COMP 546

Lecture 3

Color, Photoreceptors

Thurs. Jan. 18, 2018

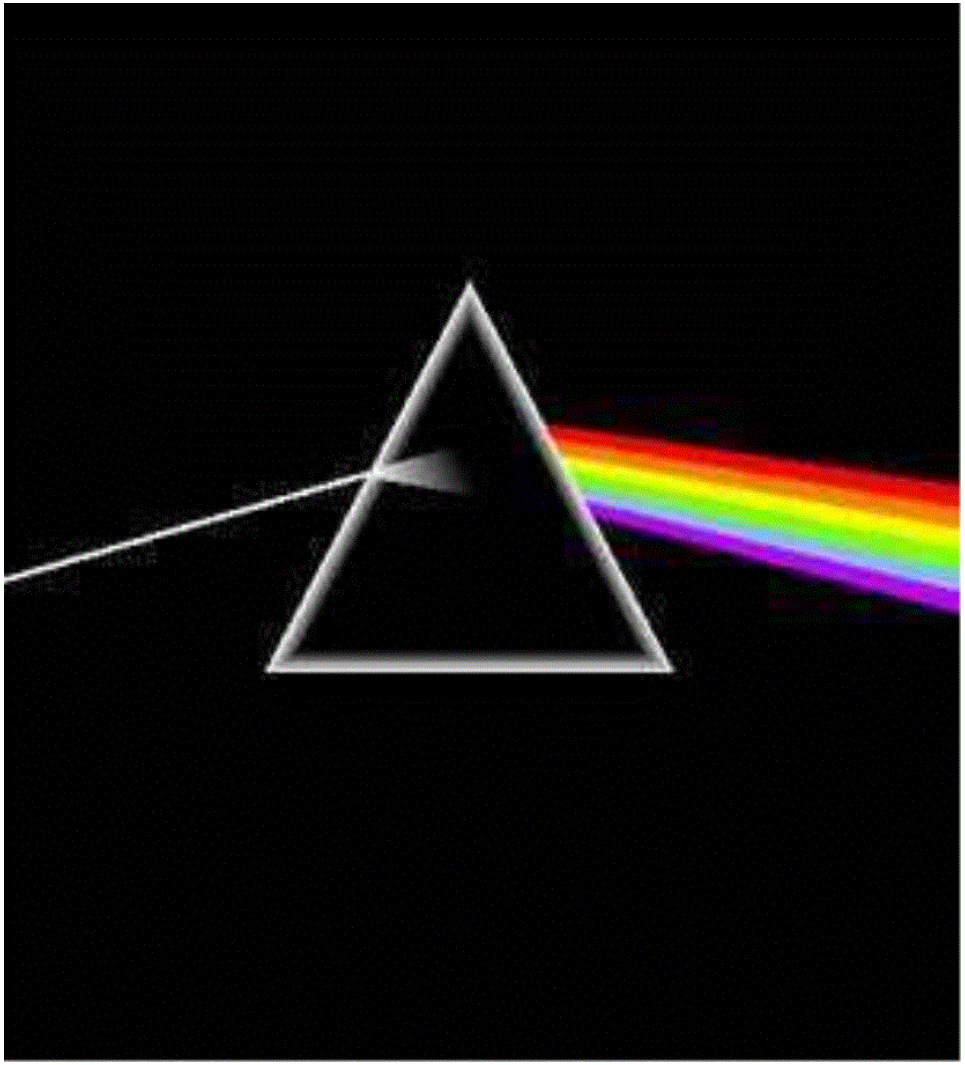
Weeks 1 & 2

- image formation and measurement

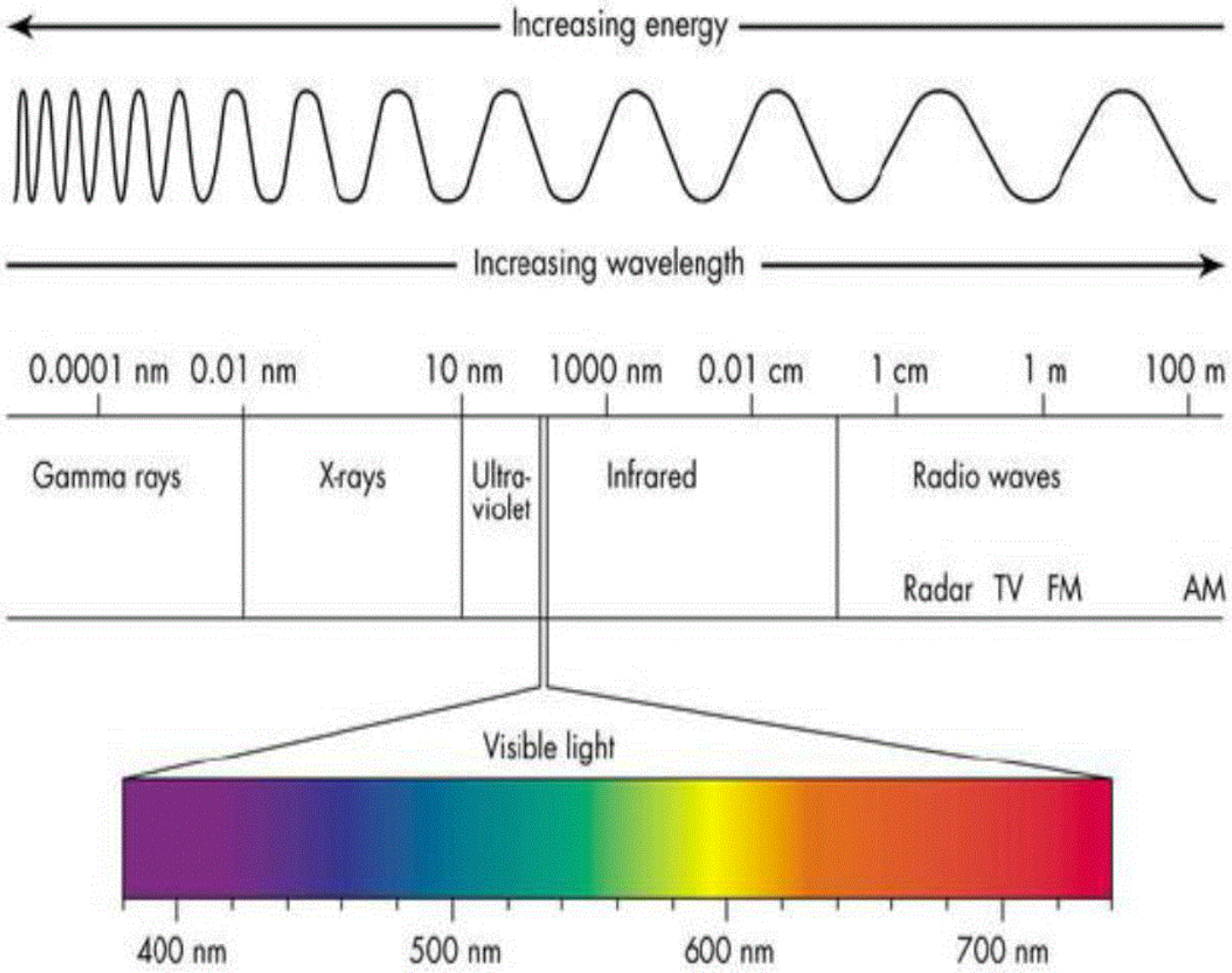
Weeks 3 & 4

- computational modelling (early vision)
- Assignment 1 to be posted by end of week 3

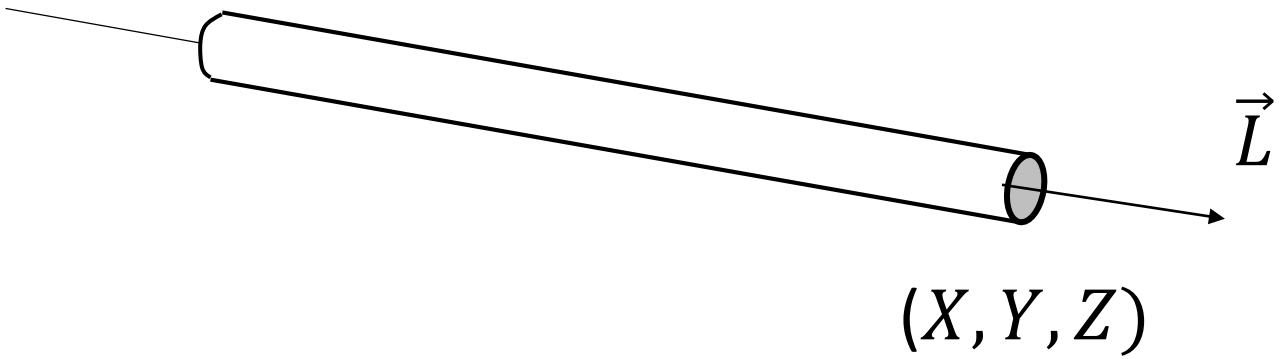
What is light ?



Light consists of electromagnetic waves from 400-700 nm.

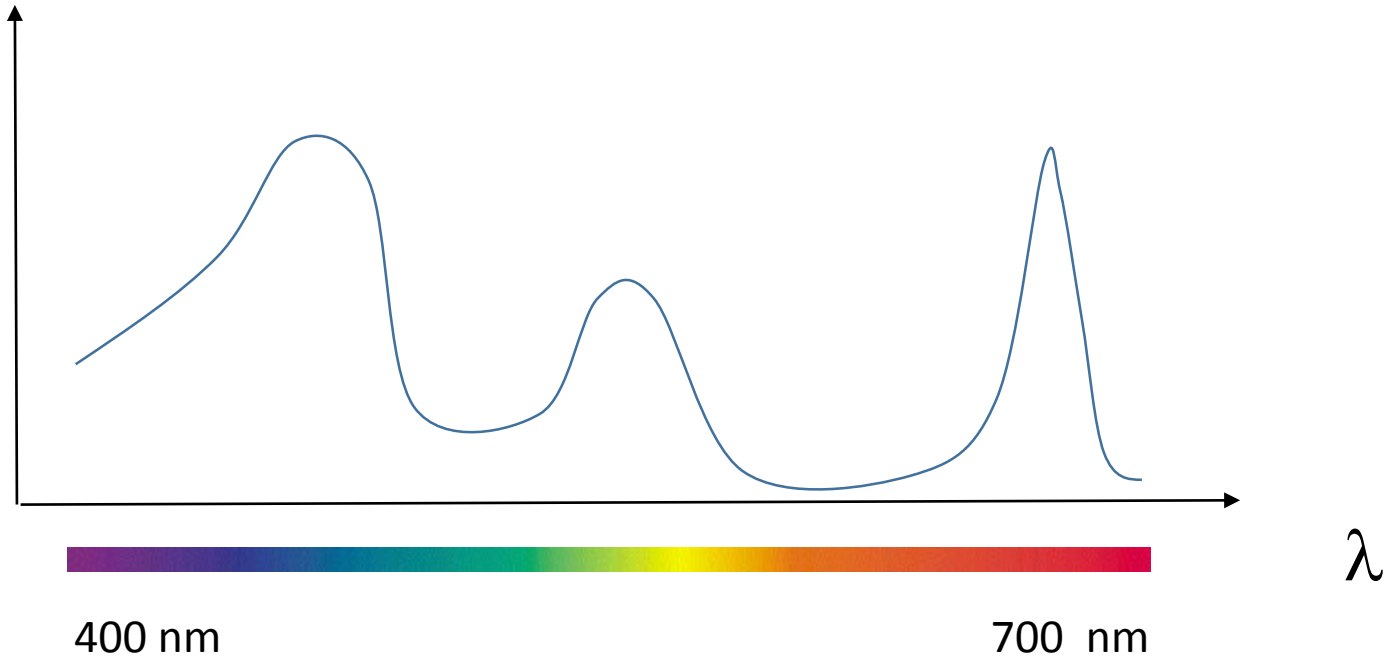


Radiance (intensity of a light ray)



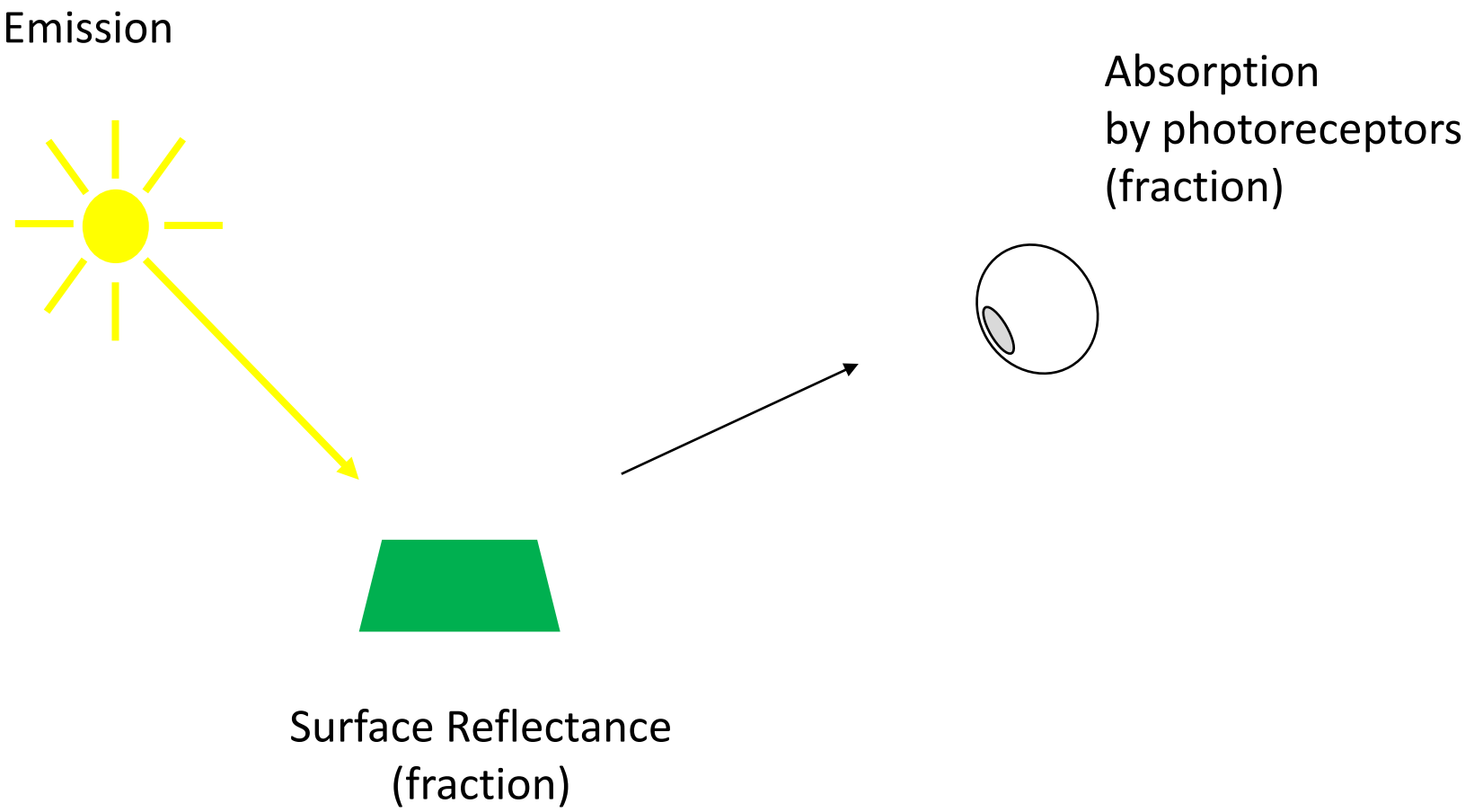
Depends on 3D position XYZ and orientation $\vec{L}$ and wavelength λ

Light Spectrum

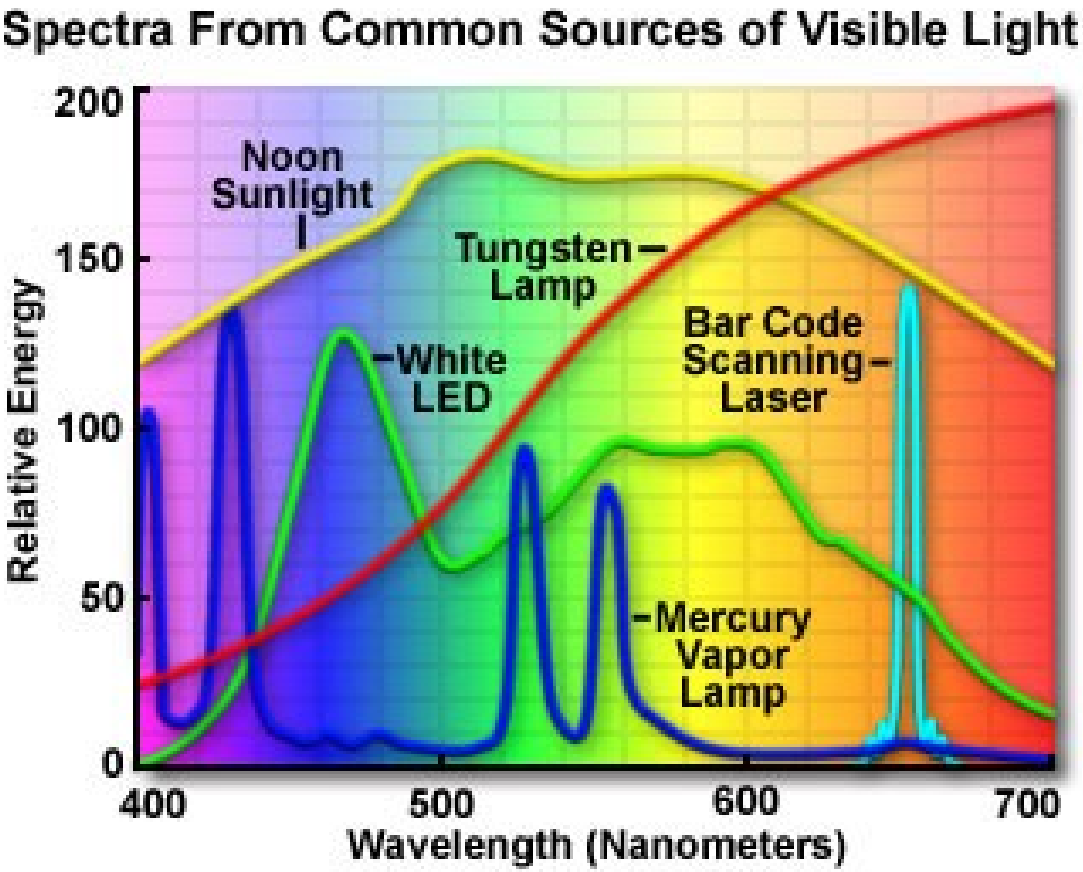


For a fixed position XYZ and direction $\vec{L}$, the radiance is a function only of wavelength λ.

Three types of spectra

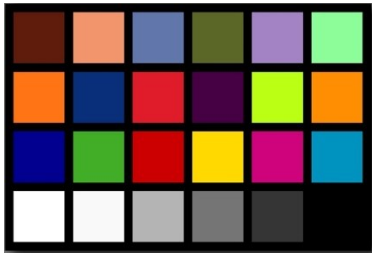


Emission spectra

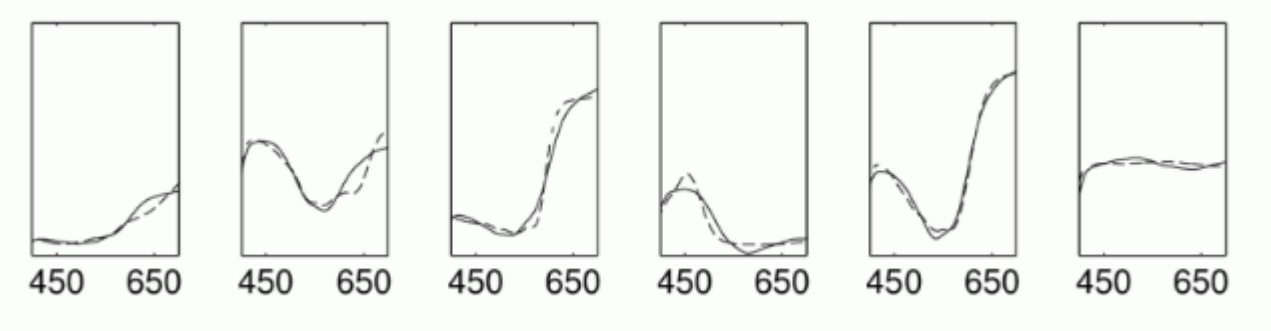


Reflectance spectra

For each wavelength, what is the fraction of light reflected from each surface ?

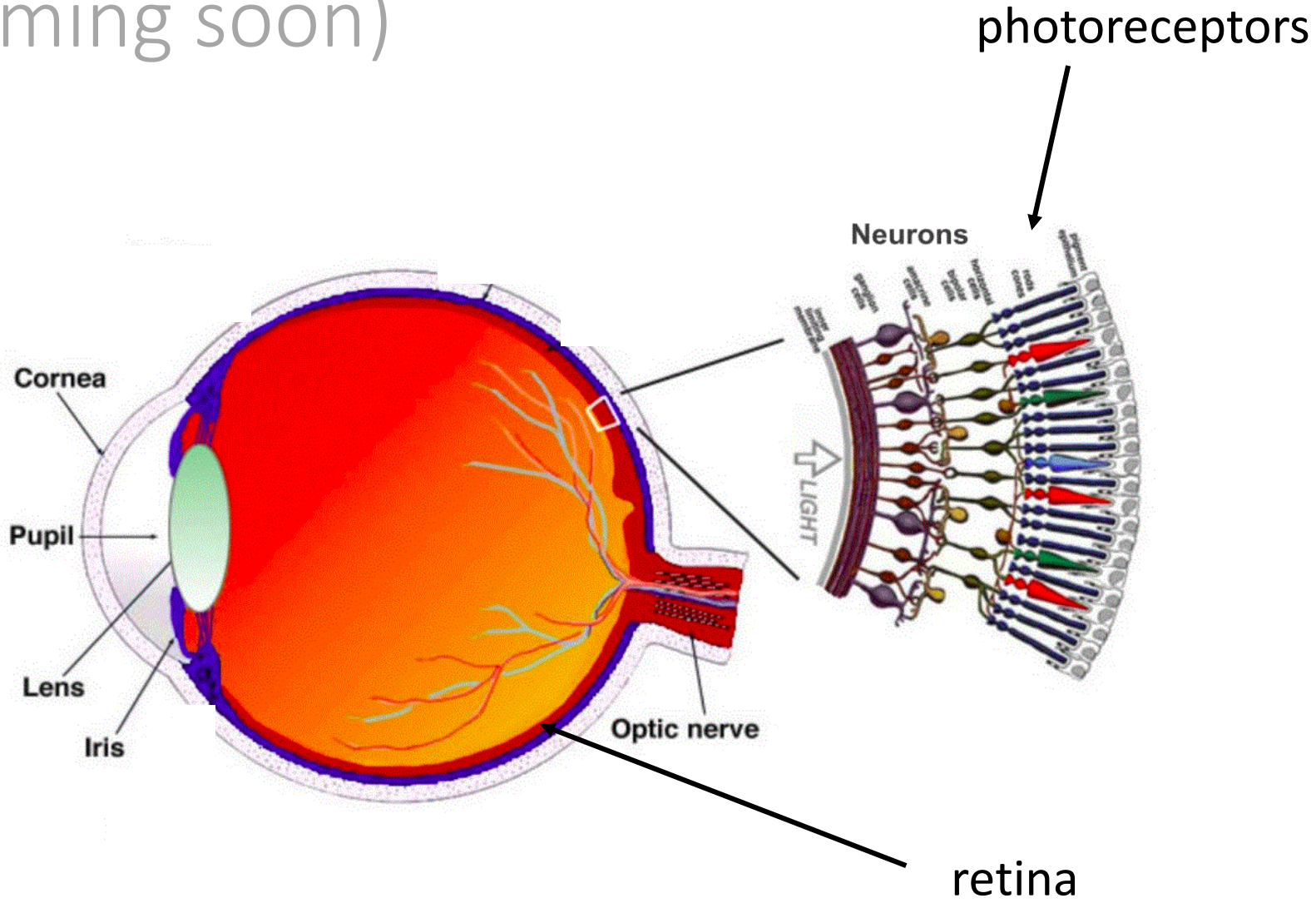


https://foundationsofvision.stanford.edu/chapter-9-color



Six samples (and model fit) from standard paper color Chart.
I'm not sure which six squares these plots correspond to.

Absorption spectra
(coming soon)



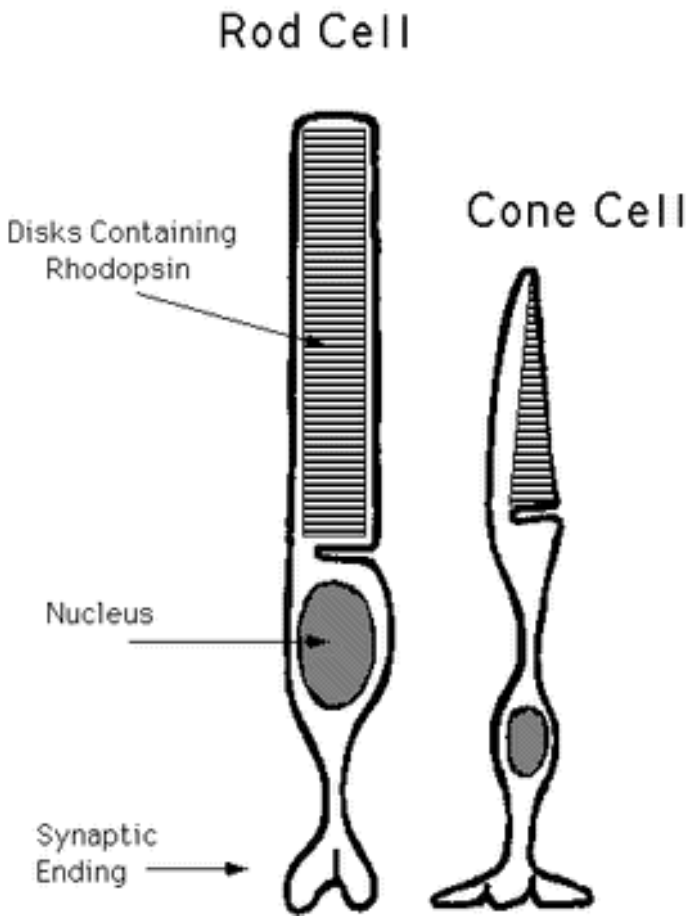
Photoreceptors: Rods and Cones

Rod →

↑

Cone

Photoreceptor response: transduction



Light is absorbed by a pigment in photoreceptor cell.

This leads to opening and closing of ion channels, causing:

- changes in electrical potential across cell membrane. (*We can measure this.*)
- release of neurotransmitters which binds to neighbor cell, i.e. communication. (*We cannot measure this.*)

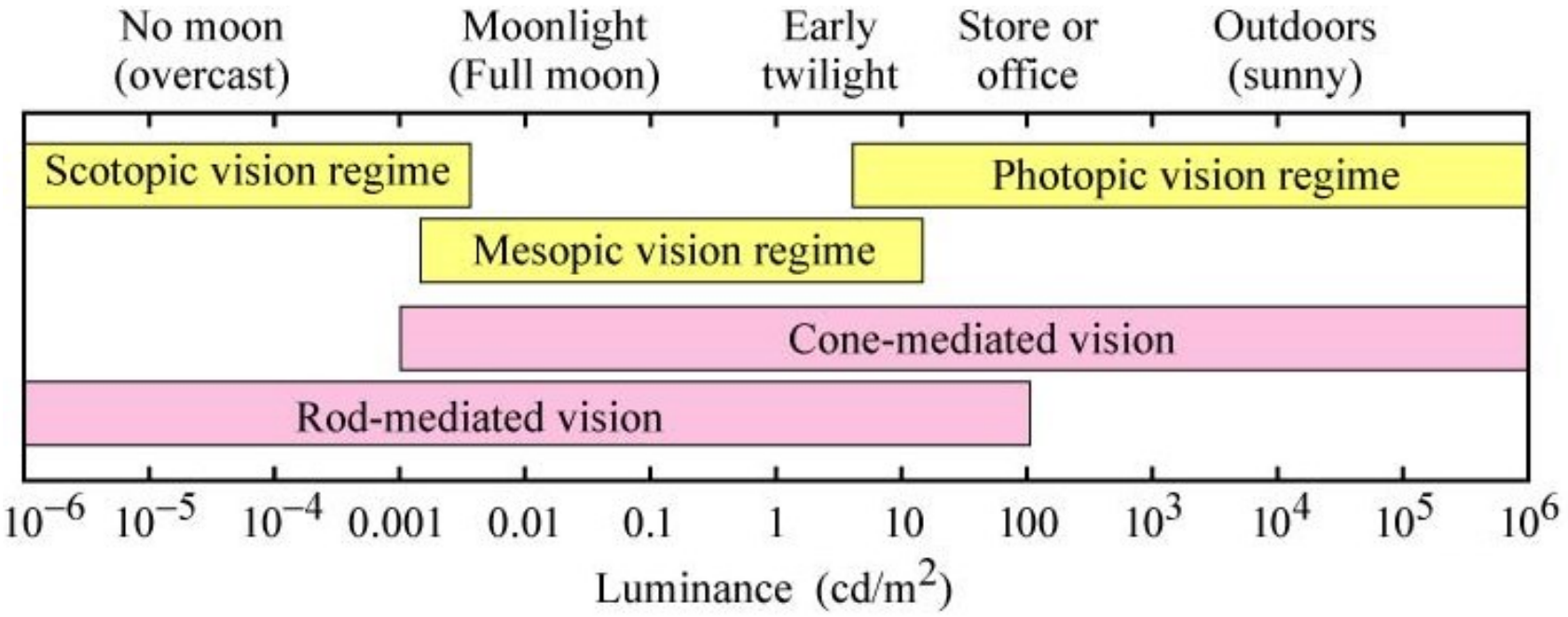
Rods

- night (dark)
- “grey level”
- peripheral vision
- high noise
- low resolution

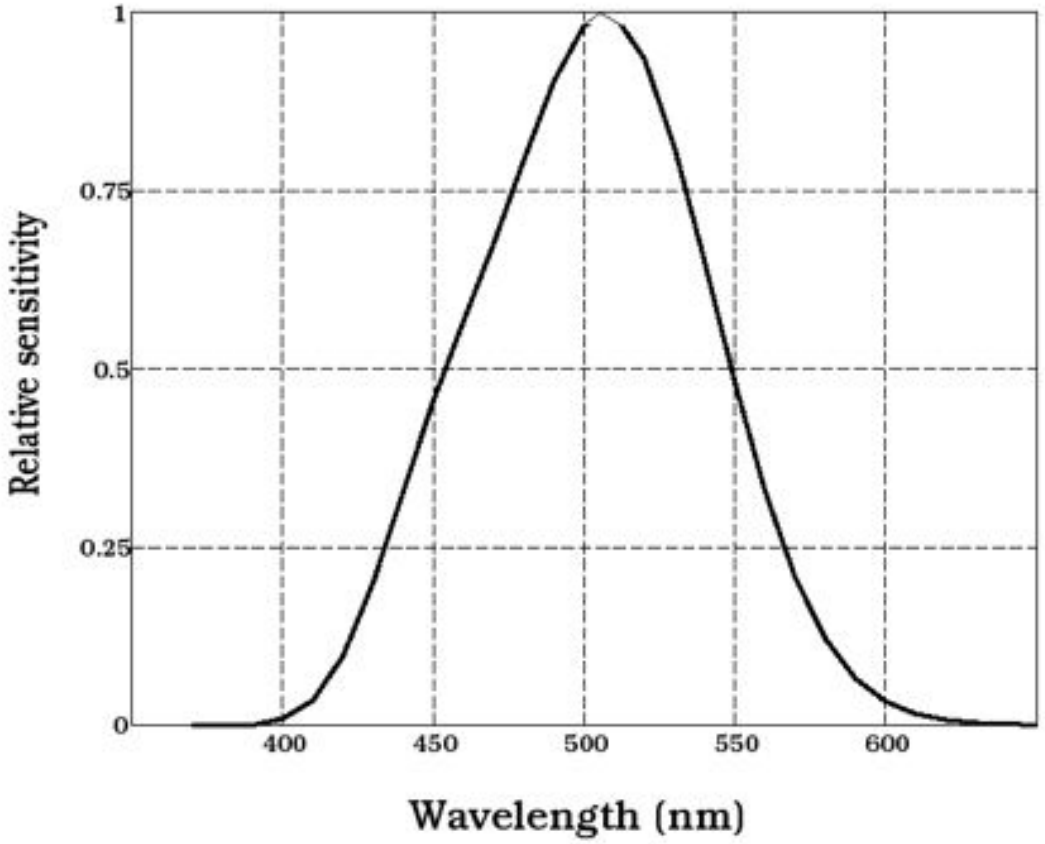
Cones

- day (bright)
- color
- central vision
- low noise
- high resolution (in center)

Rods and cones: light levels

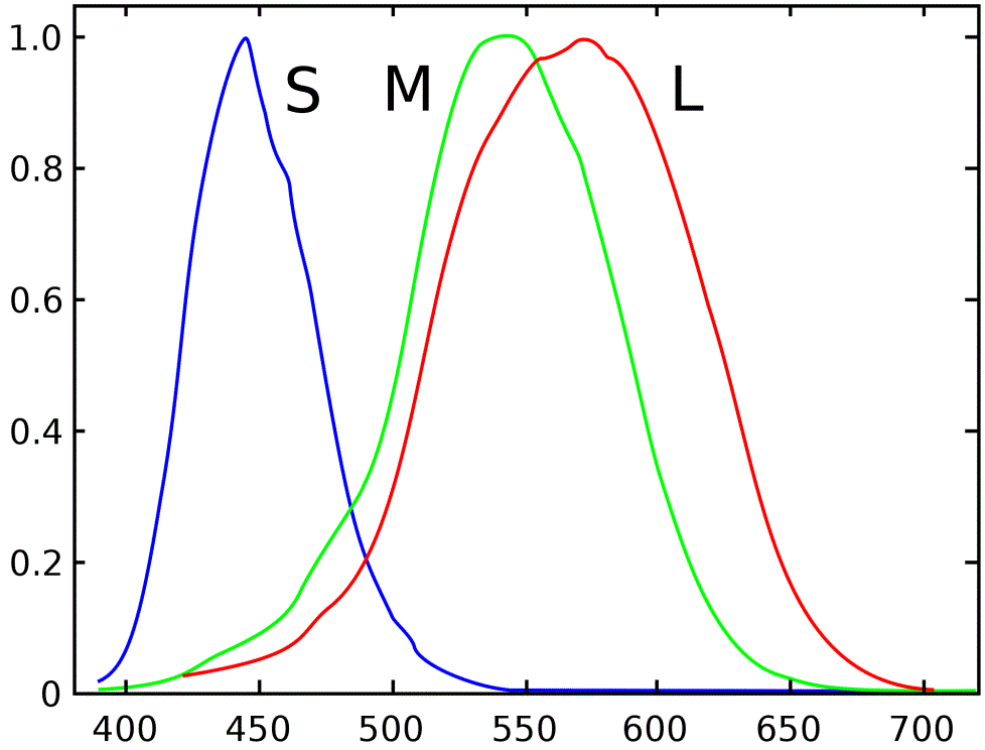


Spectral sensitivity (absorption) of rods



Fraction of light of wavelength λ absorbed by rod pigment.
(Normalized to 1 for illustration purposes)

Spectral sensitivity (absorption) of cones



L - long
M - medium
S - short

Fraction of light of wavelength λ absorbed by cone pigments.
(Normalized to 1 for illustration purposes,.)

“Principle of Univariance” (1D)

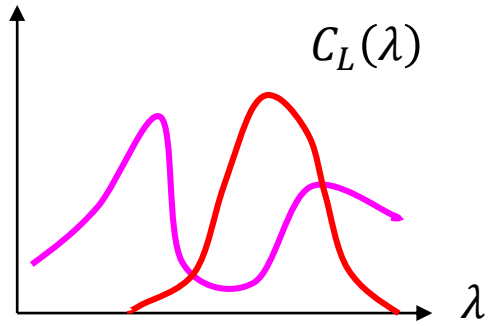
Once a photon of some wavelength is absorbed (“caught”) by the photoreceptor, detailed information about spectrum is lost.

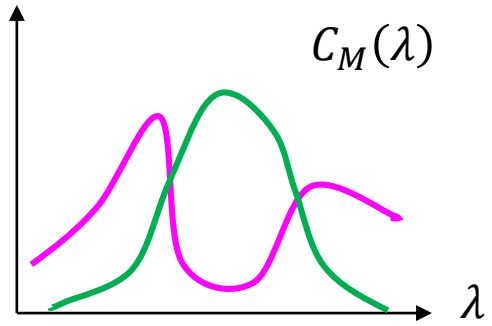
How to express this mathematically?

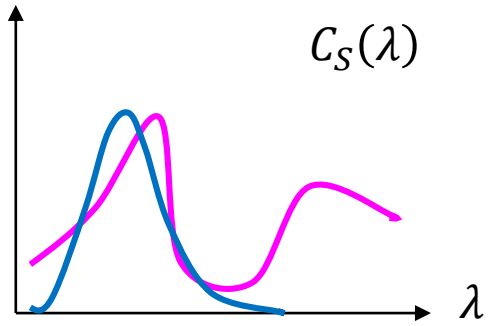
$E(x, \lambda)$ - spectrum of light arriving at cone x

$C_{LMS}(\lambda)$ - spectral sensitivity of a photoreceptor (either L, M, or S)

$$I_{LMS}(x) = \int C_{LMS}(\lambda) \; E(x, \lambda) \; d\lambda$$



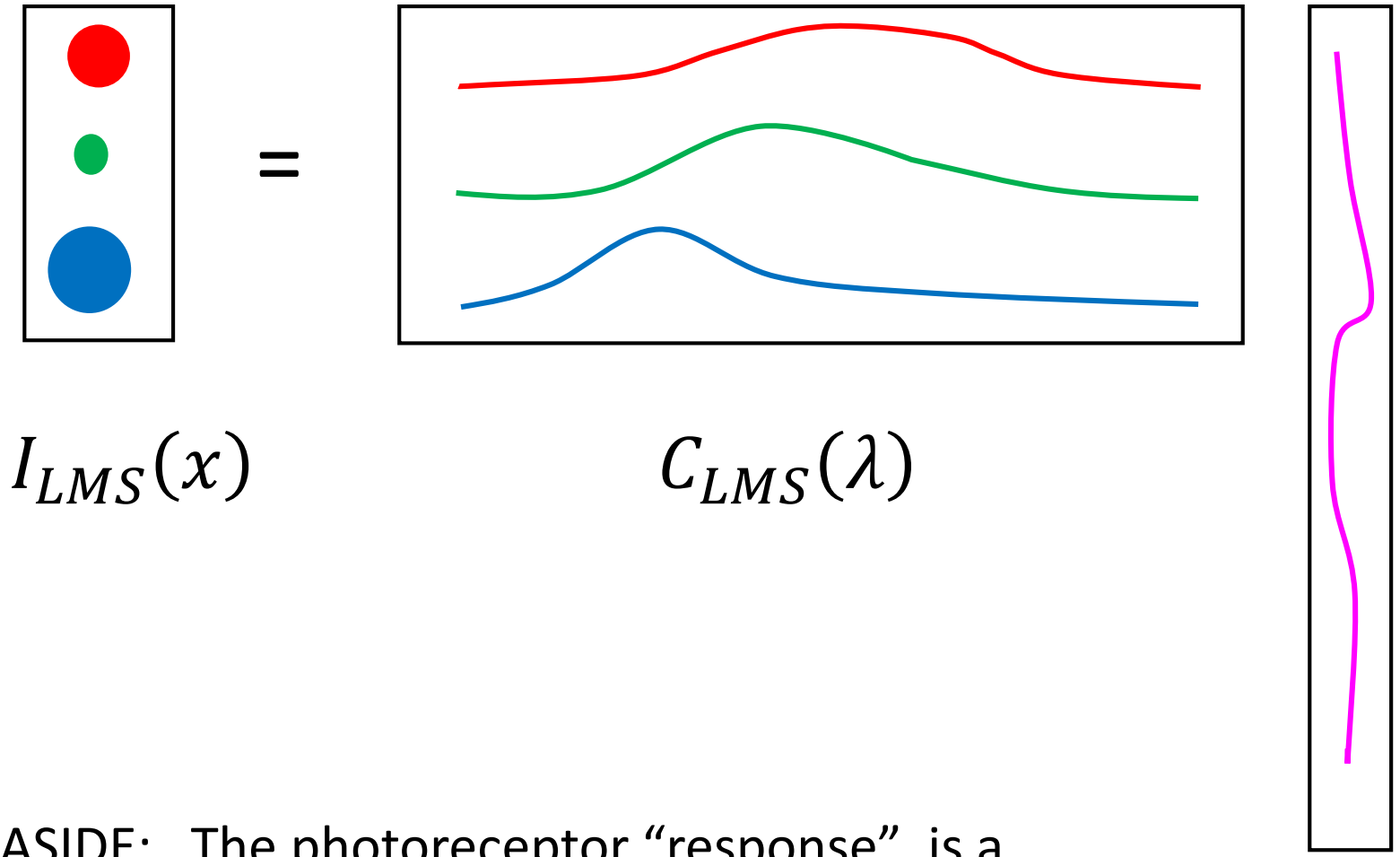




3 x 1

3 x N

N x 1



$I_{LMS}(x)$

$C_{LMS}(\lambda)$

$E(x, \lambda)$

ASIDE: The photoreceptor "response" is a function of $I_{LMS}(x)$.

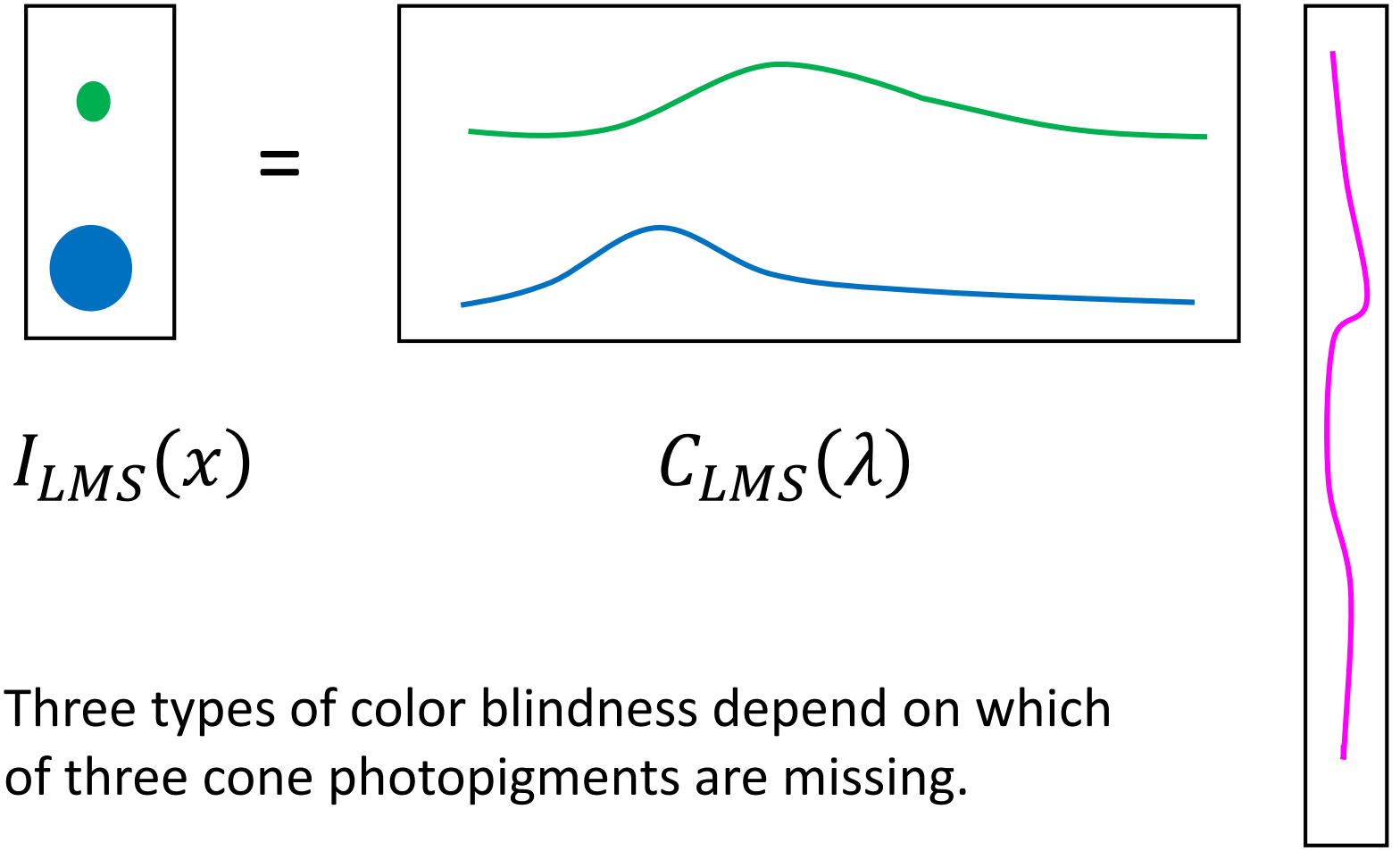
Metamers

Two different spectra can map to the same LMS triplet, i.e.

$$C_{LMS}\ E_1 \ = \ C_{LMS}\ E_2$$

Such spectra are visually indistinguishable, and are called “metamers”.

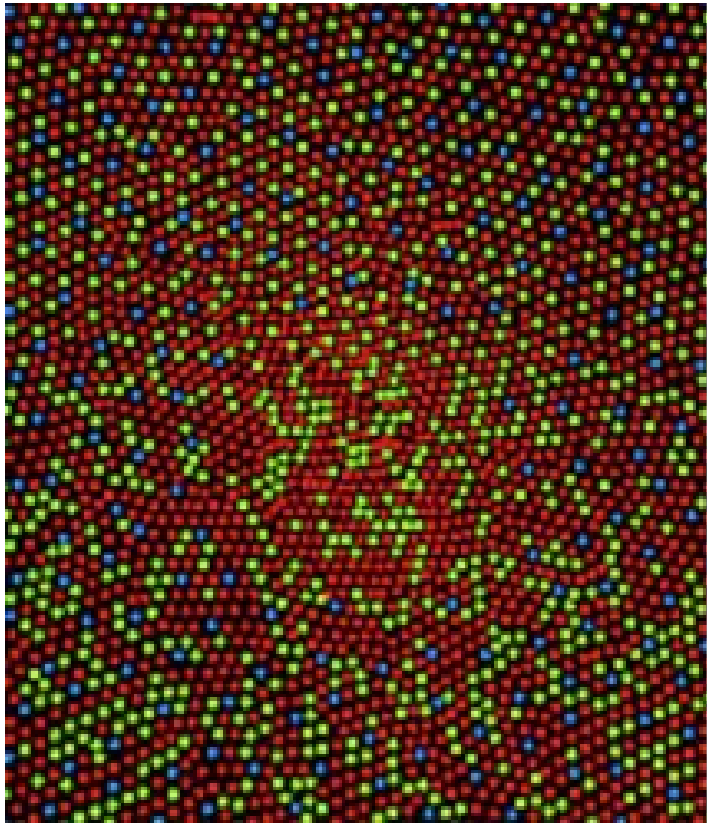
Color blindness



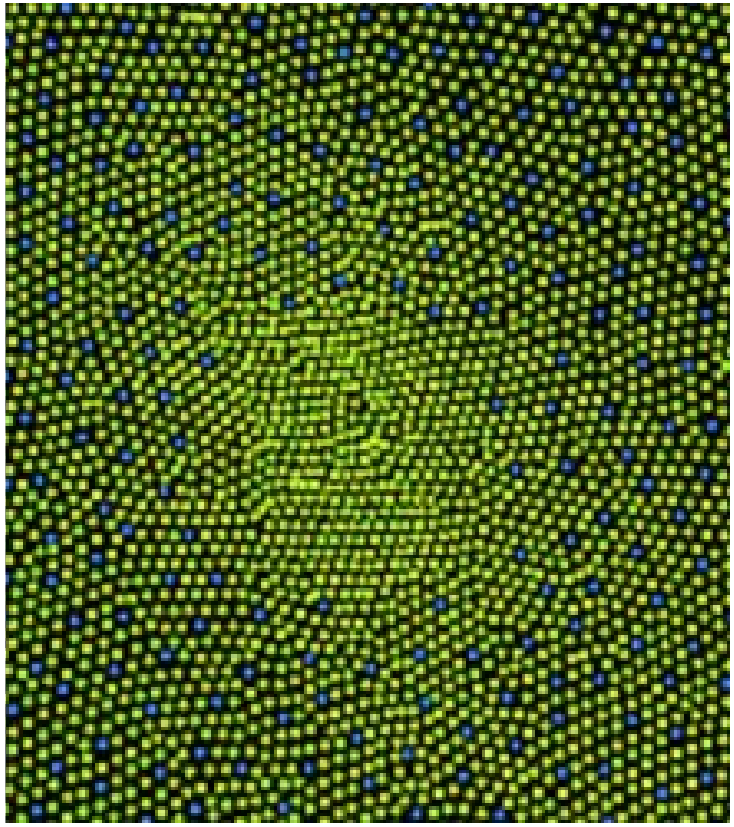
$I_{LMS}(x)$ $C_{LMS}(\lambda)$ $E(x,\lambda)$

Three types of color blindness depend on which of three cone photopigments are missing.

Cone mosaic

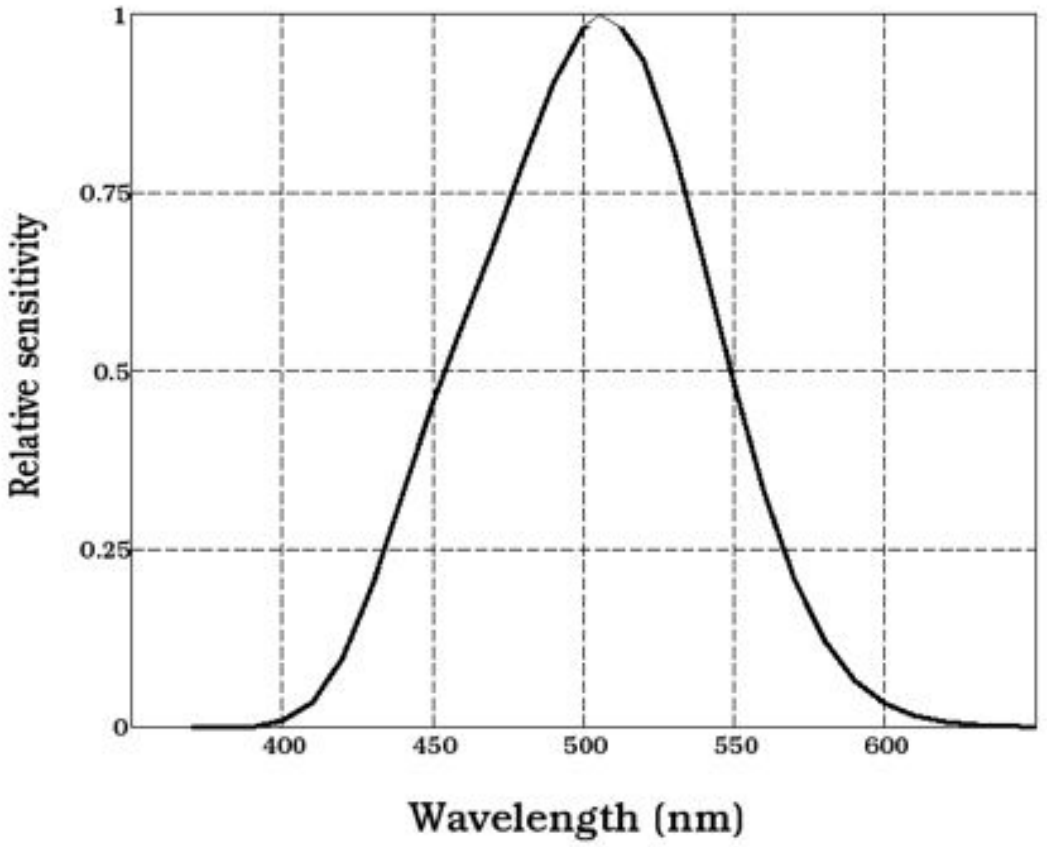


Normal

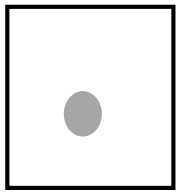


Color blind
(e.g. missing L cones)

Rod (night) vision is an extreme case of metamerism



Rod sensitivity



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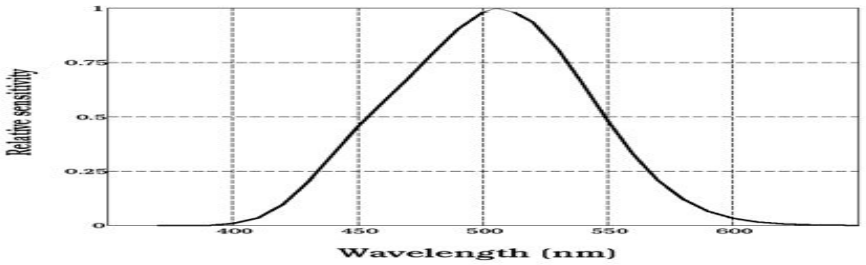
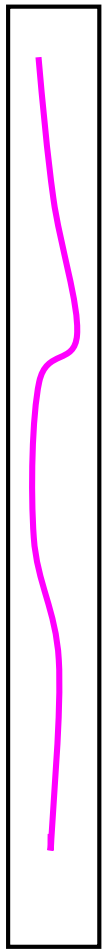


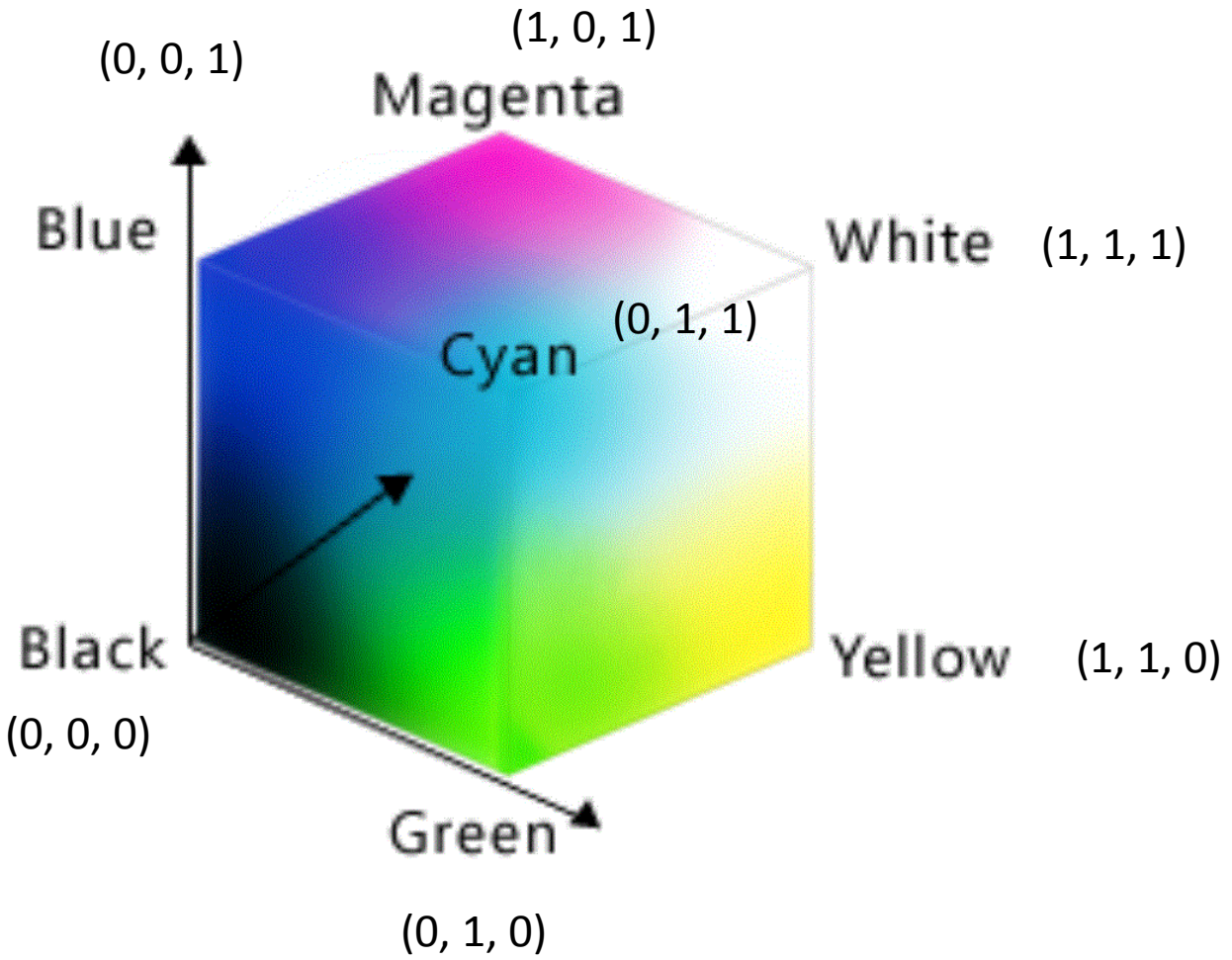
$I_{rod}(x)$

$C_{rod}(\lambda)$

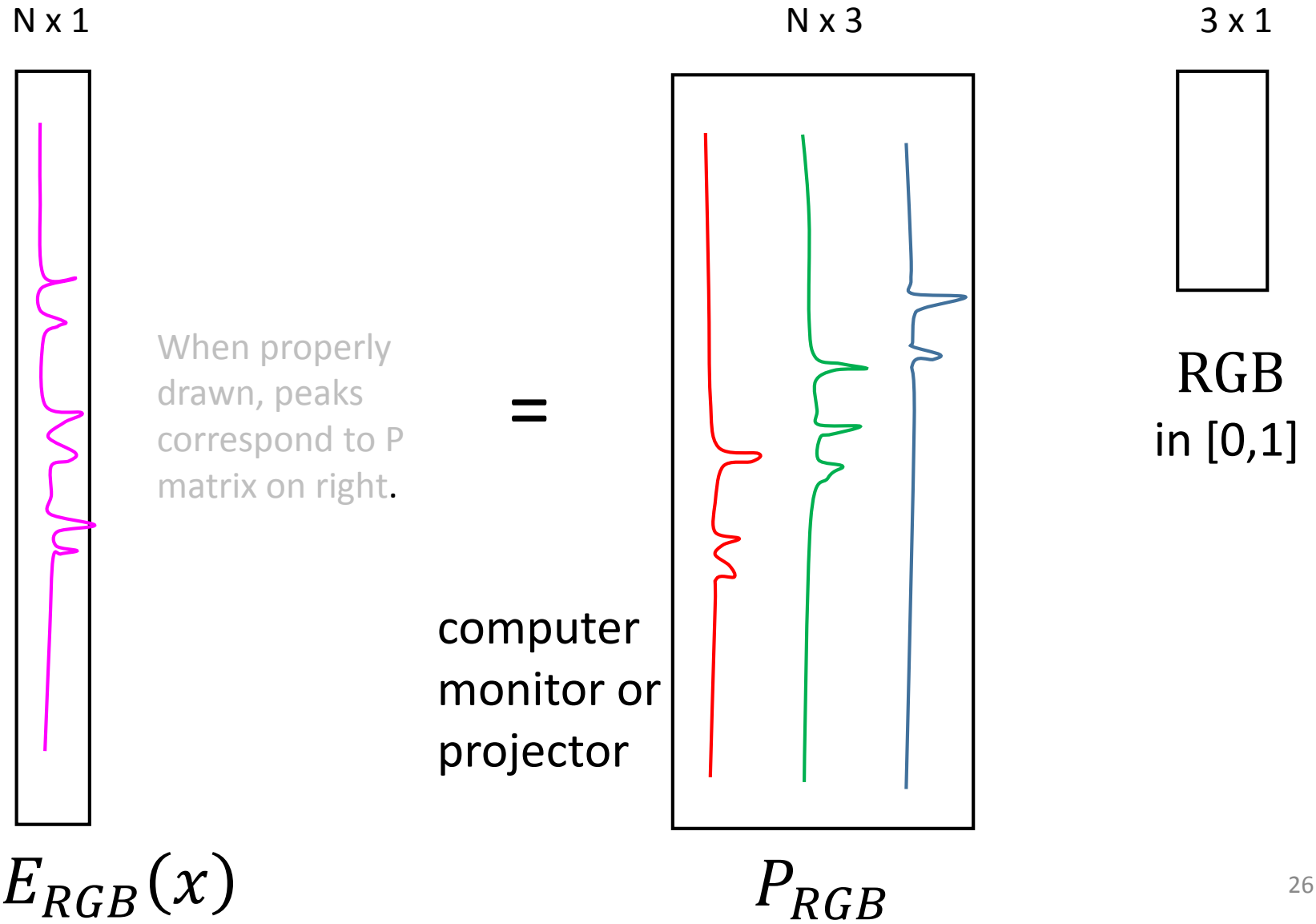


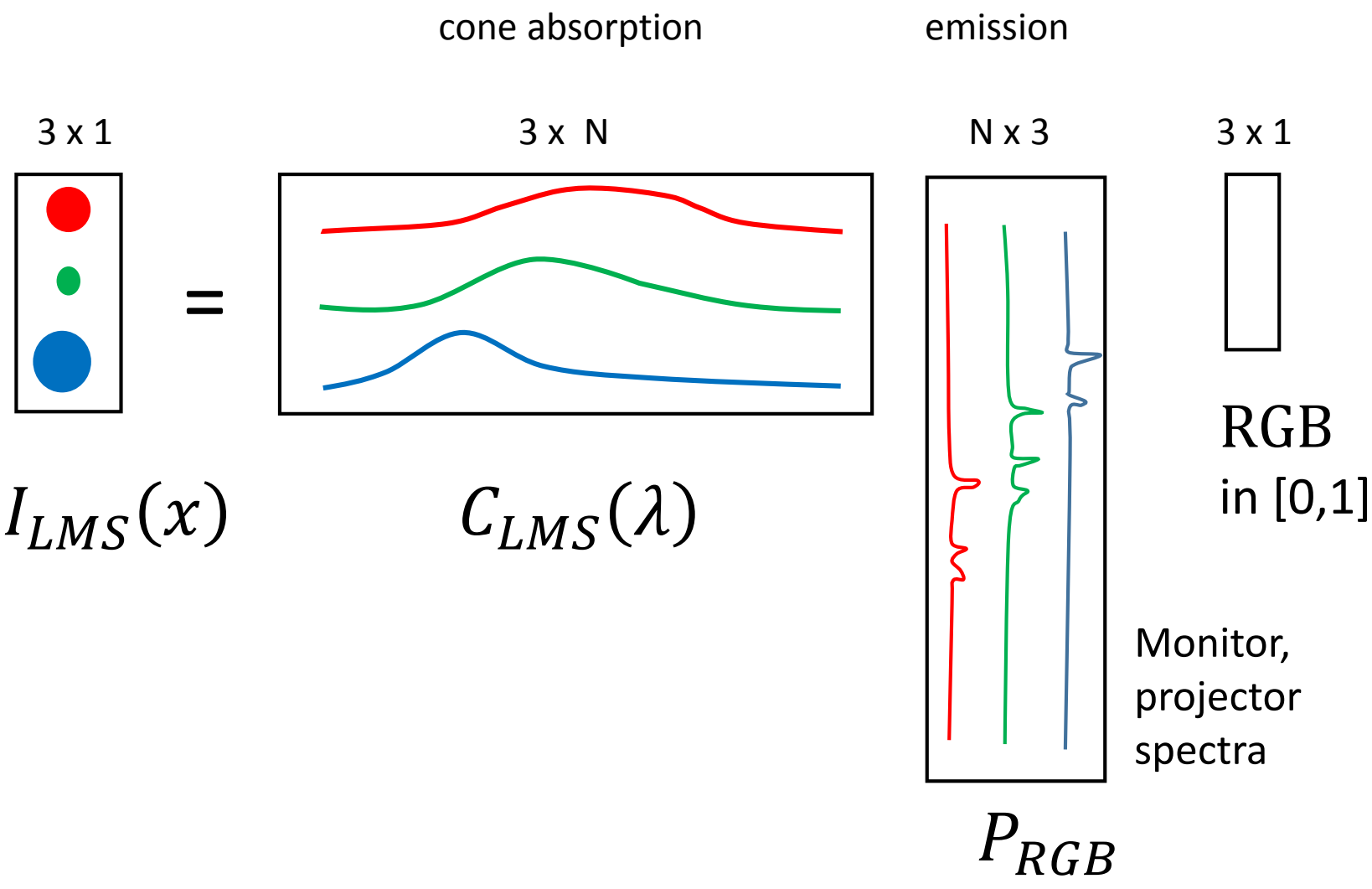
$E(x, \lambda)$

Application: RGB images and color displays

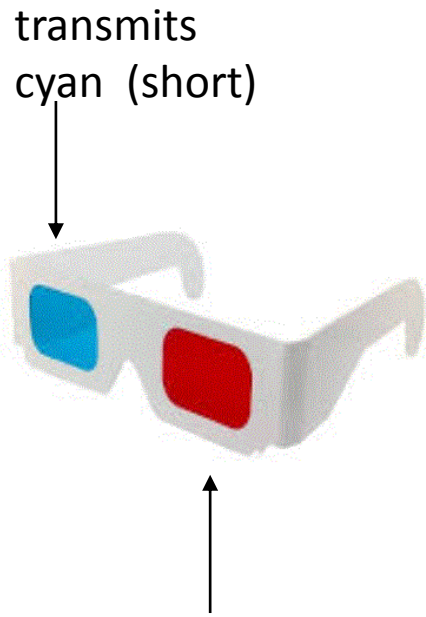


Emitted spectra from color displays



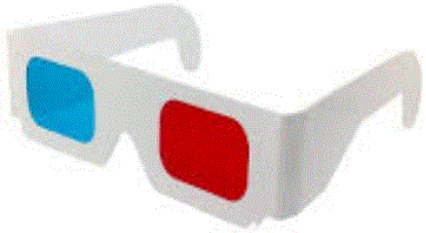

cone absorption
emission
3 x 1
3 x N
N x 3
3 x 1
=
$I_{LMS}(x)$
$C_{LMS}(\lambda)$
P_{RGB}
RGB
in [0,1]
Monitor,
projector
spectra
3 x 3 transform from RBG pixel
values to cone absorptions

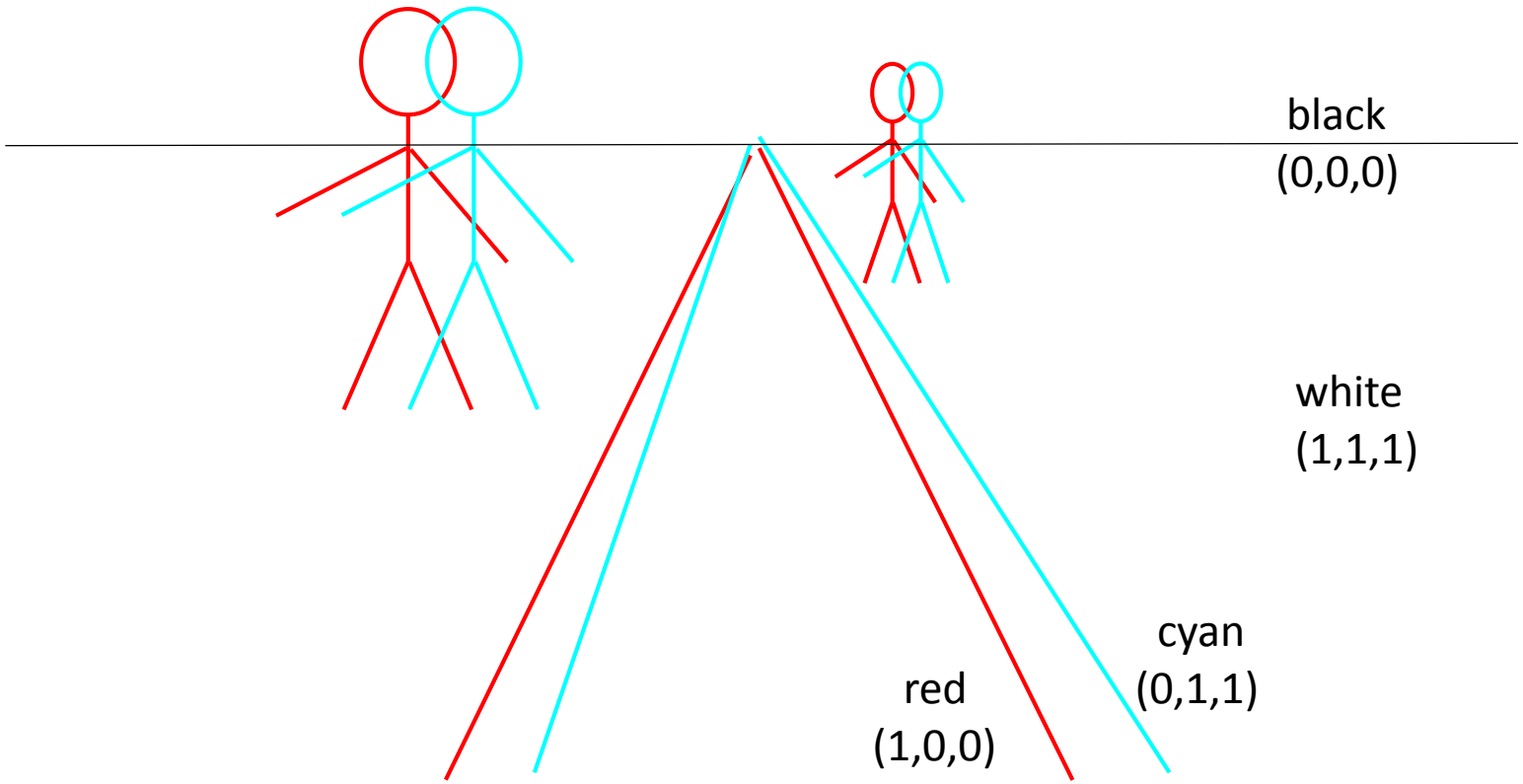
Anaglyph 3D Displays



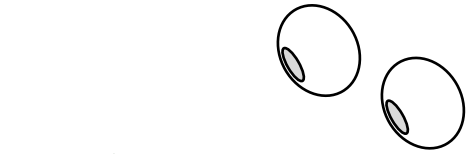
Anaglyph (definition): a photograph with the two images superimposed and printed in different colors, producing a 3D effect when viewed through correspondingly colored filters.

left and right eye image





Absorption
by photoreceptors
(fraction)

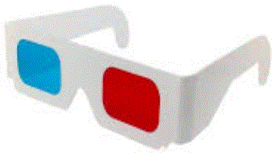


Emission from 3DTV

Transmission
(fraction)

Simplified anaglyph model

	emitted (RBG)	*	transmitted (filter)
Examples:			
	(1, 0, 0)	*	(1, 0, 0)
=	(1, 1, 1)	*	(1, 0, 0)
=	(0, 1, 1)	*	(1, 0, 0)
=	(1, 0, 0)	*	(0, 1, 1)
=	(0, 1, 1)	*	(0, 1, 1)
=	(1, 1, 1)	*	(0, 1, 1)



Simplified anaglyph model

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(1, 0, 0)	=	(1, 0, 0)	*	(1, 0, 0)
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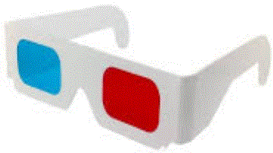
(0, 0, 0)	=	(0, 1, 1)	*	(1, 0, 0)
(0, 0, 0)	=	(1, 0, 0)	*	(0, 1, 1)
(0, 1, 1)	=	(0, 1, 1)	*	(0, 1, 1)
(0, 1, 1)	=	(1, 1, 1)	*	(0, 1, 1)



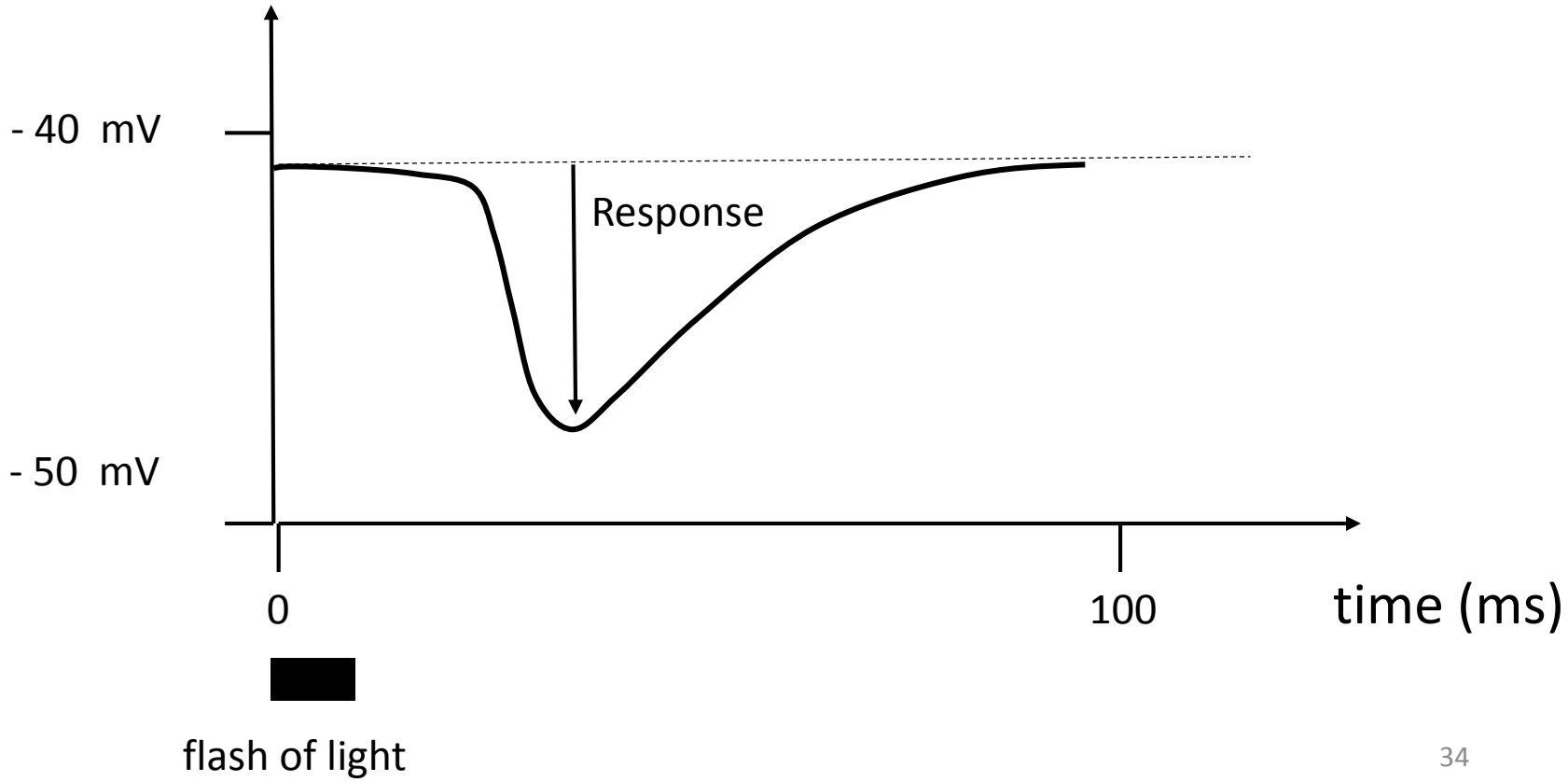
Summary of today

- Types of spectra
- Rods and cones
- Metamers and color blindness
- Color displays

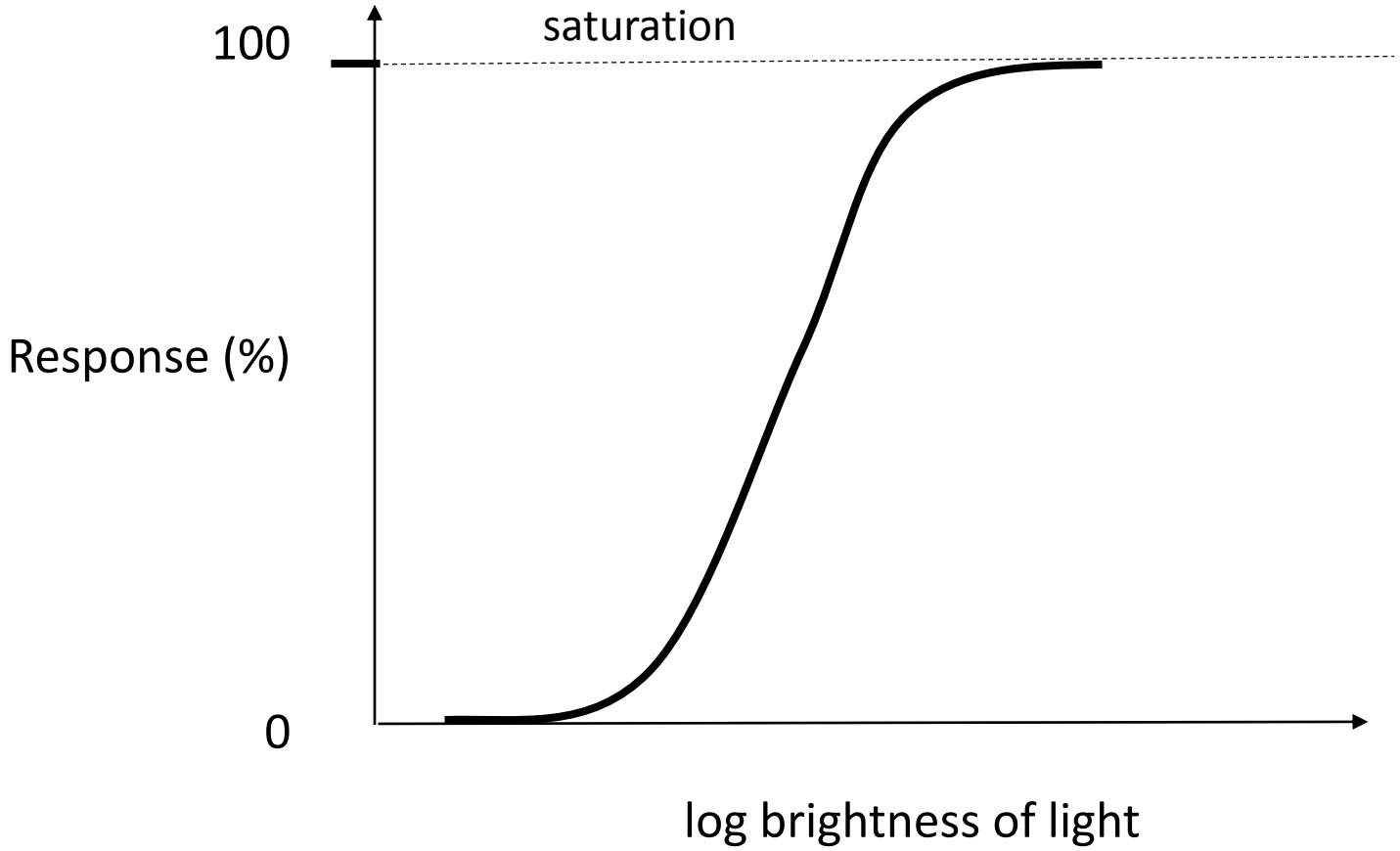
- Temporal issues
- Spatial issues (next class)

Photoreceptor response to a *brief flash of light*

(depends on intensity, duration, background level)

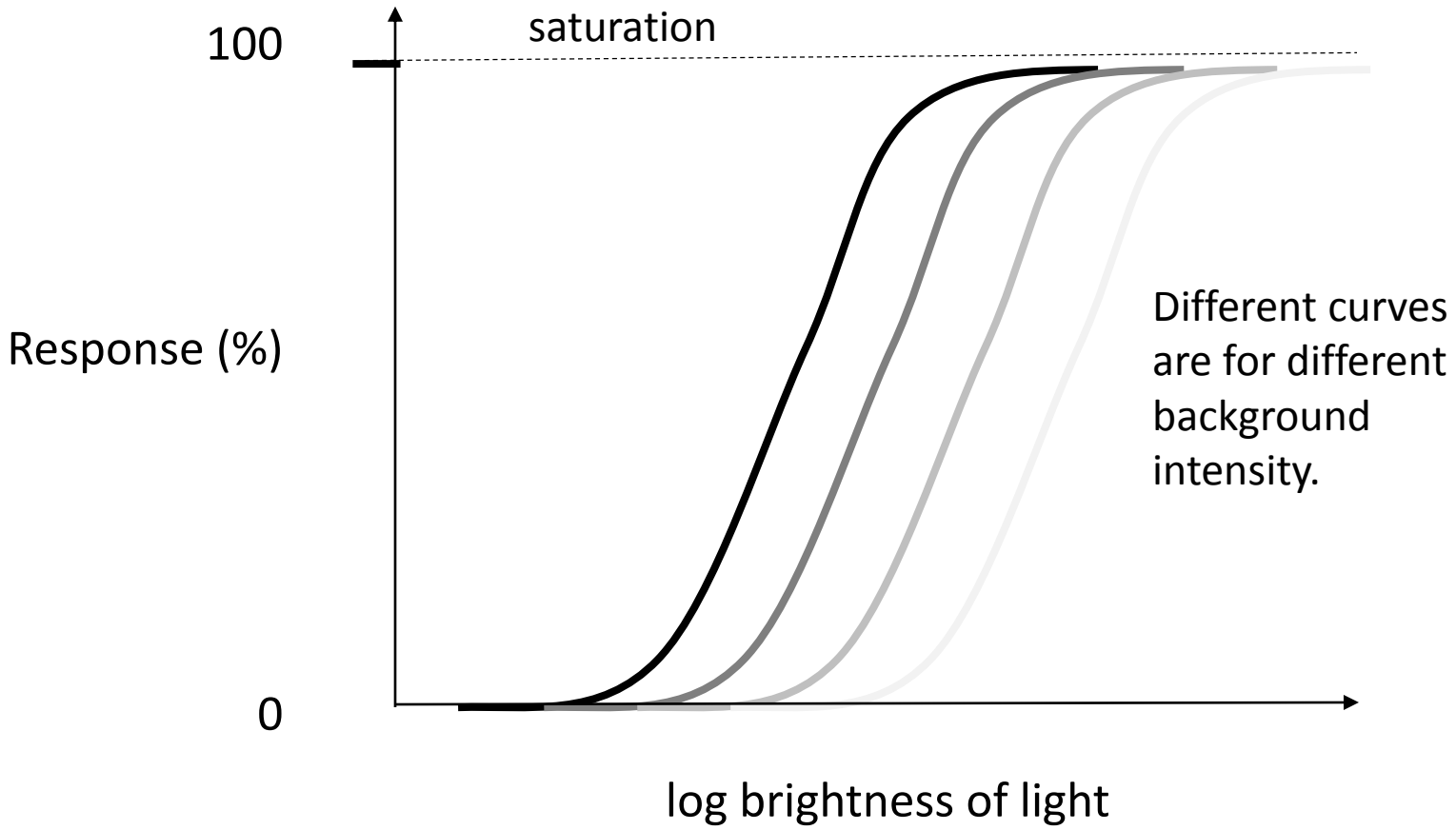


Response of photoreceptor*
(non-linear)



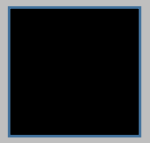
*You get the same sigmoidal behavior for cameras.

Response of photoreceptor*
(non-linear)

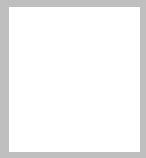


*You get the same sigmoidal behavior for cameras.

Adaptation



Look at dot
for 30 sec



Then, look
at this dot.

Adaptation Time Scales

- fraction of a second

  as we scan a scene with eye movements

- minutes

  as we change environments

  light adaptation: rods to cones

  dark adaptation: cones to rods

Pupil Response

Partly compensates for changes in average light level over the whole image.

Diameter of pupil ~2 - 8 mm.

This is only a small contribution to huge operating range of the visual system.