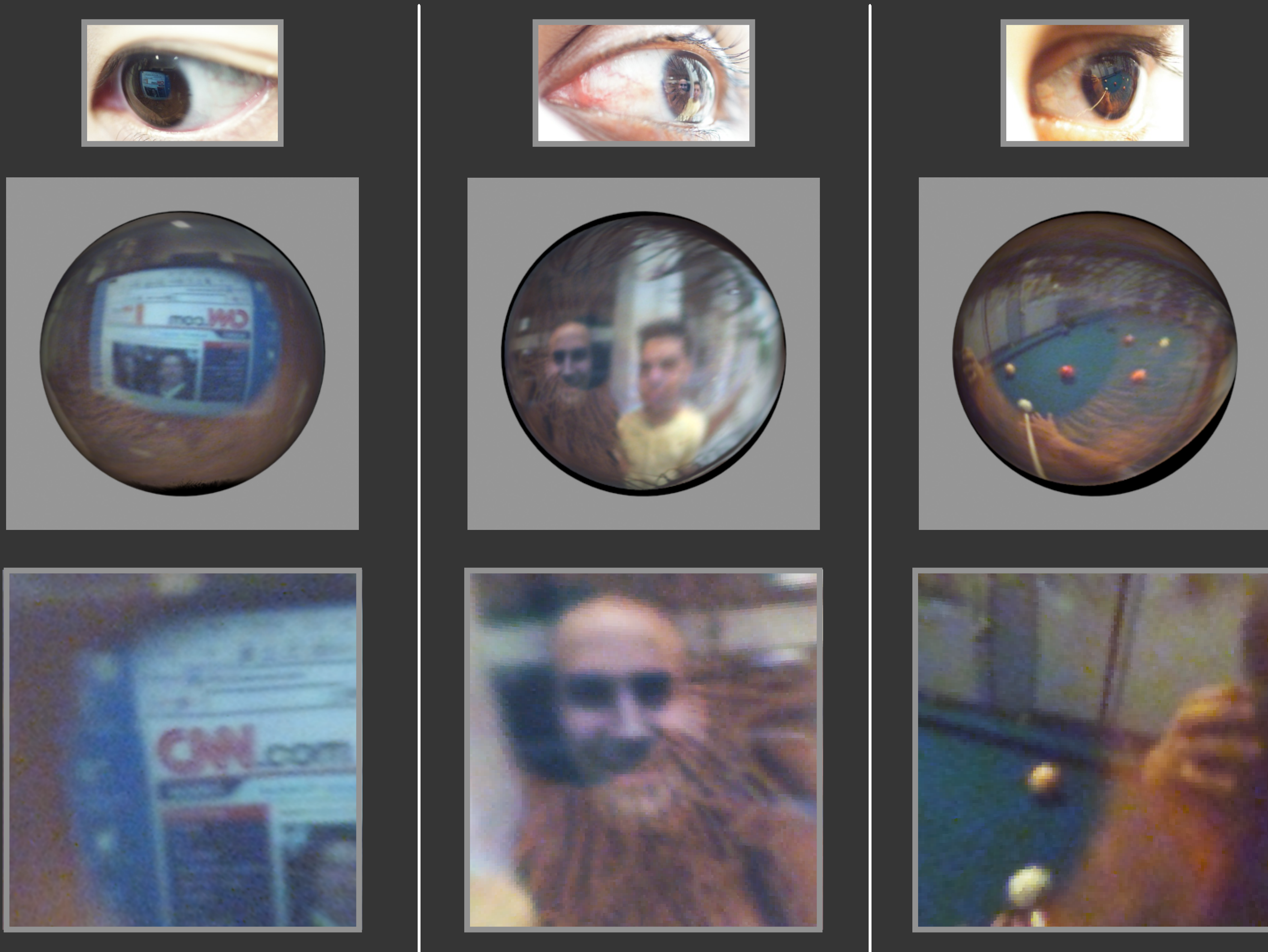
Environment Map from an Eye

What Exactly You are Looking At

Eye Image:

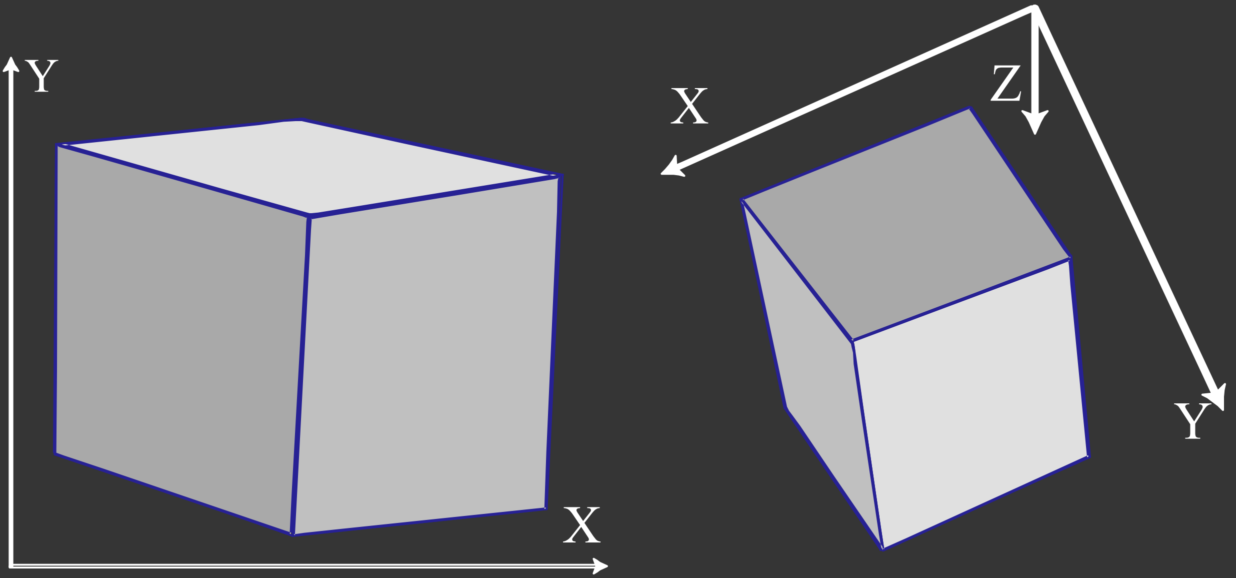
Computed Retinal Image:




CNN.com

Watching a Bus

From Two Eyes in an Image …



Reconstructed Structure (frontal and side view)

Eyes Reveal …

- Where the person is
- What the person is looking at
- The structure of objects

Implications

Human Affect Studies: Social Networks

Security: Human Localization

Advanced Interfaces: Robots, Computers

Computer Graphics: Relighting [SIGGRAPH 04]

Questions?

Compound Eyes

http://en.wikipedia.org/wiki/File:Dragonfly_compound_eyes02.jpg

Human Compound Eyes

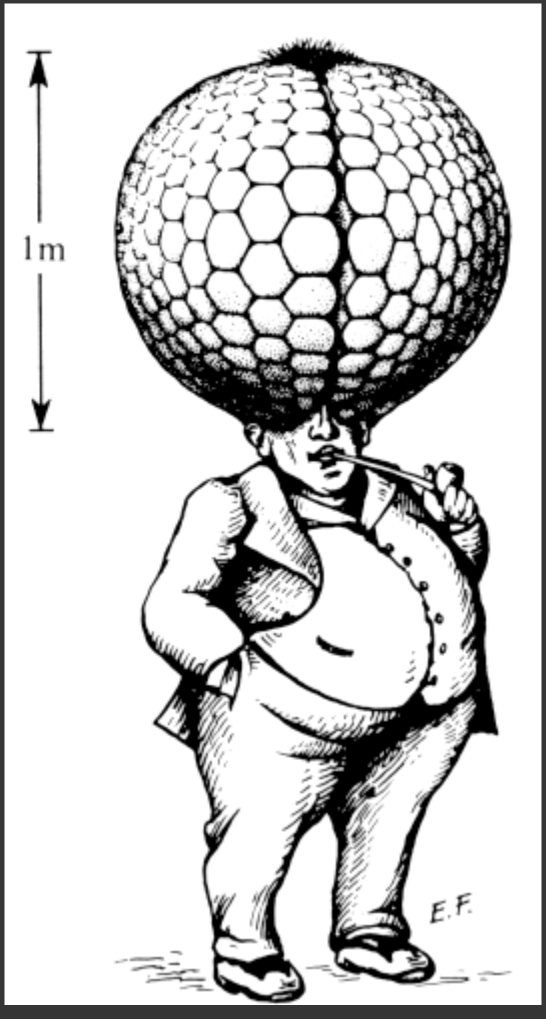
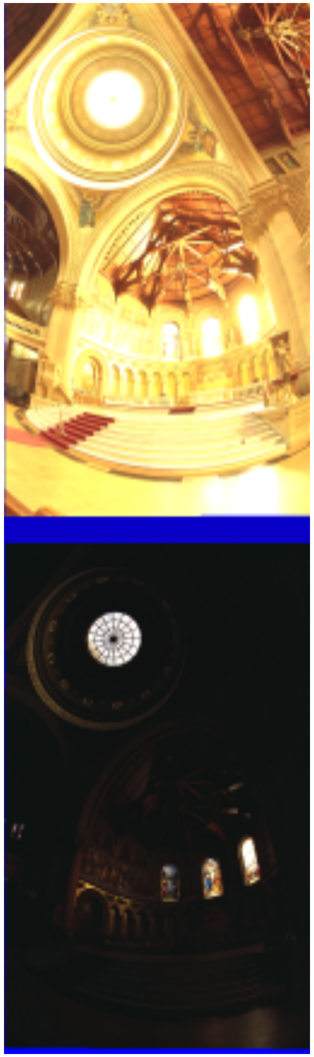
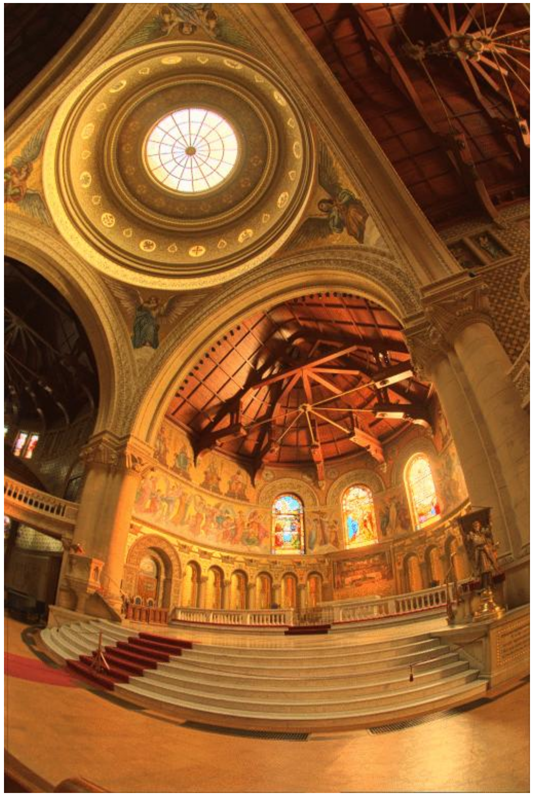


Fig. 2.8. A man would need a compound eye of at least 1 m diameter to get the same angular resolution as his lens eye. (From Kirschfeld 1976.)

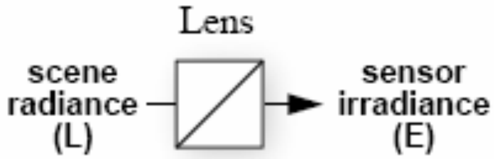
What do we see?



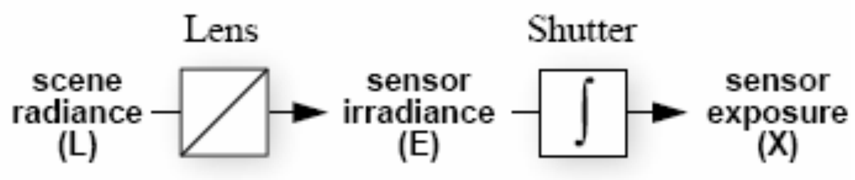
Vs.



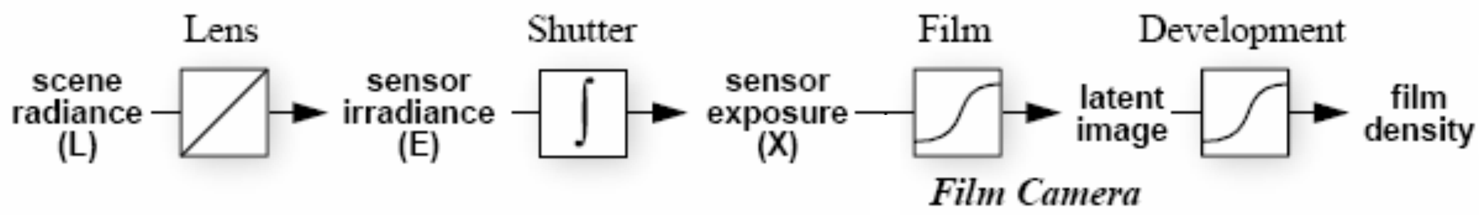
Camera pipeline



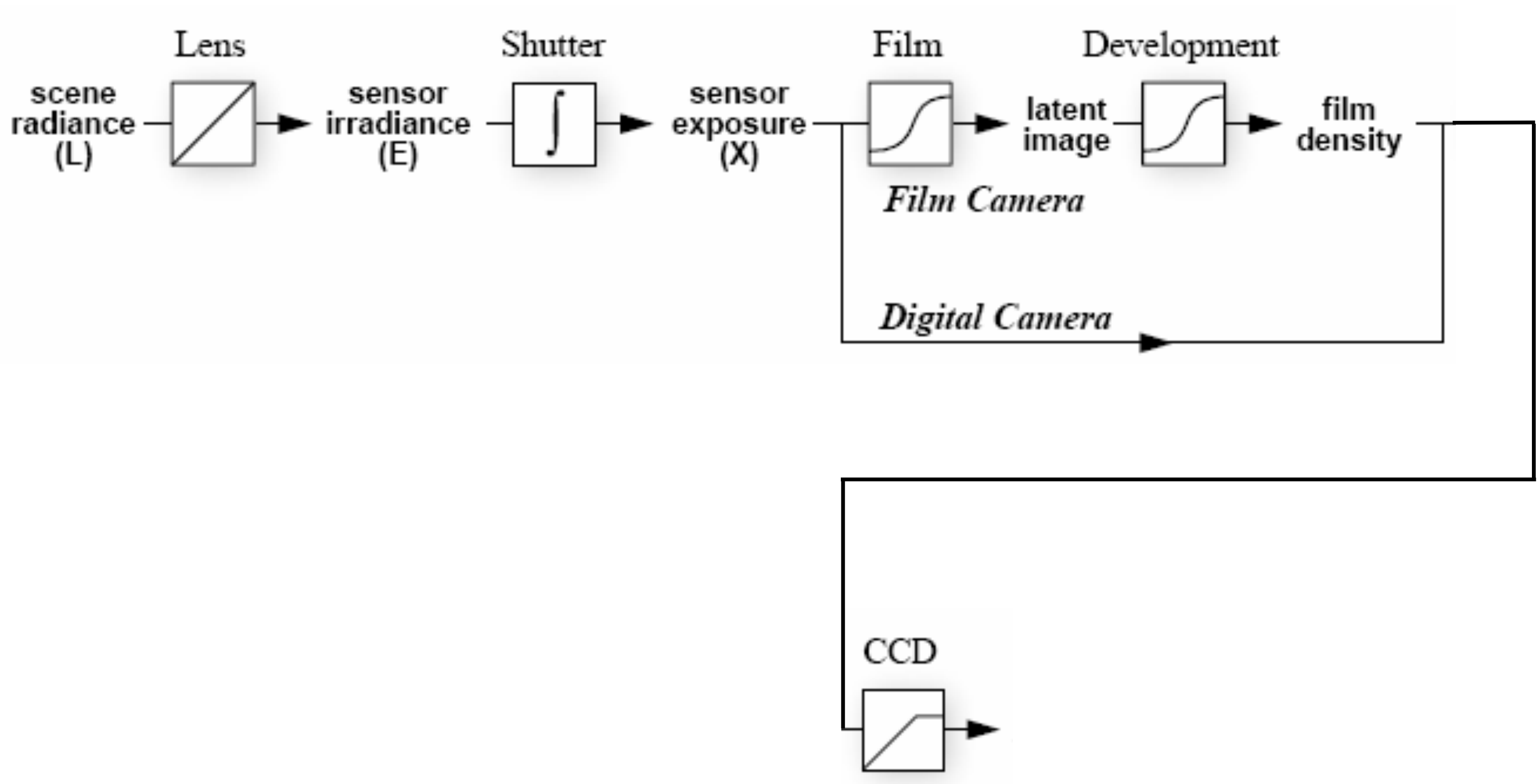
Camera pipeline



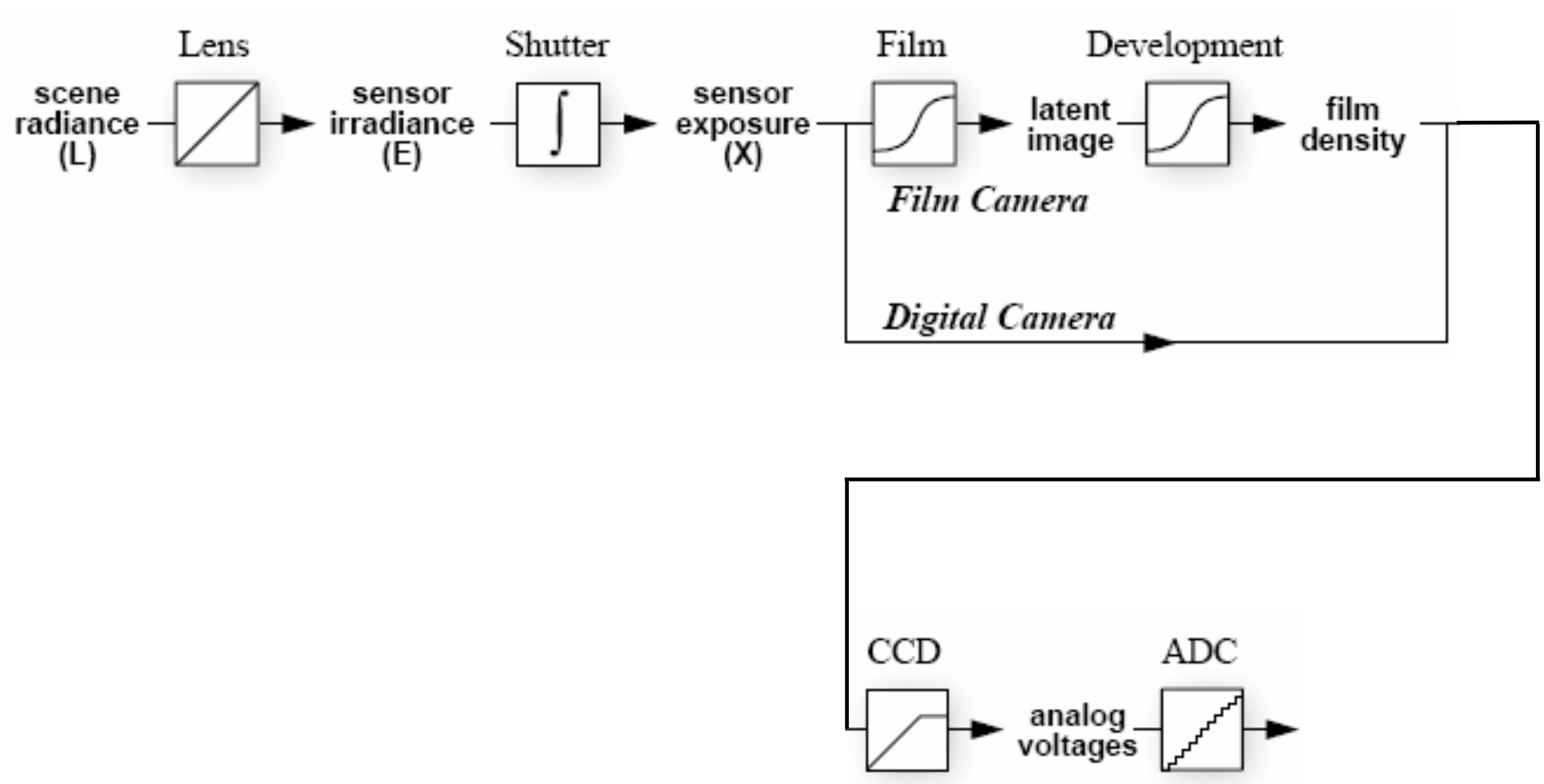
Camera pipeline



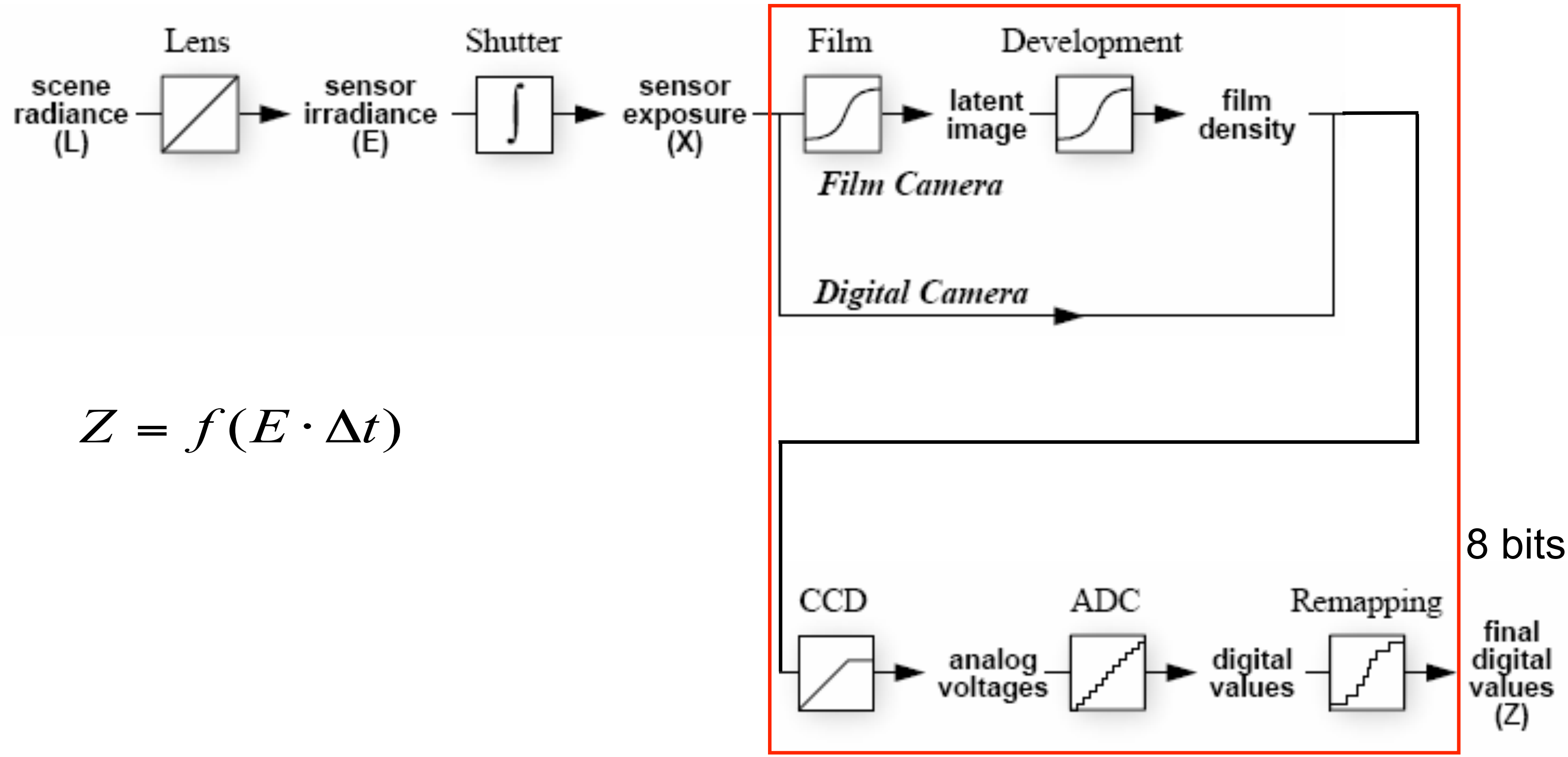
Camera pipeline



Camera pipeline



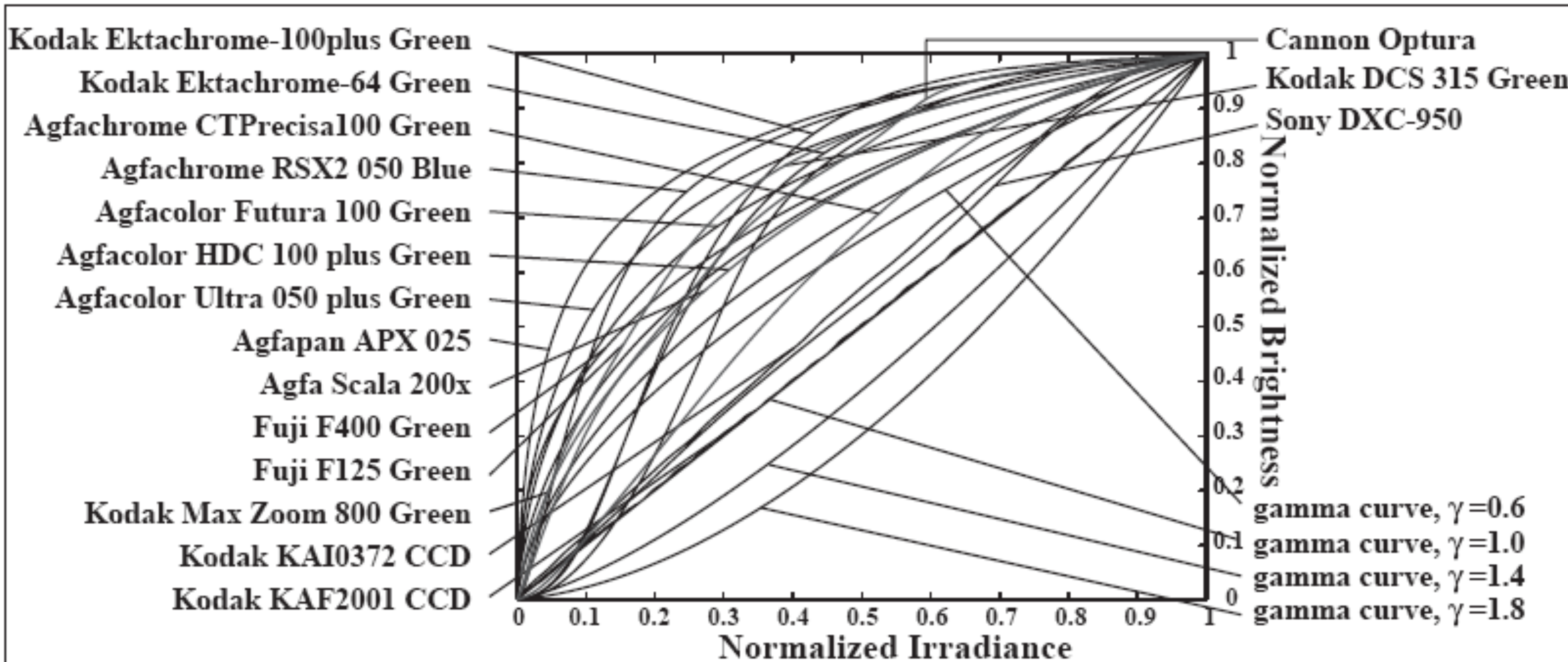
Camera pipeline



$$Z = f(E \cdot \Delta t)$$

Real-world response functions

In general, the response function is not provided by camera makers who consider it part of their proprietary product differentiation. In addition, they are beyond the standard gamma curves.

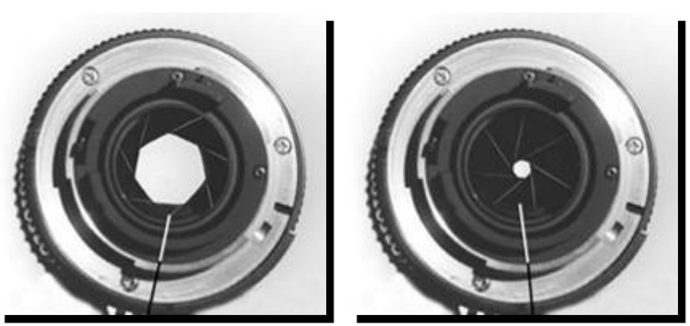


Camera is not a photometer

- Limited dynamic range
  - $\Rightarrow$ Perhaps use multiple exposures?
- Unknown, nonlinear response
  - $\Rightarrow$ Not possible to convert pixel values to radiance
- Solution:
  - Recover response curve from multiple exposures, then reconstruct the ***radiance map***

Varying exposure

- Ways to change exposure
  - Shutter speed
  - Aperture
  - Neutral density filters



Shutter speed

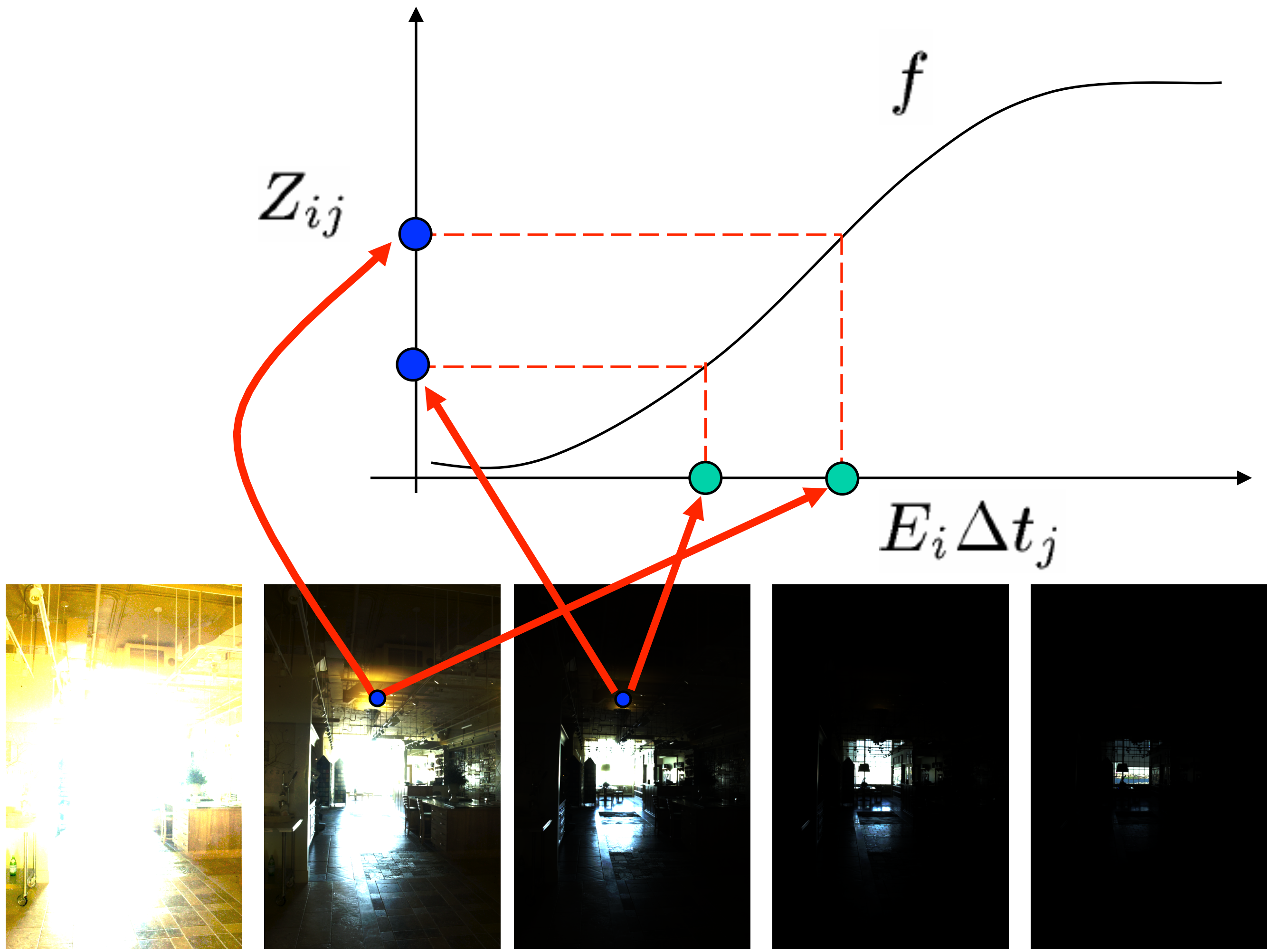
- Note: shutter times usually obey a power series – each “stop” is a factor of 2
- ¼, 1/8, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500, 1/1000 sec

Usually really is:

¼, 1/8, 1/16, 1/32, 1/64, 1/128, 1/256, 1/512, 1/1024 sec

HDRI capturing from multiple exposures

- We want to obtain the response curve



HDRI capturing from multiple exposures

Image series

Δt = 2 sec	**Δt = 1 sec**	**Δt = 1/2 sec**	**Δt = 1/4 sec**	**Δt = 1/8 sec**

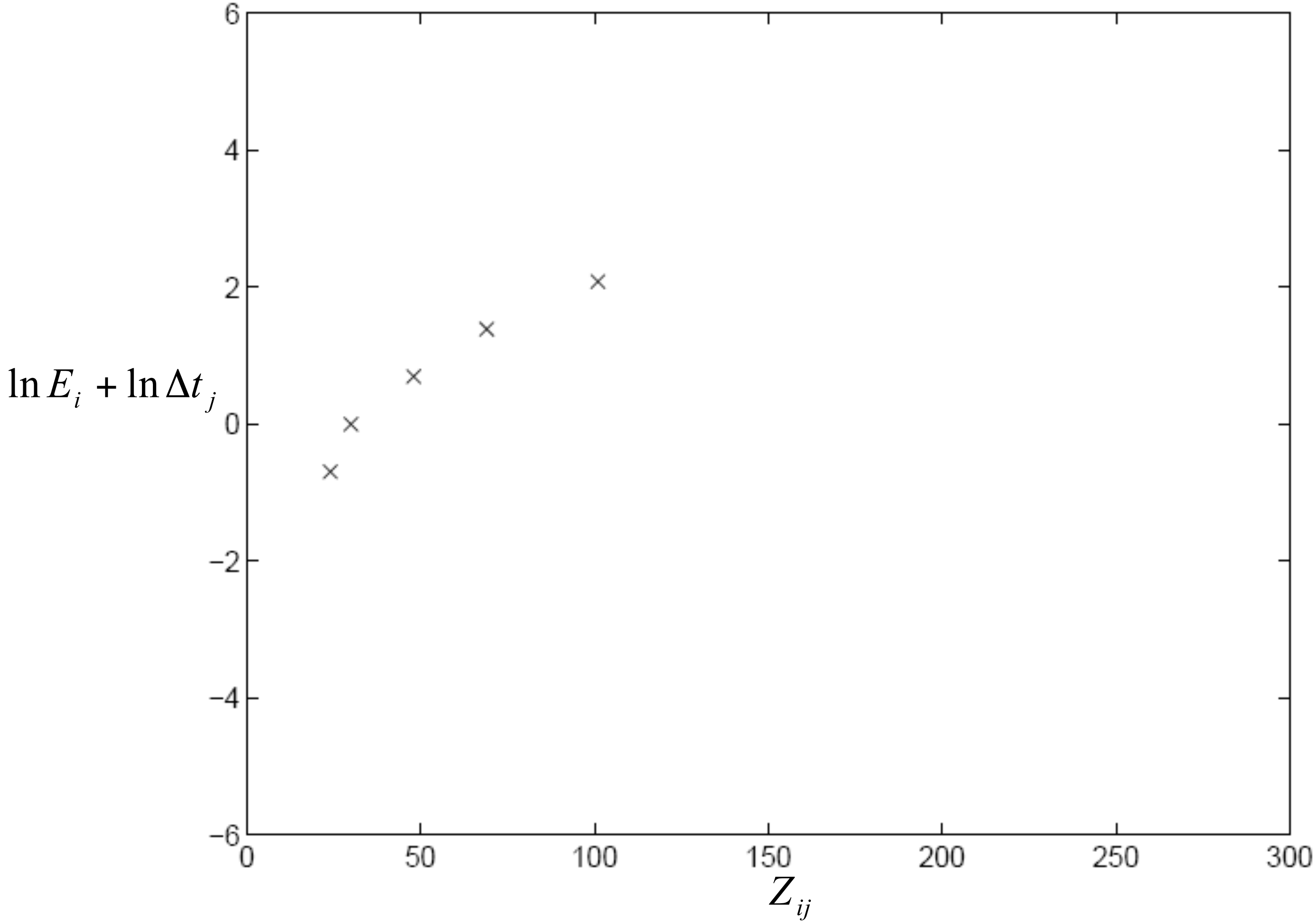
$$Z_{ij} = f(E_i \Delta t_j)$$

$$f^{-1}(Z_{ij}) = E_i \Delta t_j$$

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j, \text{ where } g = \ln f^{-1}$$

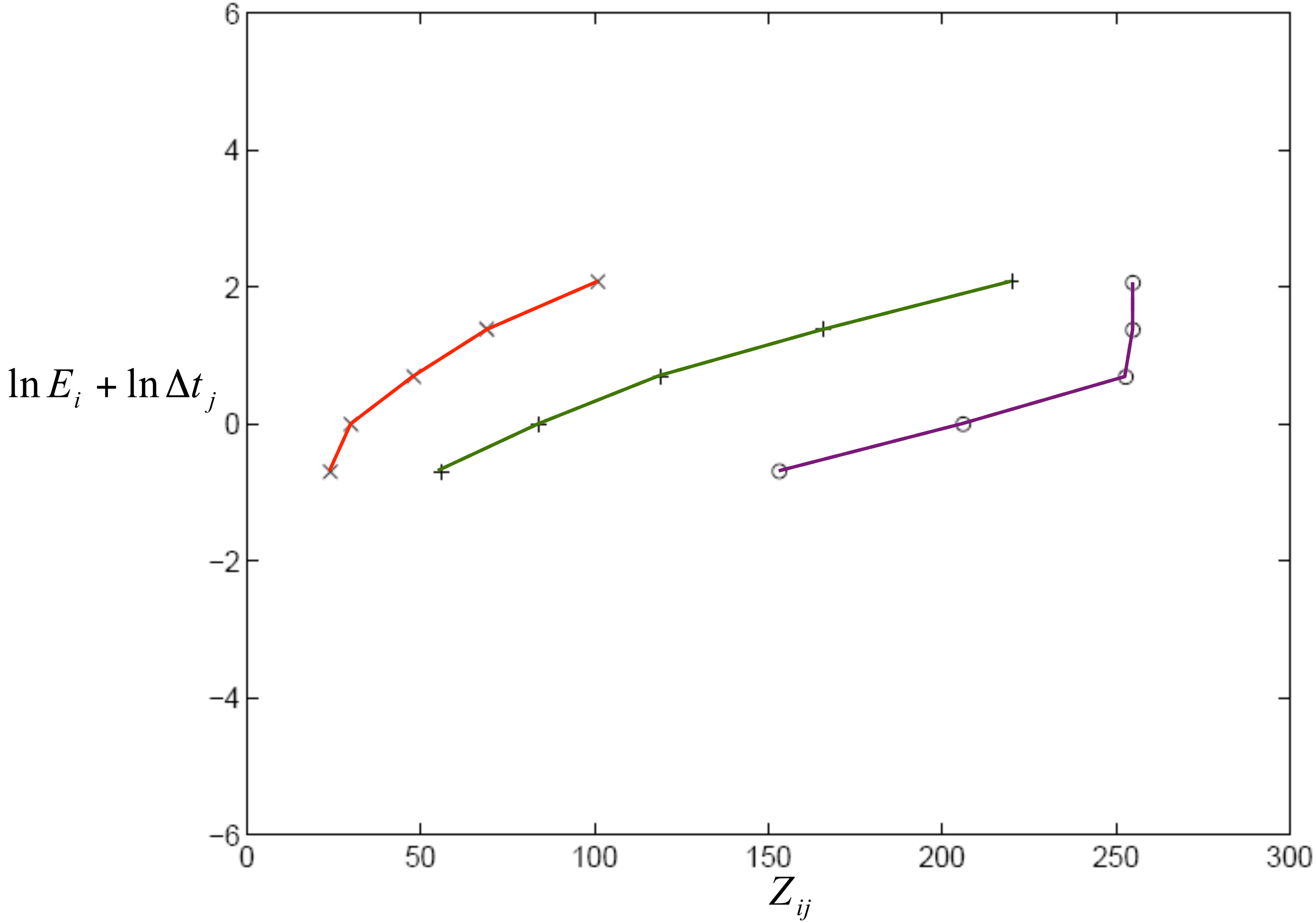
Idea behind the math

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

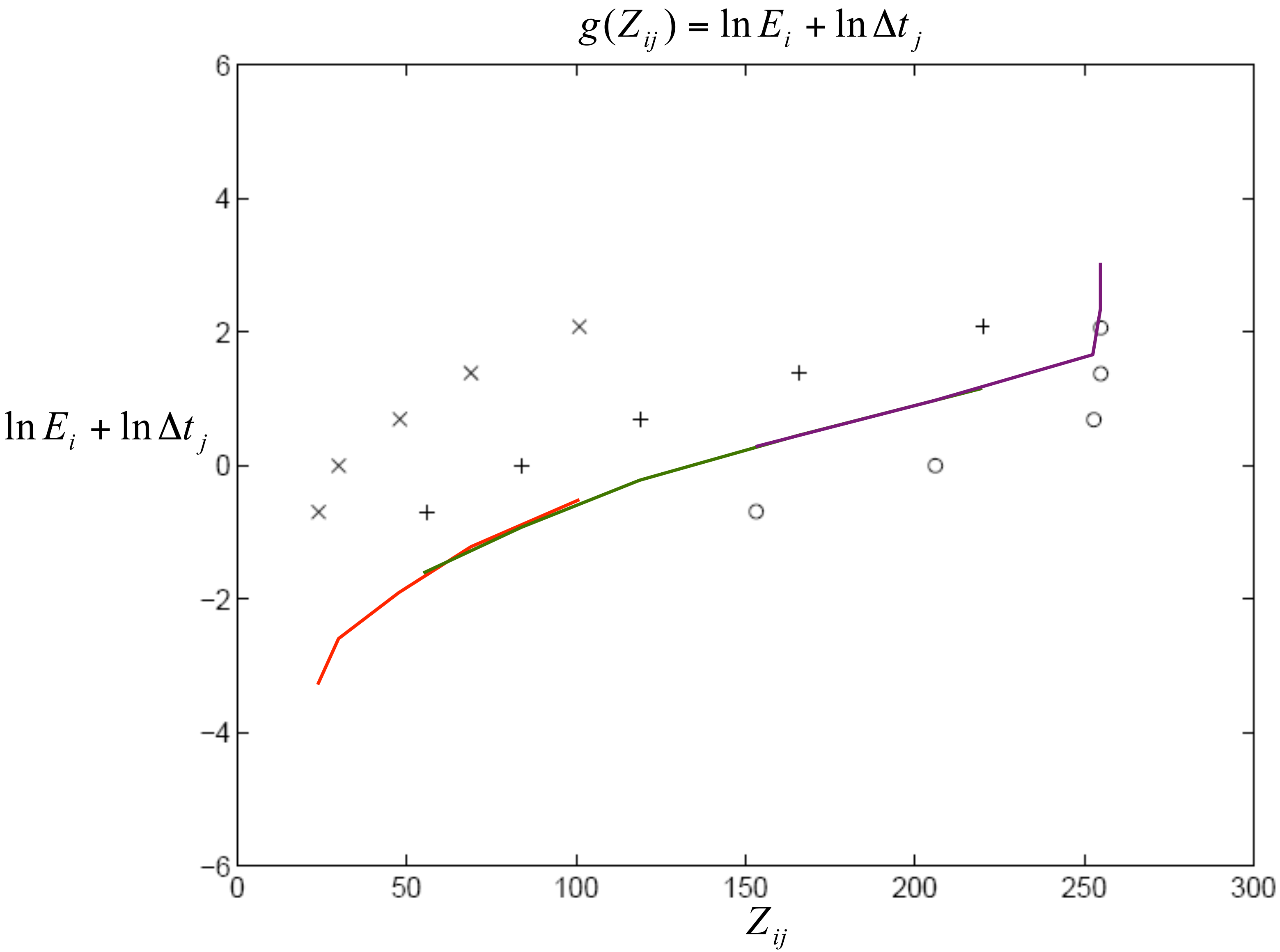


Idea behind the math

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j$$



Idea behind the math



Math for recovering response curve

$$Z_{ij} = f(E_i \Delta t_j)$$

f is monotonic, it is invertible

$$\ln f^{-1}(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

let us define function $g = \ln f^{-1}$

$$g(Z_{ij}) = \ln E_i + \ln \Delta t_j$$

minimize the following

$$\mathcal{O} = \sum_{i=1}^{N} \sum_{j=1}^{P} [g(Z_{ij}) - \ln E_i - \ln \Delta t_j]^2 + \lambda \sum_{z=Z_{min}+1}^{Z_{max}-1} g''(z)^2$$

$$g''(z) = g(z-1) - 2g(z) + g(z+1)$$