COSC428 Computer Vision

Colour

Readings: F & P chapter 6

Why does a visual system need color?

http://www.hobbylinc.com/gr/pll/pll5019.jpg

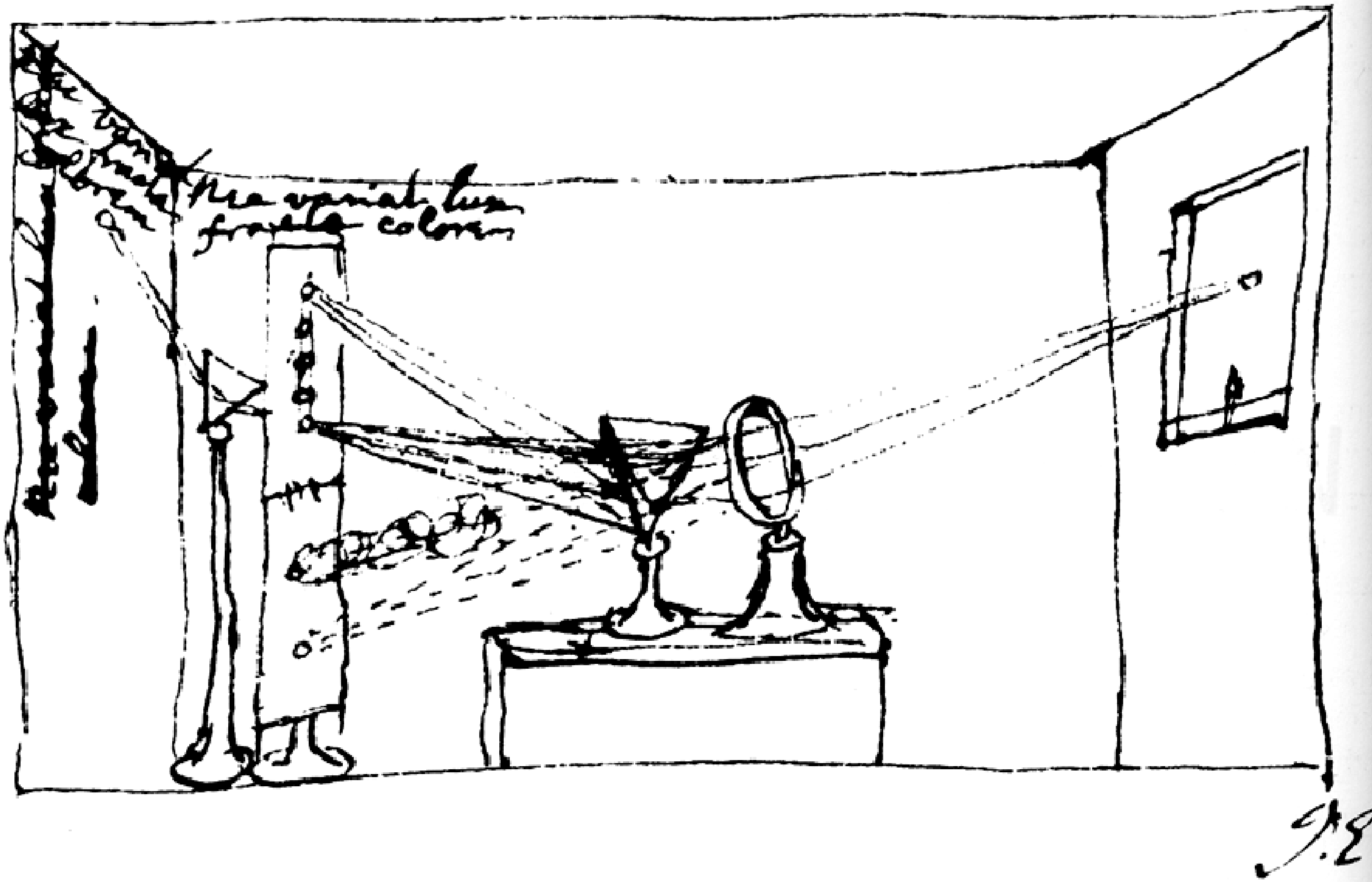
Why does a visual system need color? (an incomplete list…)

- To tell what food is edible.
- To distinguish material changes from shading changes.
- To group parts of one object together in a scene.
- To find people's skin.
- Check whether a person's appearance looks normal/healthy.
- To compress images

Lecture outline

- Color physics.
- Color perception and color matching..

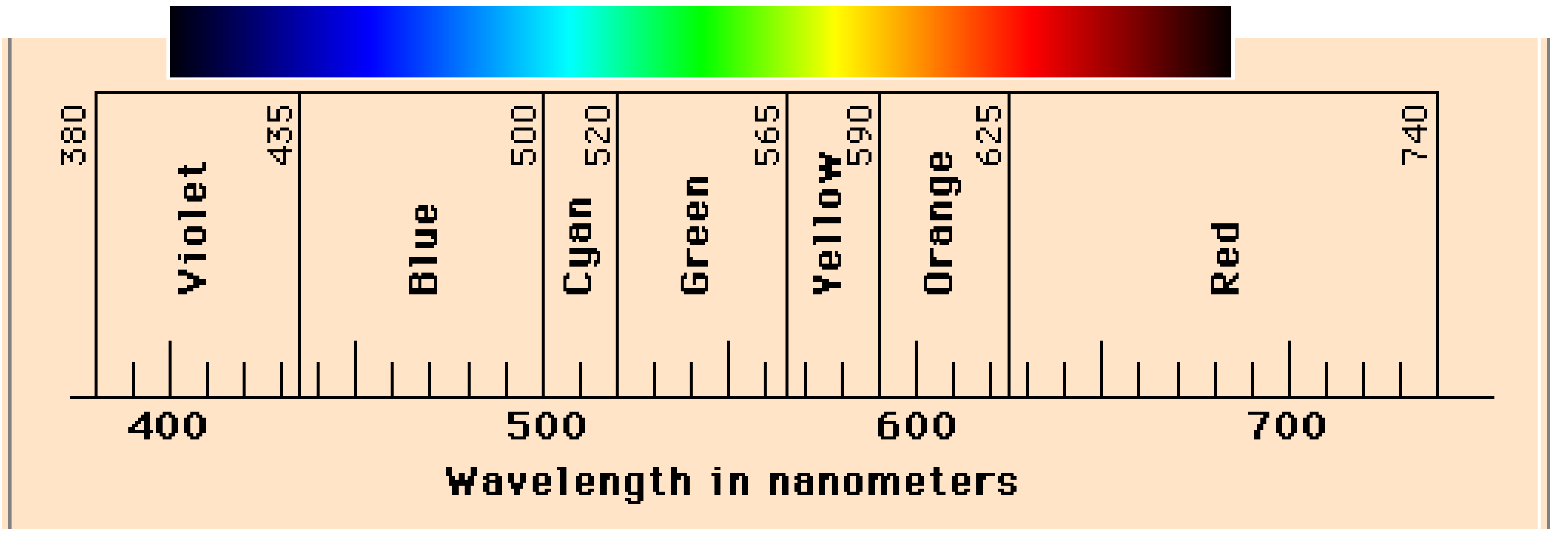
Color



4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.

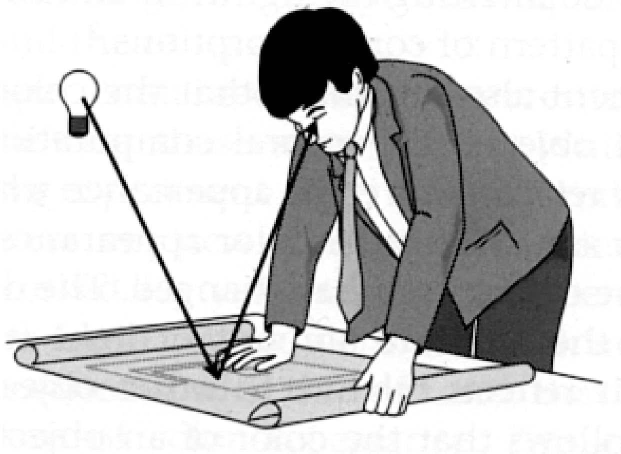
From Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Spectral colors

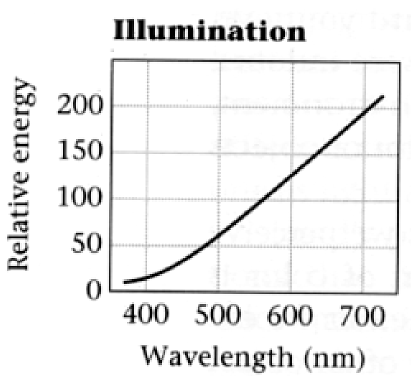


http://hyperphysics.phy-astr.gsu.edu/hbase/vision/specol.html#c2

Simplified rendering models: reflectance



Often are more interested in relative spectral composition than in overall intensity, so the spectral BRDF computation simplifies a wavelength-by-wavelength multiplication of relative energies.



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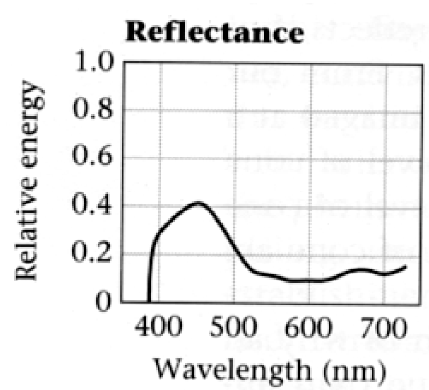

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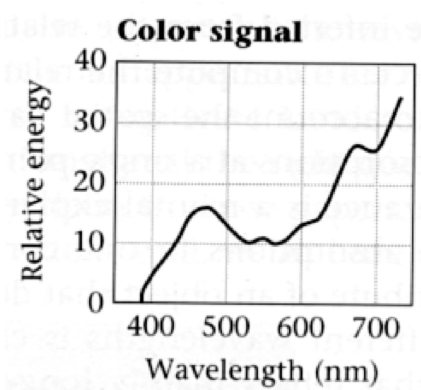
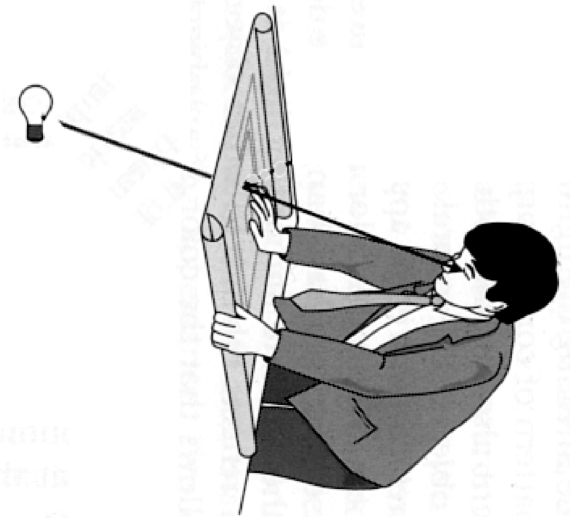
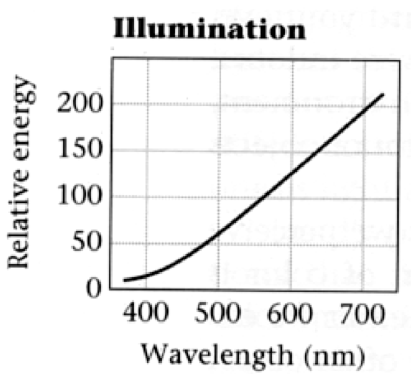


Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Simplified rendering models: transmittance





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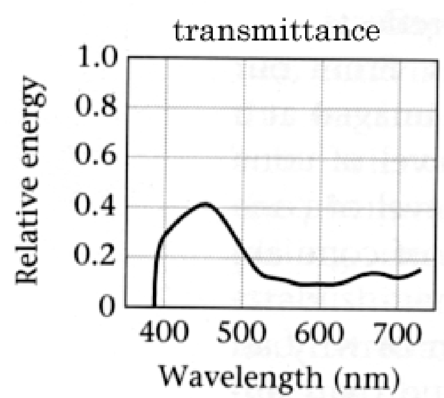

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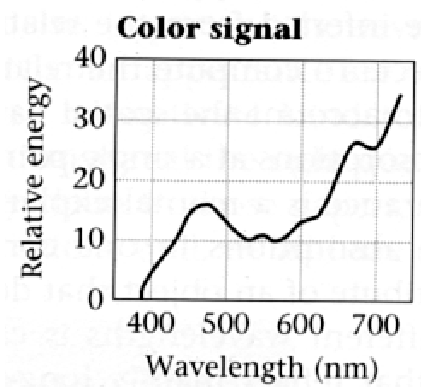
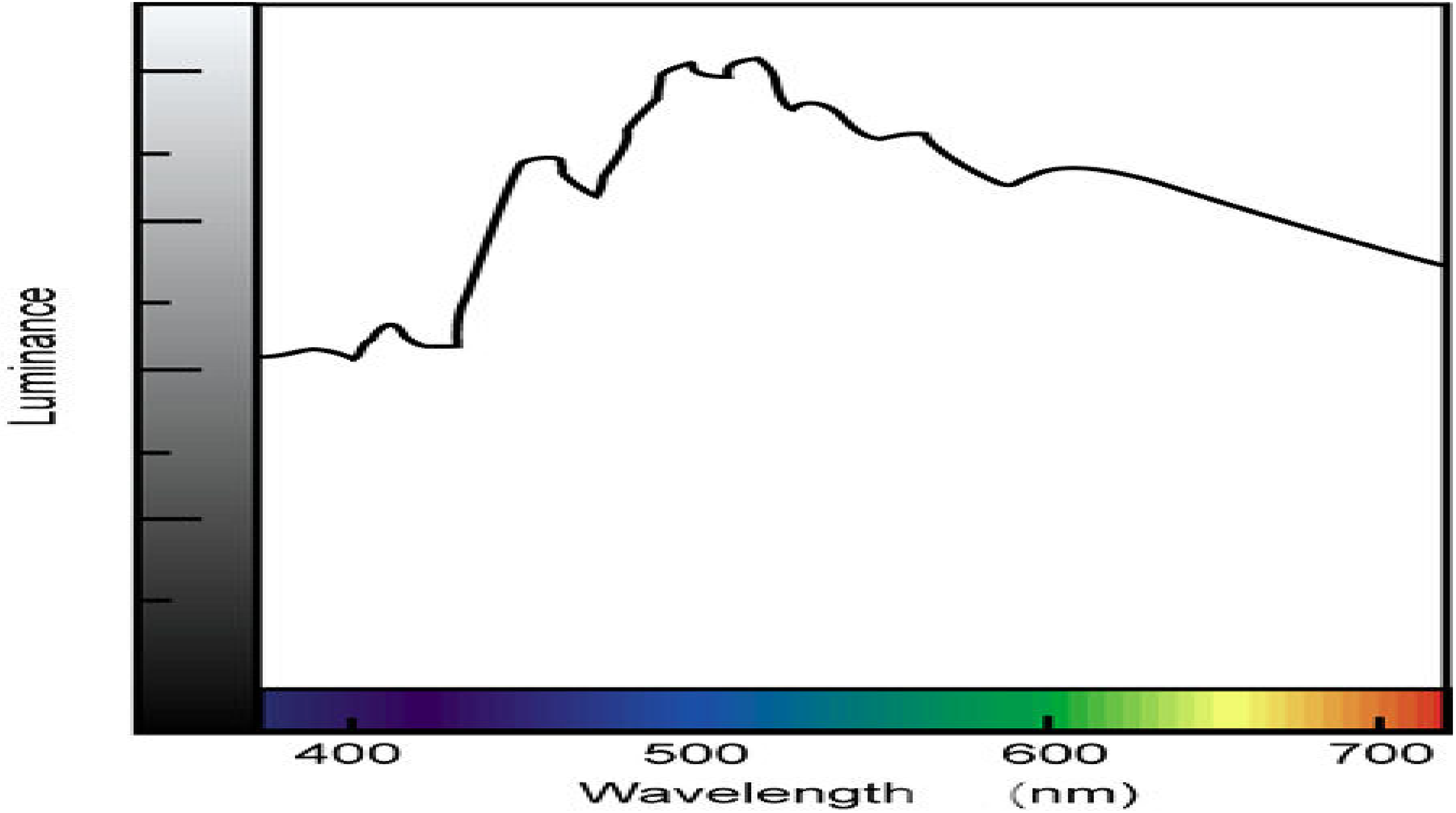
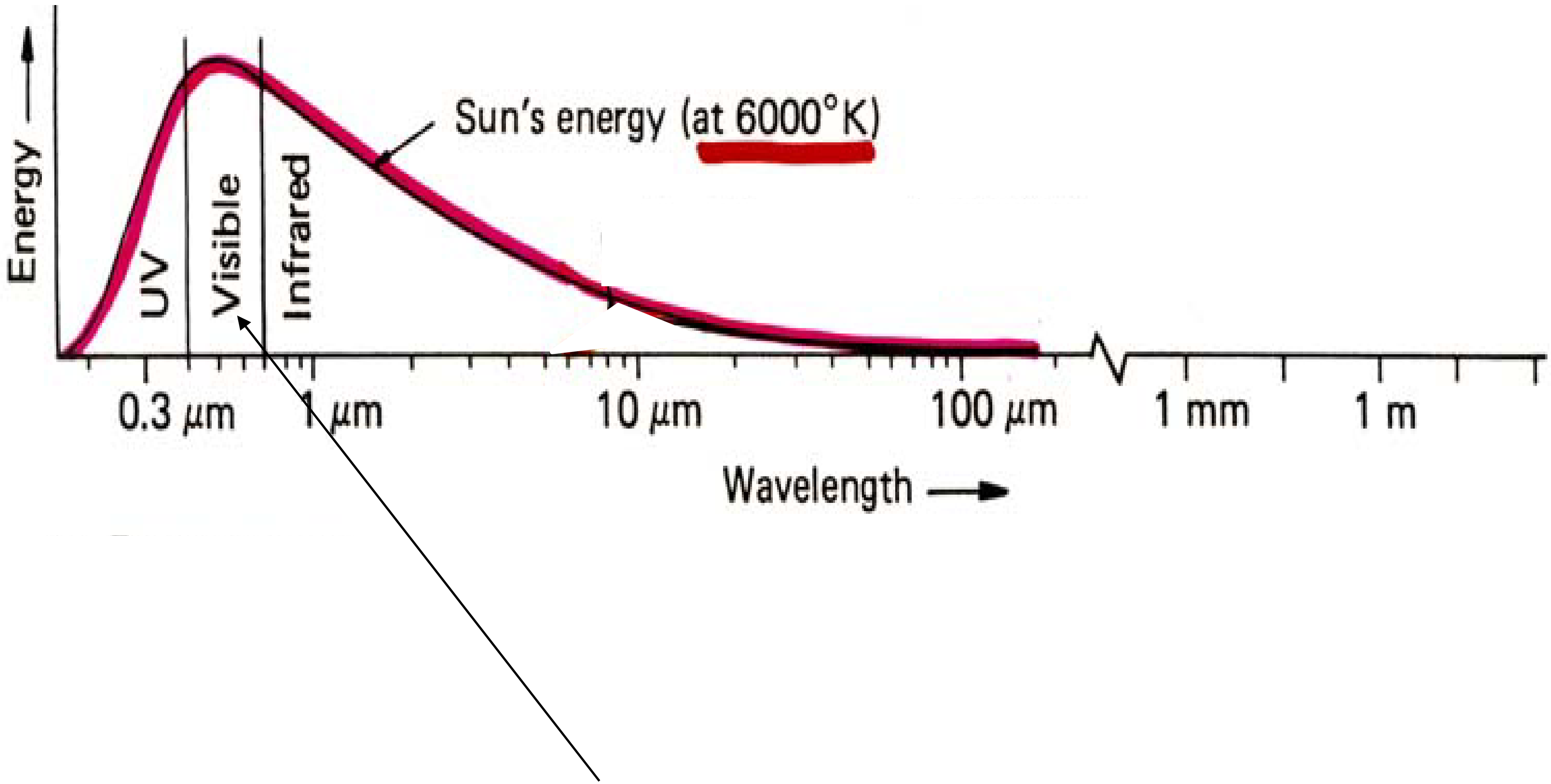


Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

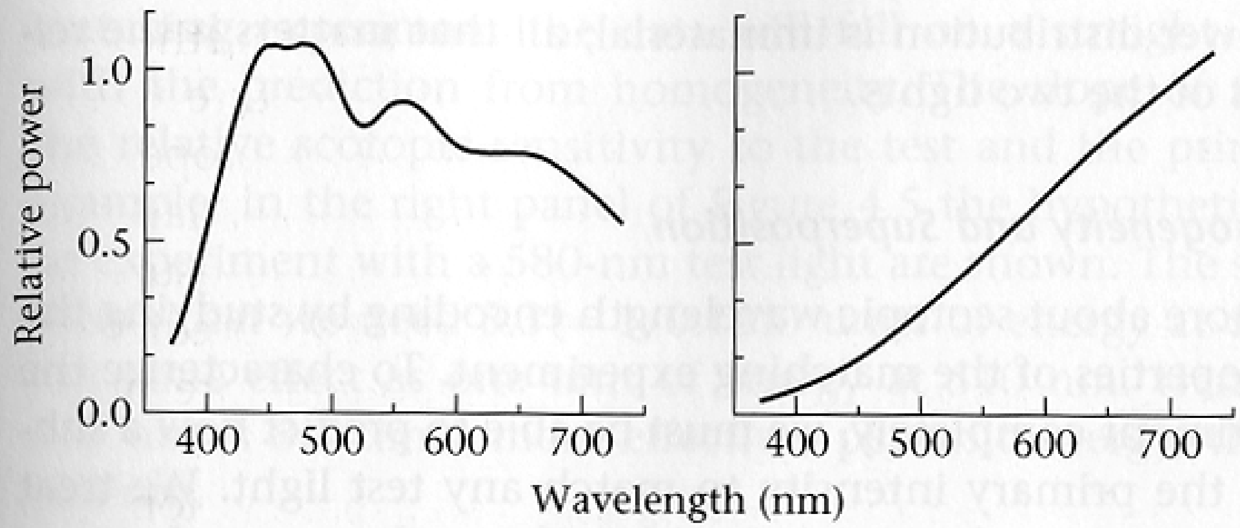


Within the visible range, the spectral curve of the sun indicates that many wavelengths of light are present at different luminance levels. (The wavelengths of highest intensity are in the 500nm range.)



Our vision is optimized for receiving the most abundant spectral radiance our star emits.

Two illumination spectra



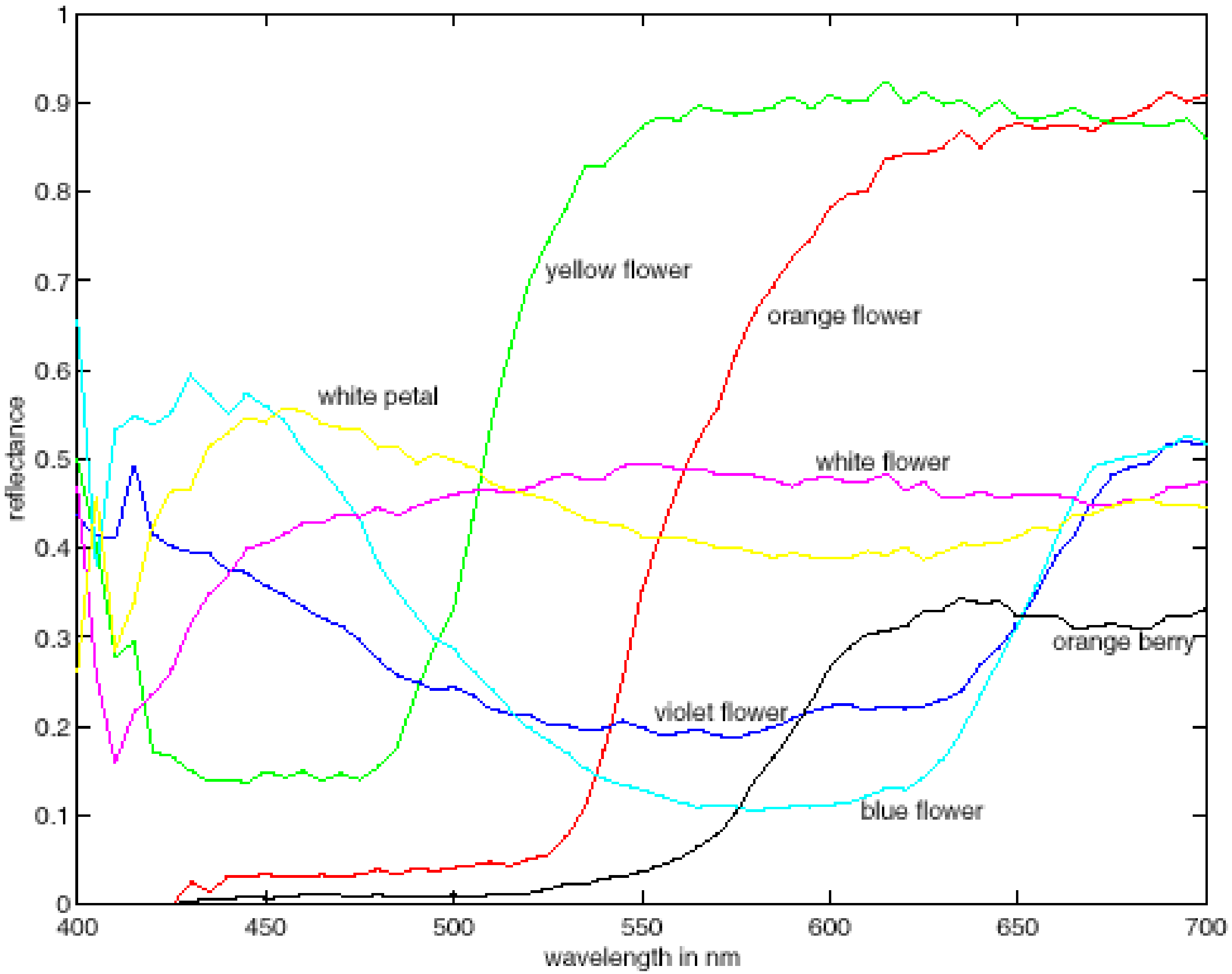
4.4 **THE SPECTRAL POWER DISTRIBUTION** of two important light sources are shown: (left) blue skylight and (right) a tungsten bulb.

Blue sky

Tungsten light bulb

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

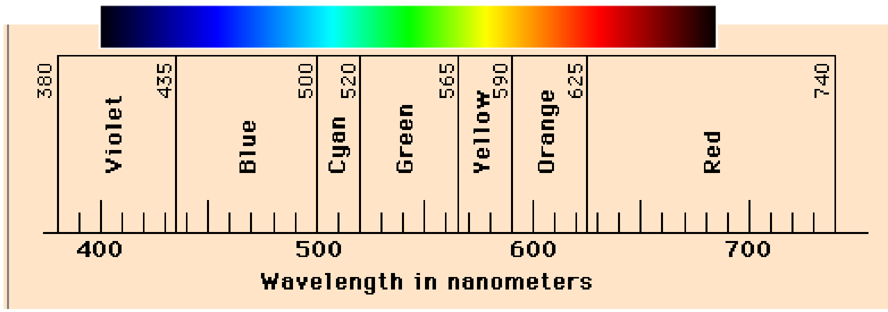
Some reflectance spectra

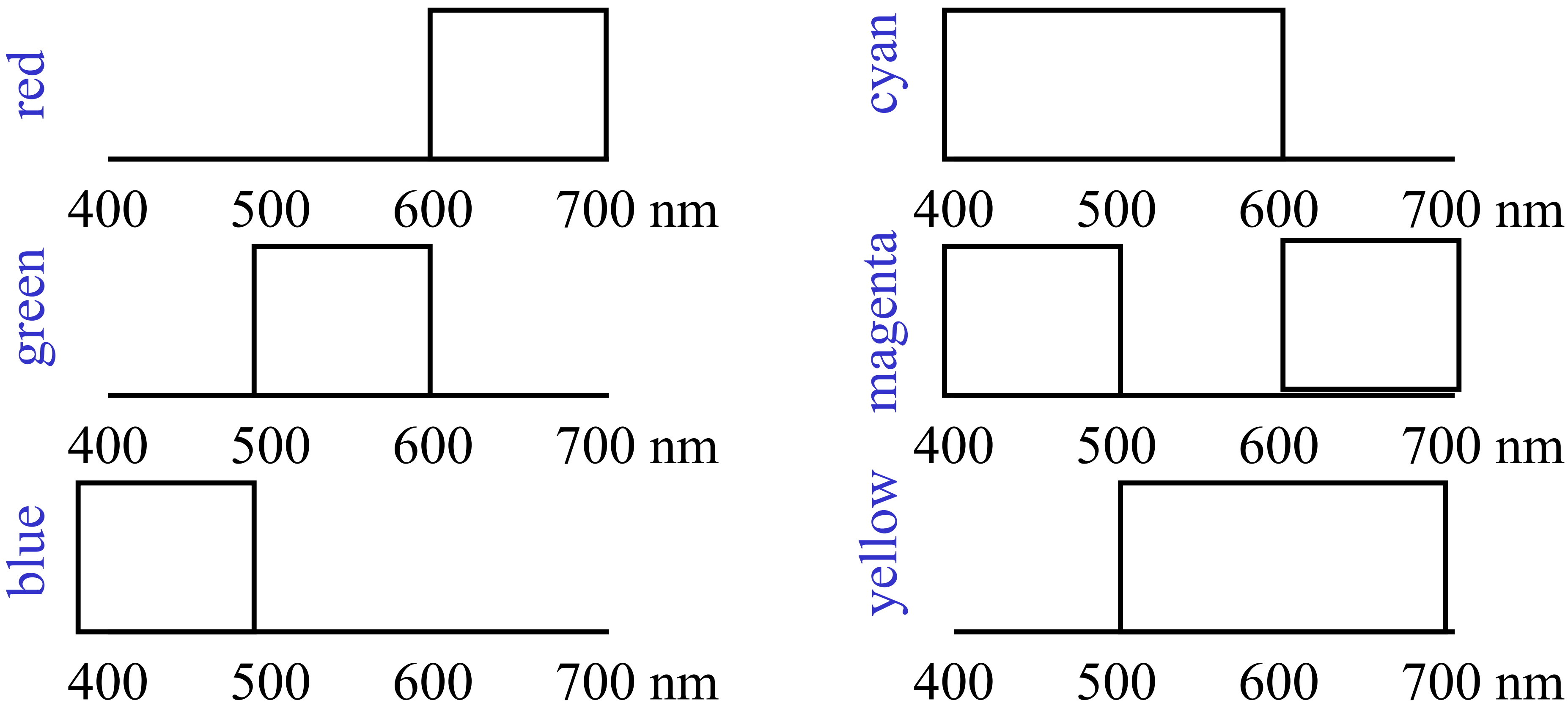


Spectral albedoes for several different leaves, with color names attached. Notice that different colours typically have different spectral albedo, but that different spectral albedoes may result in the same perceived color (compare the two whites). Spectral albedoes are typically quite smooth functions. Measurements by E.Koivisto.

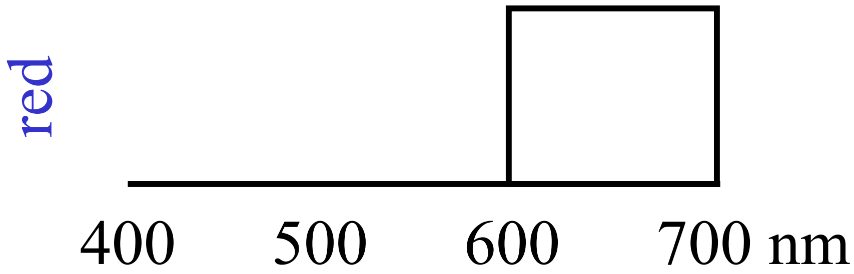
Forsyth, 2002

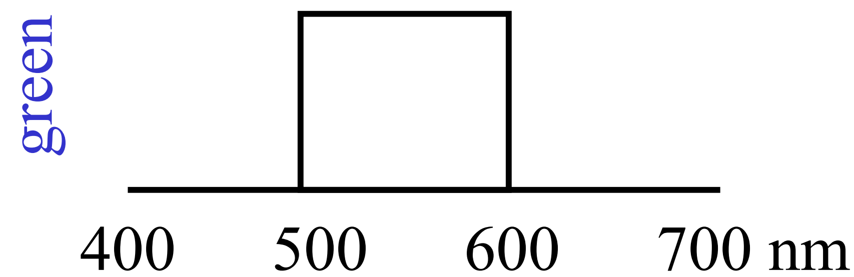
Color names for cartoon spectra

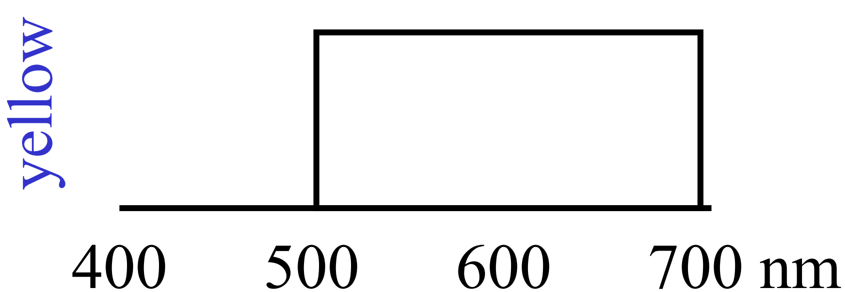




Additive color mixing





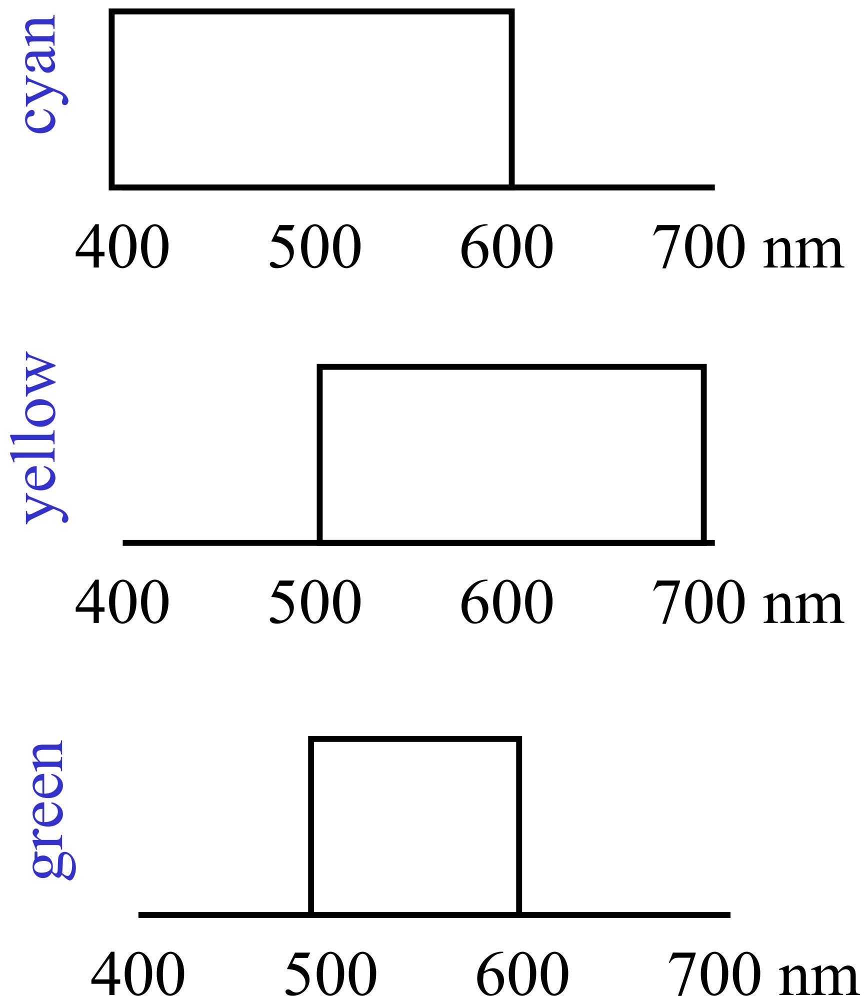


When colors combine by *adding* the color spectra. Examples that follow this mixing rule: CRT phosphors, multiple projectors aimed at a screen, Polachrome slide film.

Red and green make…

Yellow!

Subtractive color mixing



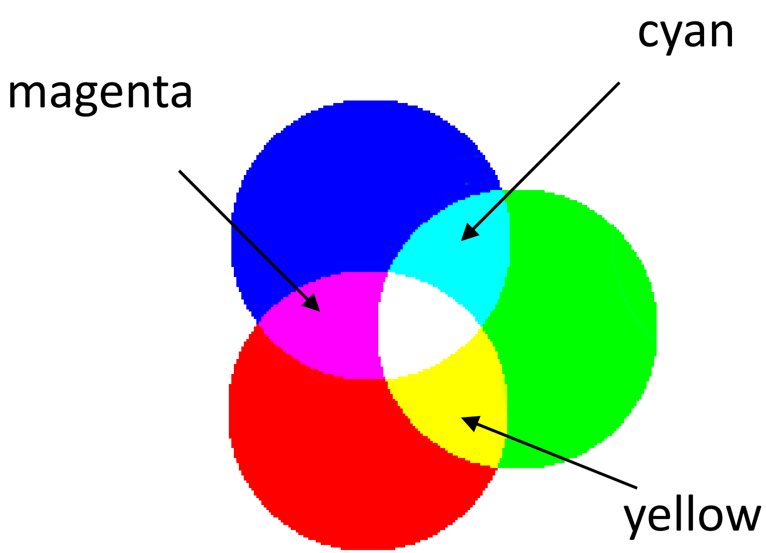
When colors combine by *multiplying* the color spectra. Examples that follow this mixing rule: most photographic films, paint, cascaded optical filters, crayons.

Cyan and yellow (in crayons, called “blue” and yellow) make…

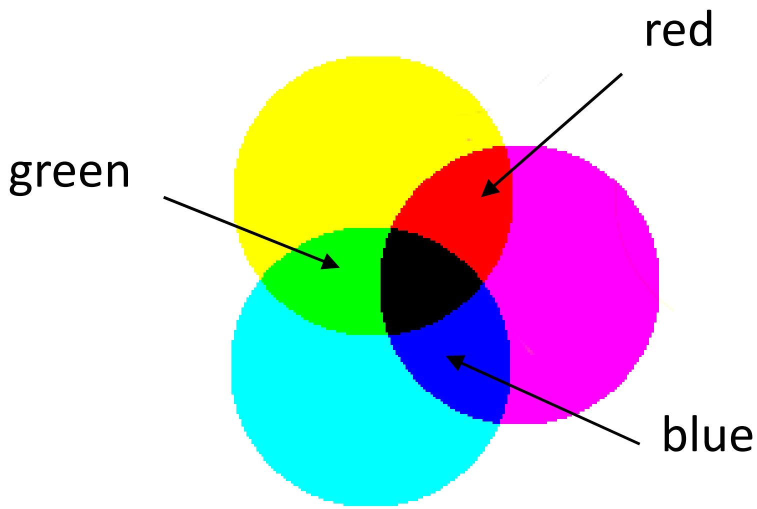
Green!

Adding and Subtracting Colors

Adding Colors



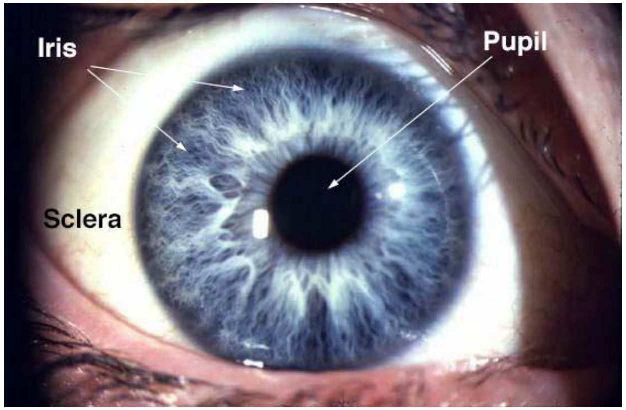
Subtracting Colors



Outline

- Color physics.
- Color perception and color matching.

The Human Eye



- **Spectral Resolution: 400** (violet) **- 700 nm** (red)

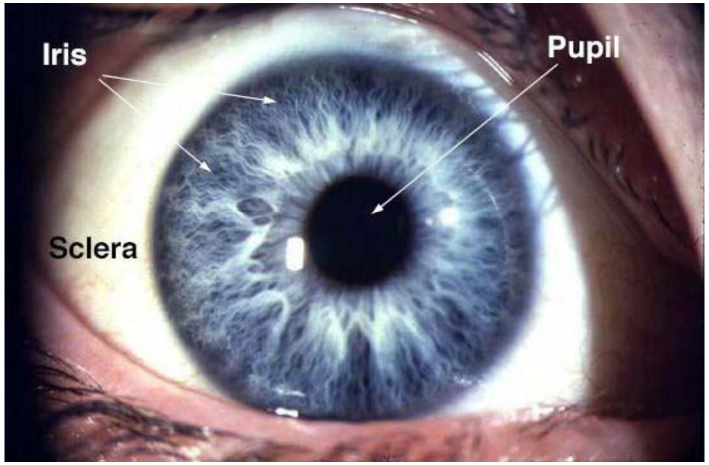
  Humans can perceive 10 octaves of sound frequencies, from 20Hz to 20kHz.
  Yet, we can perceive less than one octave of light frequencies

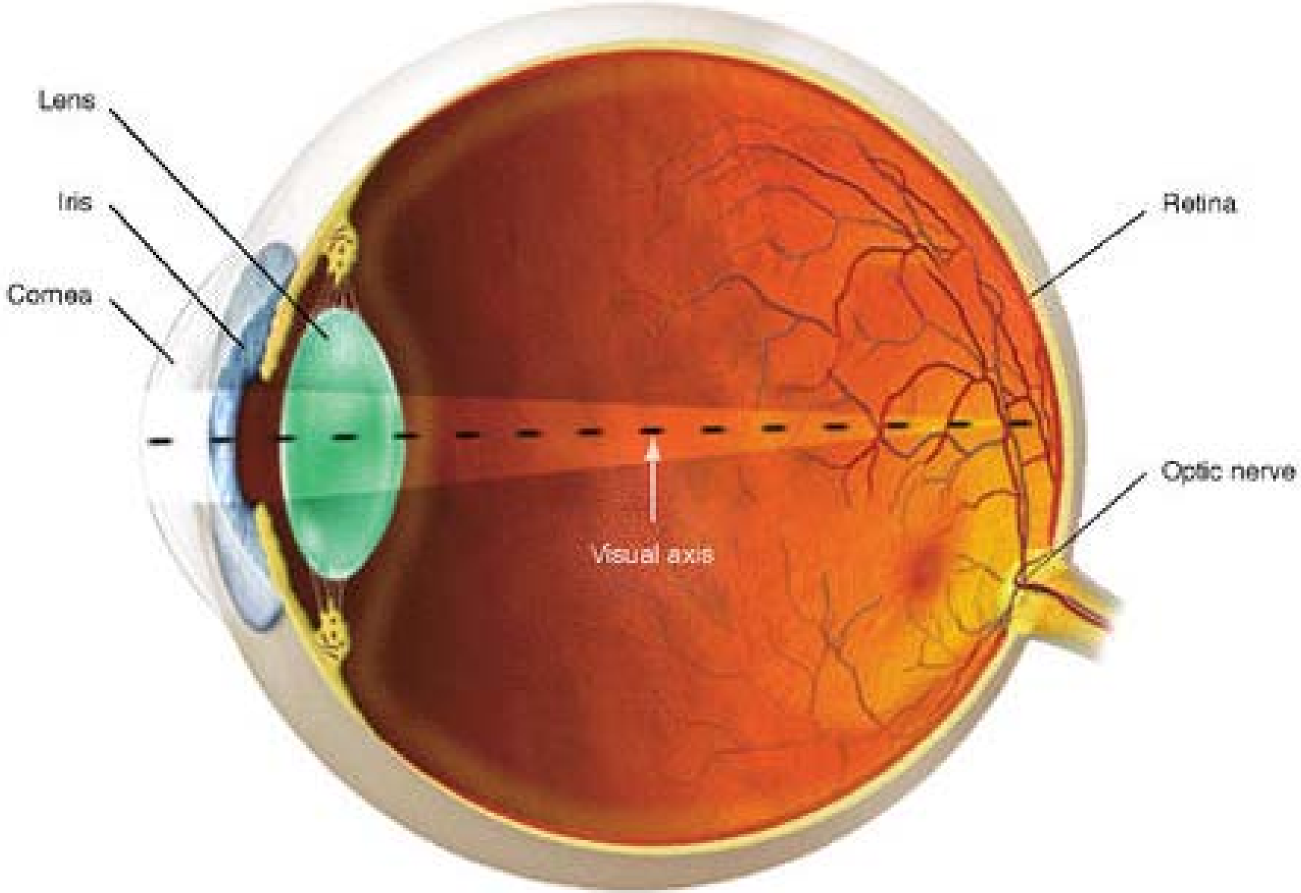
- **Dynamic range ~ 10^8 : 1**

  This is the difference between the lowest perceptible light intensity and the highest intensity we can tolerate without glare.
  The difference in intensity between the softest perceivable sound and the loudest sound that can be tolerated without pain is a ratio of 10^9:1

- **Spatial Resolution: ~ 1-3 cm @ 20 m**
- **Radiometric Resolution: ~ 16-32 shades B&W, ~ 100 colors**

Physiology



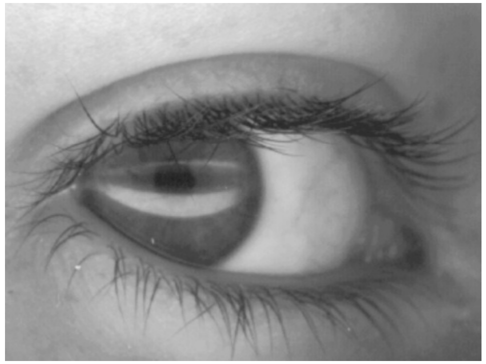


As light enters the eye, it is focused by the cornea and lens and strikes the retina at the back of the eye. The retina includes two types of cells that are stimulated by visible light: **rods and cones**. Information from the rods and cones is sent to the brain via the optic nerve.

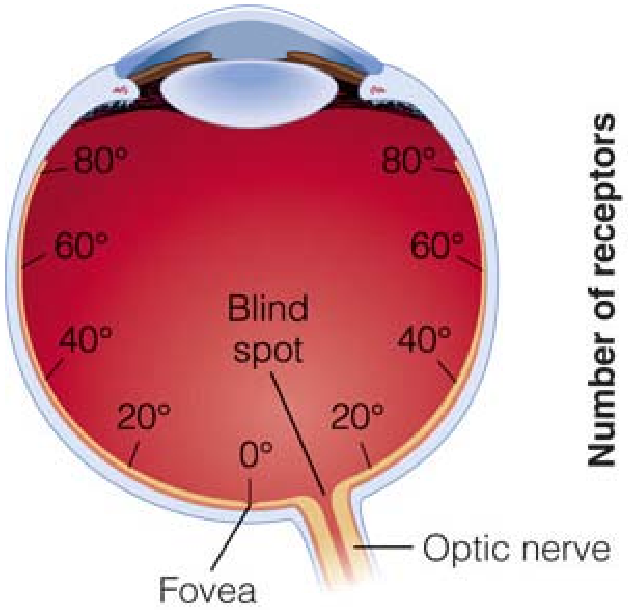
Rods and Cones

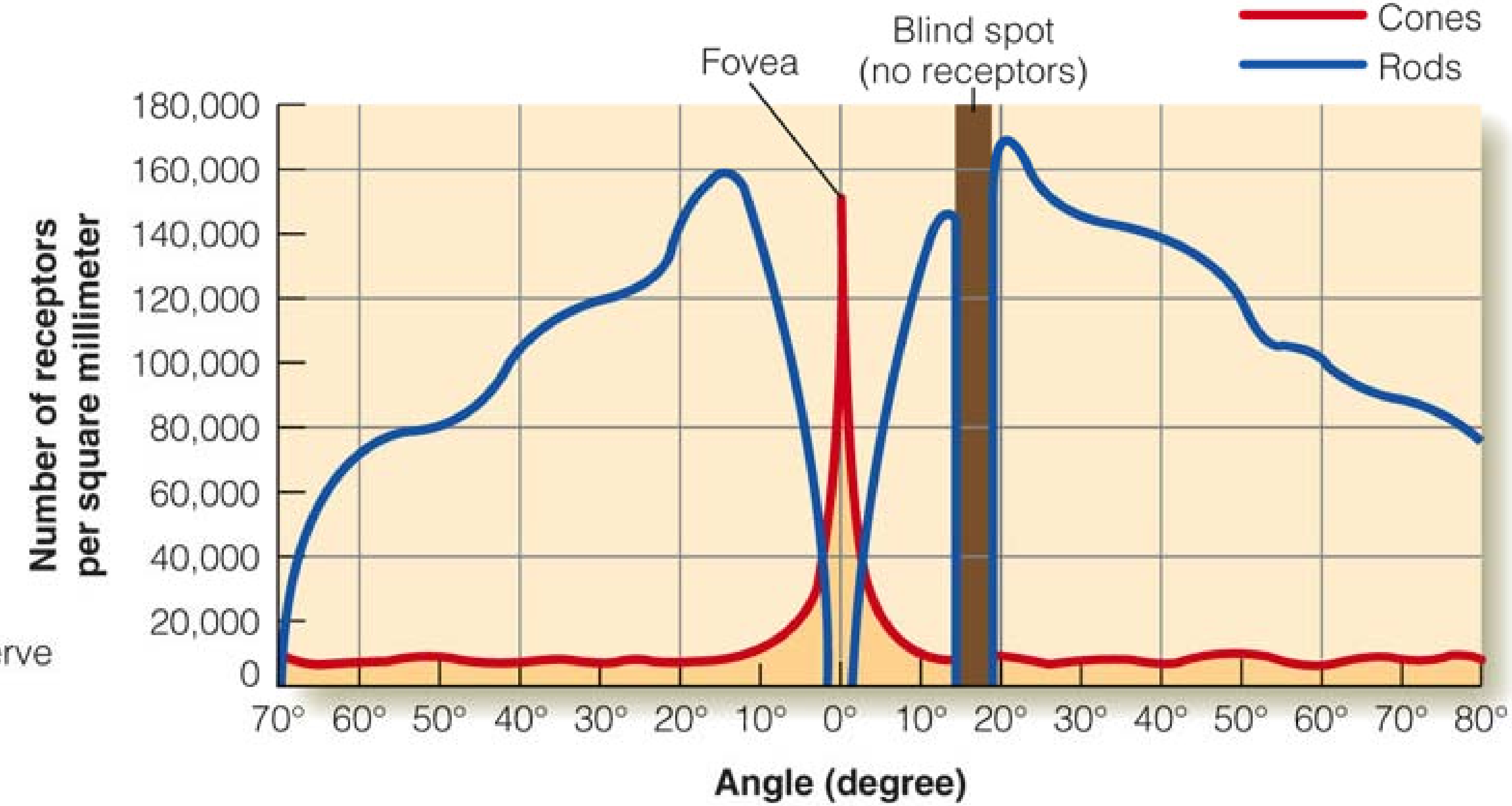
- **Cones**
  - Cones see color
    - "red" "green" and "blue"
  - ~6.5 Million
    - 74% "red" 10% "green" 16% "blue"
  - High resolution - closely packed
  - Light-adapted (daylight) vision is called photopic, in which the cones dominate. The cones are not as sensitive to intensity as the rods, but they respond to all visible wavelengths, which gives rise to our perception of colour.
  - The cones are generally shorter and thicker in structure than rods

Rods and Cones



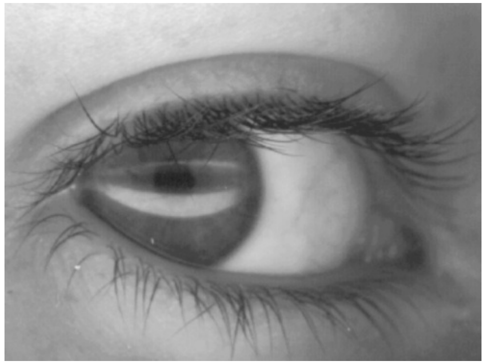
- **Rods**
  - Rods don’t see colour
  - ~100 Million
  - May be excited by single photon
  - Respond to higher frequencies (blue/green)
  - Peripheral and night vision
  - Dark-adapted (night) vision is called scotopic, and is ruled by the rods. Scotopic vision is most active in the short wavelengths, which is why things appear blue in the dark.
  - The rods are long slender receptors
  - For the most part, we ignore rods

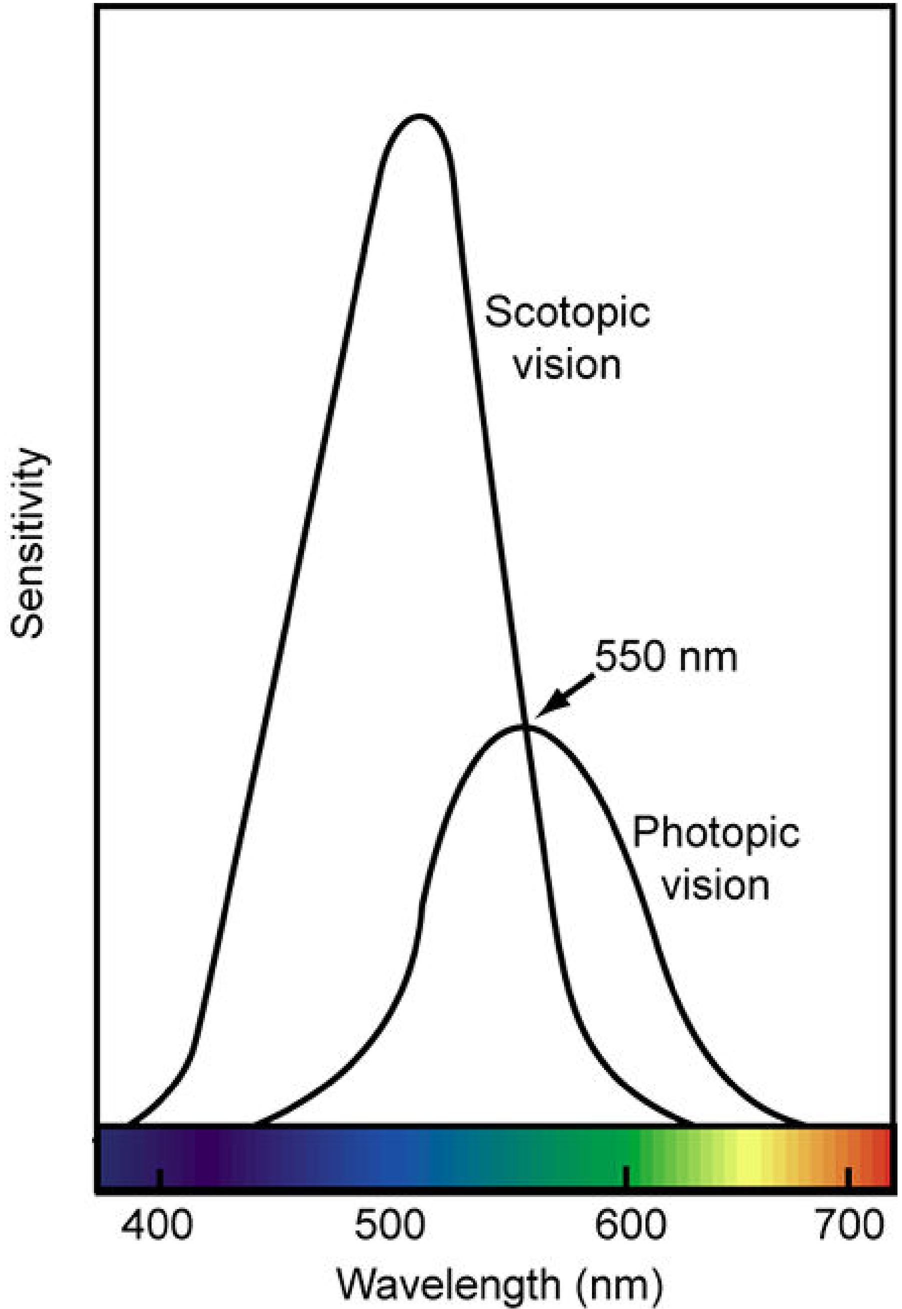




- The 6.5 million cones (2 degrees) and 100 million rods (~200 degrees) are not distributed evenly around the retina.
- The density of the cones is greatest at the fovea, this is the region of sharpest vision.
- The brown bar on the right indicates the place on the retina where there are no receptors because this is where the ganglion cells leave the eye to form the optic nerve.
- The eye on the left indicates locations in degrees relative to the fovea.

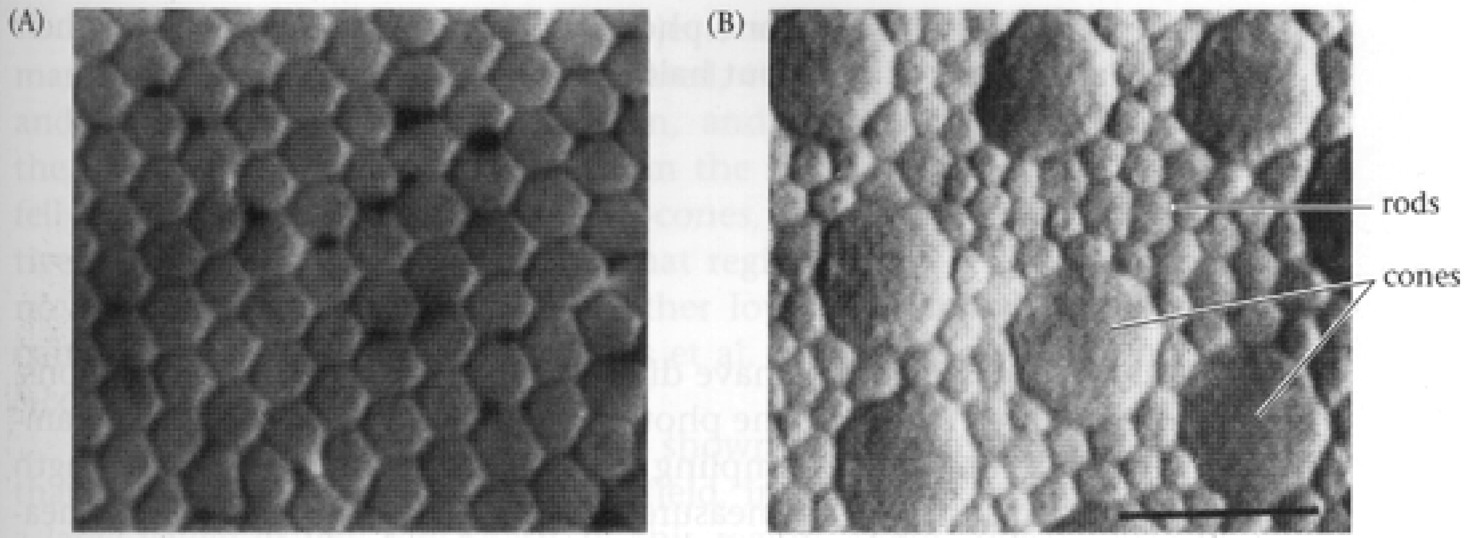
Rods and Cones

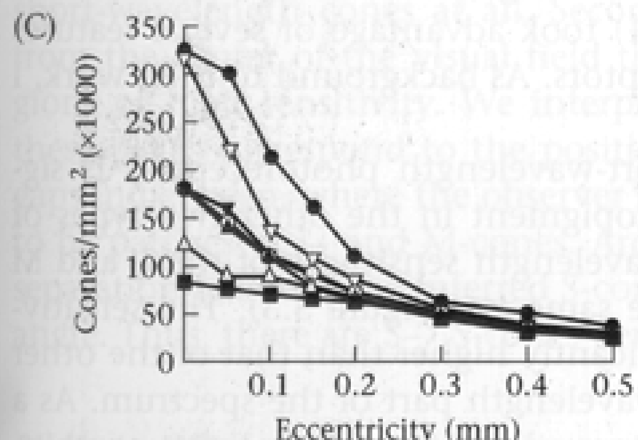




- Dark-adapted (scotopic) vision is sensitive to shorter wavelengths, while light-adapted (photopic) vision is sensitive to all visible wavelengths, although not equally.
- Also, notice where the two curves intersect: at 555nm, the peak of the photopic curve, which means that daylight vision is most sensitive to this wavelength.

Human Photoreceptors



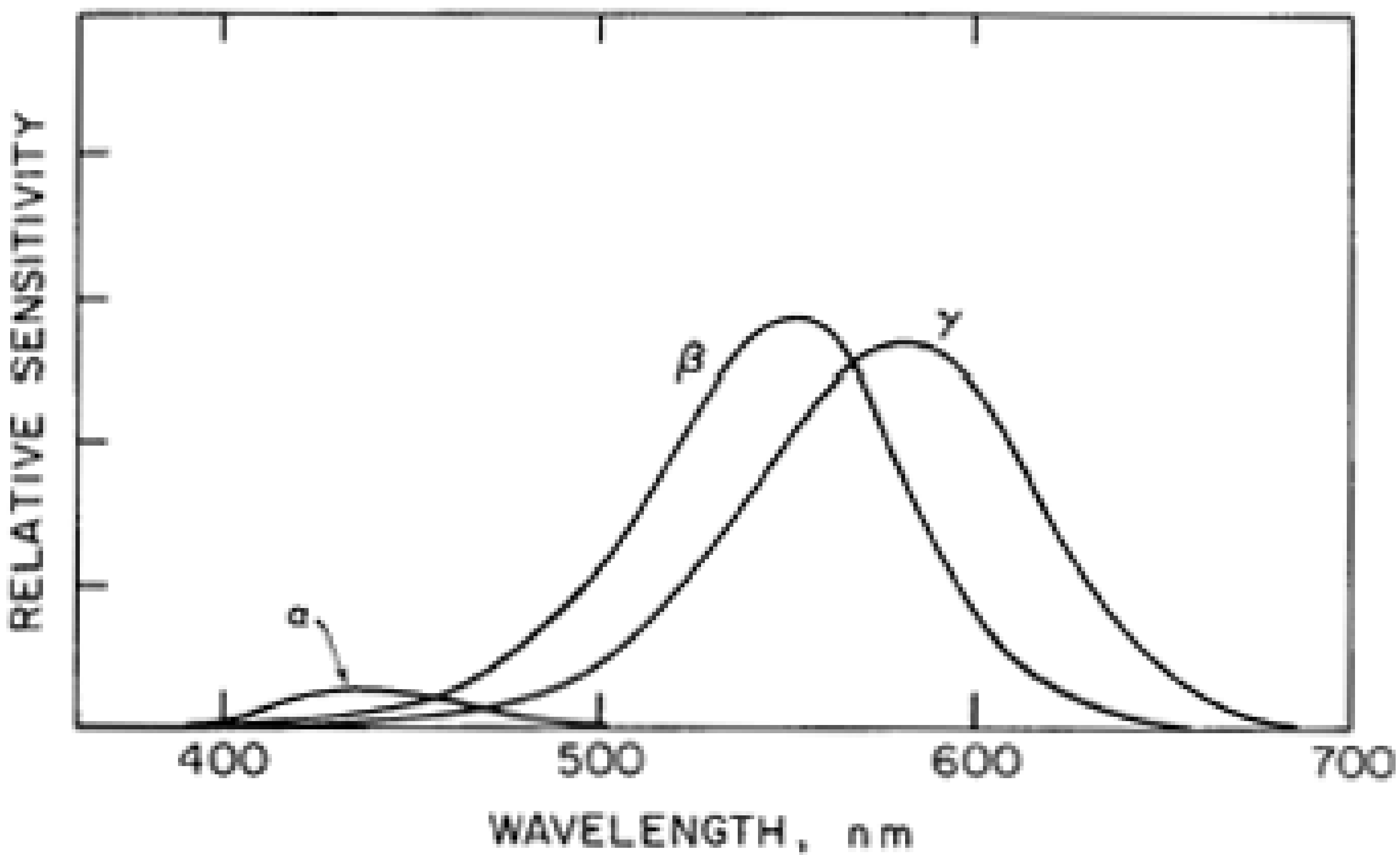


3.4 THE SPATIAL MOSAIC OF THE HUMAN CONES. Cross sections of the human retina at the level of the inner segments showing (A) cones in the fovea, and (B) cones in the periphery. Note the size difference (scale bar = 10 μm), and that, as the separation between cones grows, the rod receptors fill in the spaces. (C) Cone density plotted as a function of distance from the center of the fovea for seven human retinas; cone density decreases with distance from the fovea. Source: Curcio et al., 1990.

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Cones

- The cones have different absorption characteristics as a function of wavelength with peak absorptions in the red, green, and blue regions of the optical spectrum.

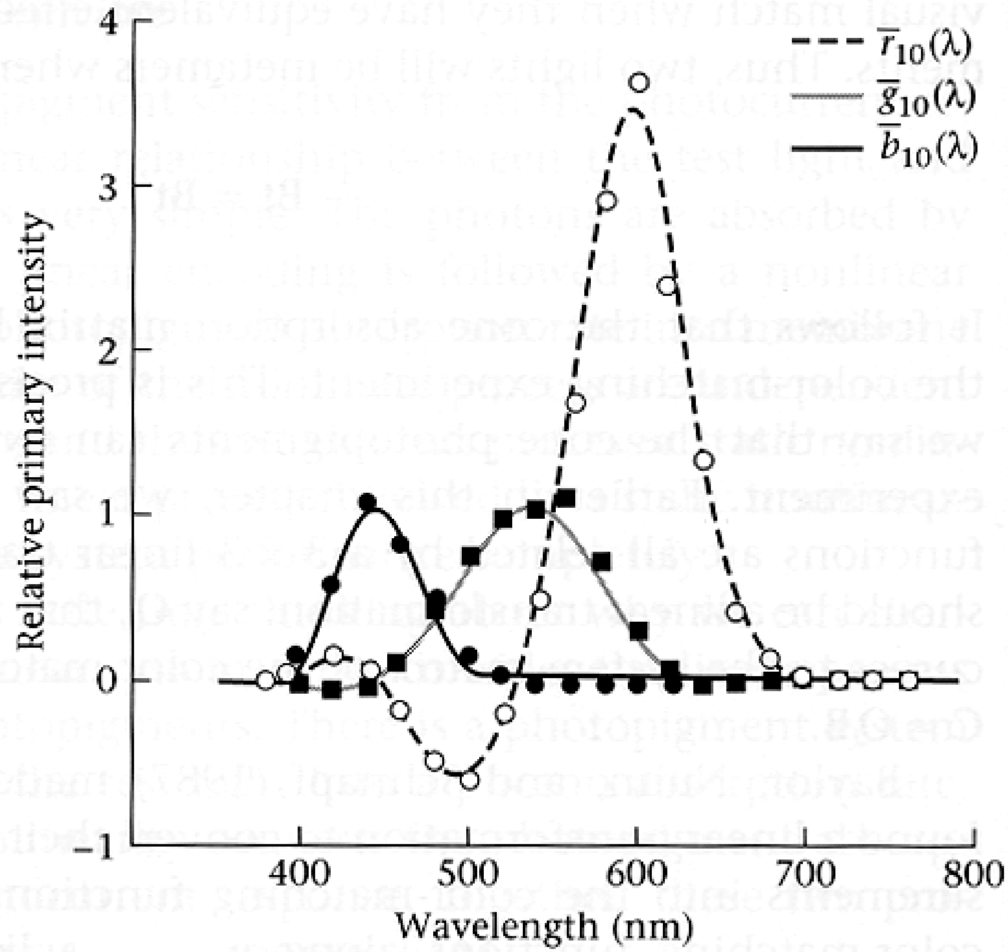


α is blue, β is green, and γ is red

There is a relatively low sensitivity to blue light

There is a lot of overlap

Comparison of color matching functions with best 3x3 transformation of cone responses



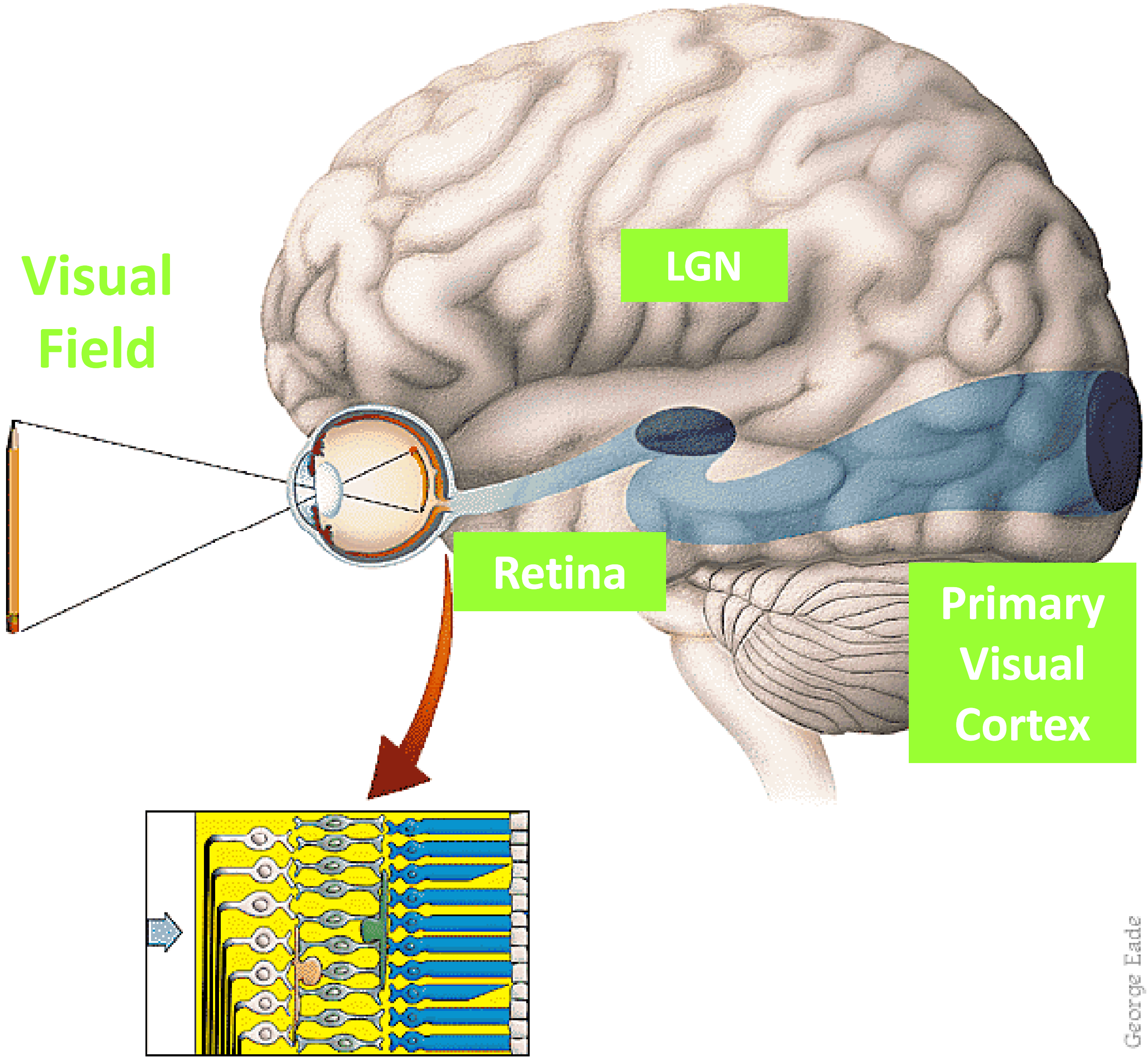
4.20 COMPARISON OF CONE PHOTOCURRENT RESPONSES AND THE COLOR-MATCHING FUNCTIONS. The cone photocurrent spectral responsivities are within a linear transformation of the color-matching functions, after a correction has been made for the optics and inert pigments in the eye. The smooth curves show the Stiles and Burch (1959) color-matching functions. The symbols show the matches predicted from the photocurrents of the three types of macaque cones. The predictions included a correction for absorption by the lens and other inert pigments in the eye. Source: Baylor, 1987.

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

Optic Nerve

LGN (Lateral Geniculate Nucleus)

- a part of the thalamus that relays signals from the eye to the visual cortex.
- It also receives signals back from the cortex.



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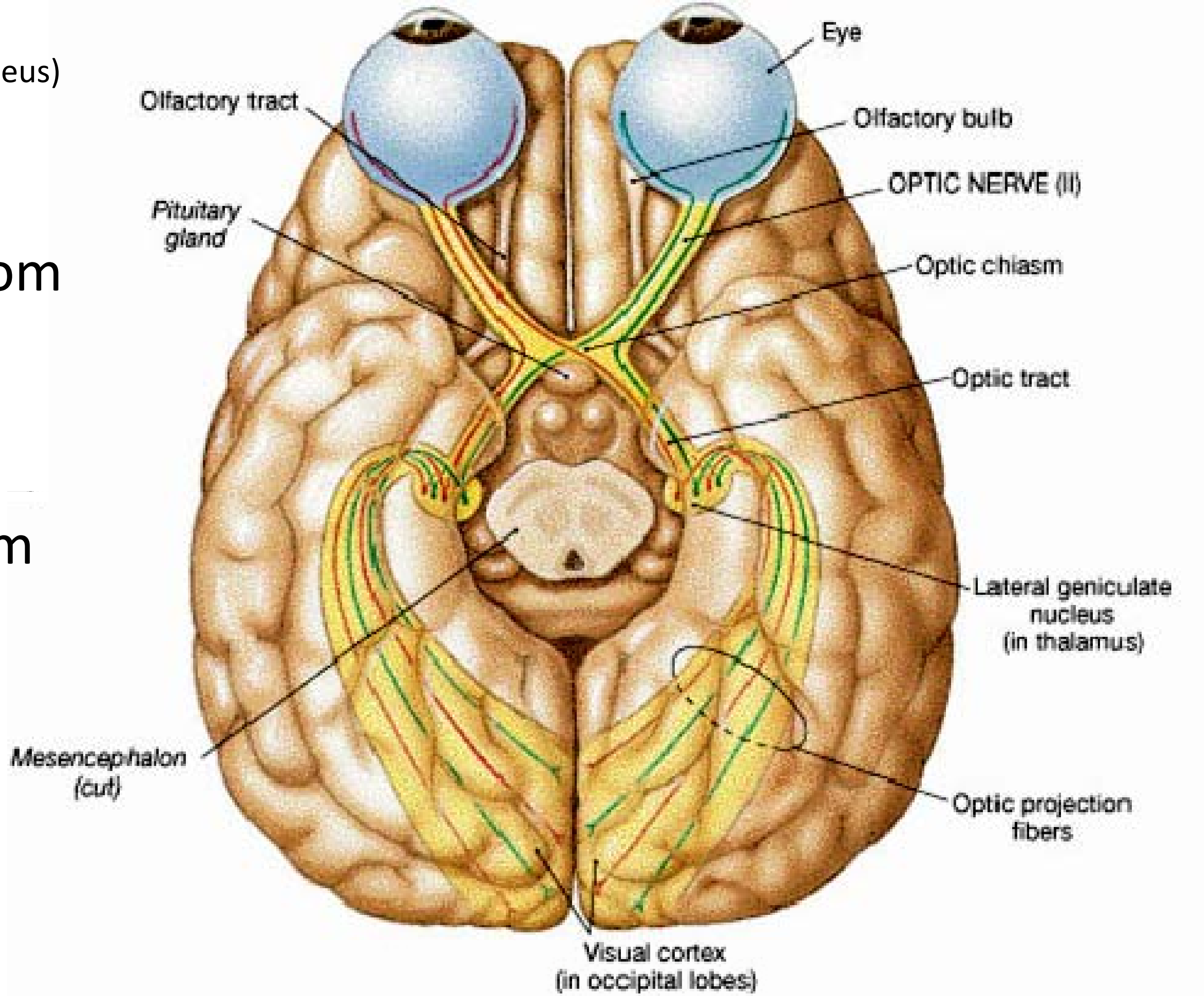
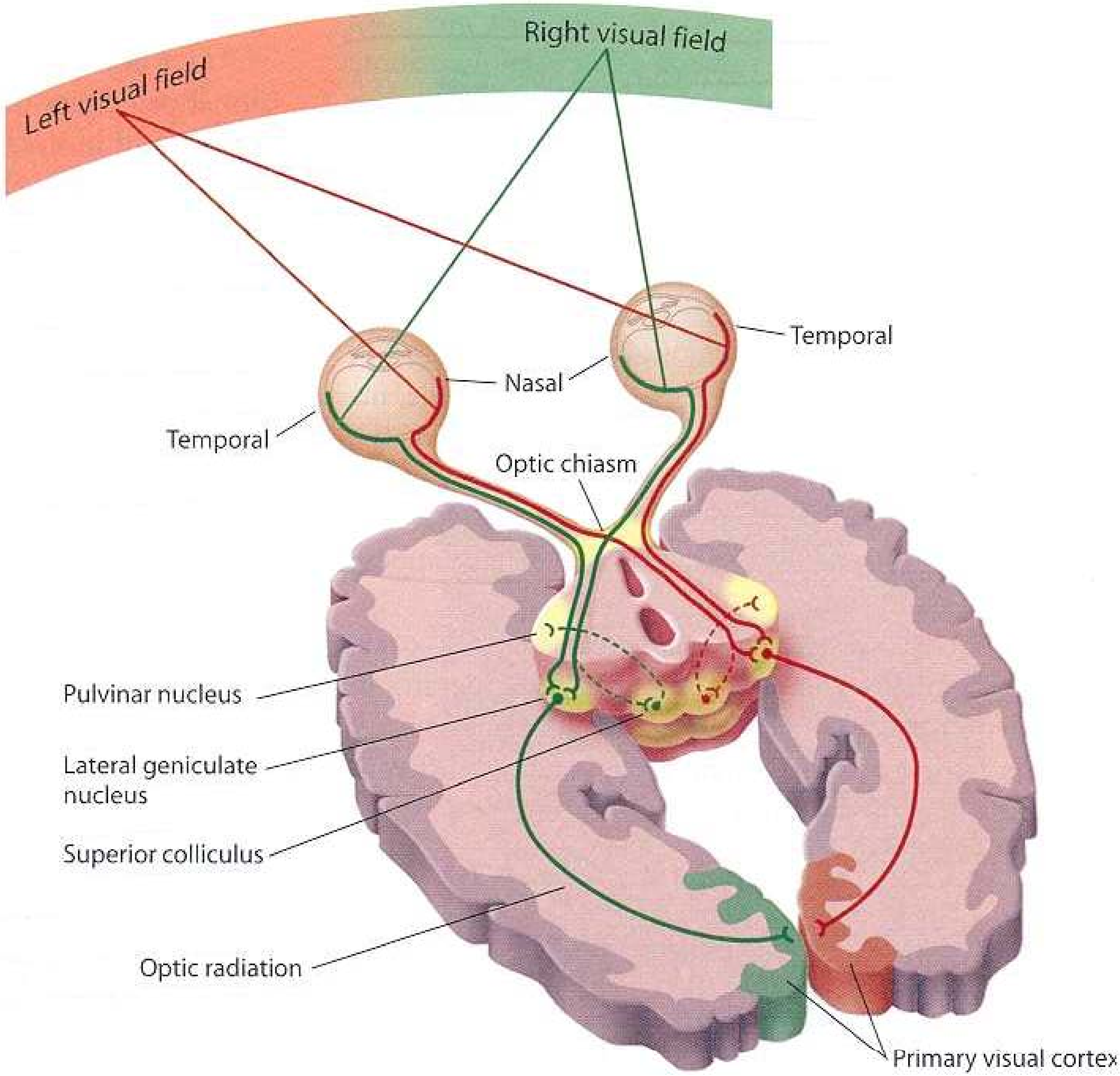




Left visual field
Right visual field
Temporal
Nasal
Temporal
Optic chiasm
Pulvinar nucleus
Lateral geniculate nucleus
Superior colliculus
Optic radiation
Primary visual cortex

Eye Physiology

- The optic nerve bundle contains on the order of 800,000 nerve fibers.
- There are over 100 million receptors in the retina which is smaller than a 10c coin.
- Therefore, the rods and cones must be interconnected to nerve fibers on a many-to-one basis.

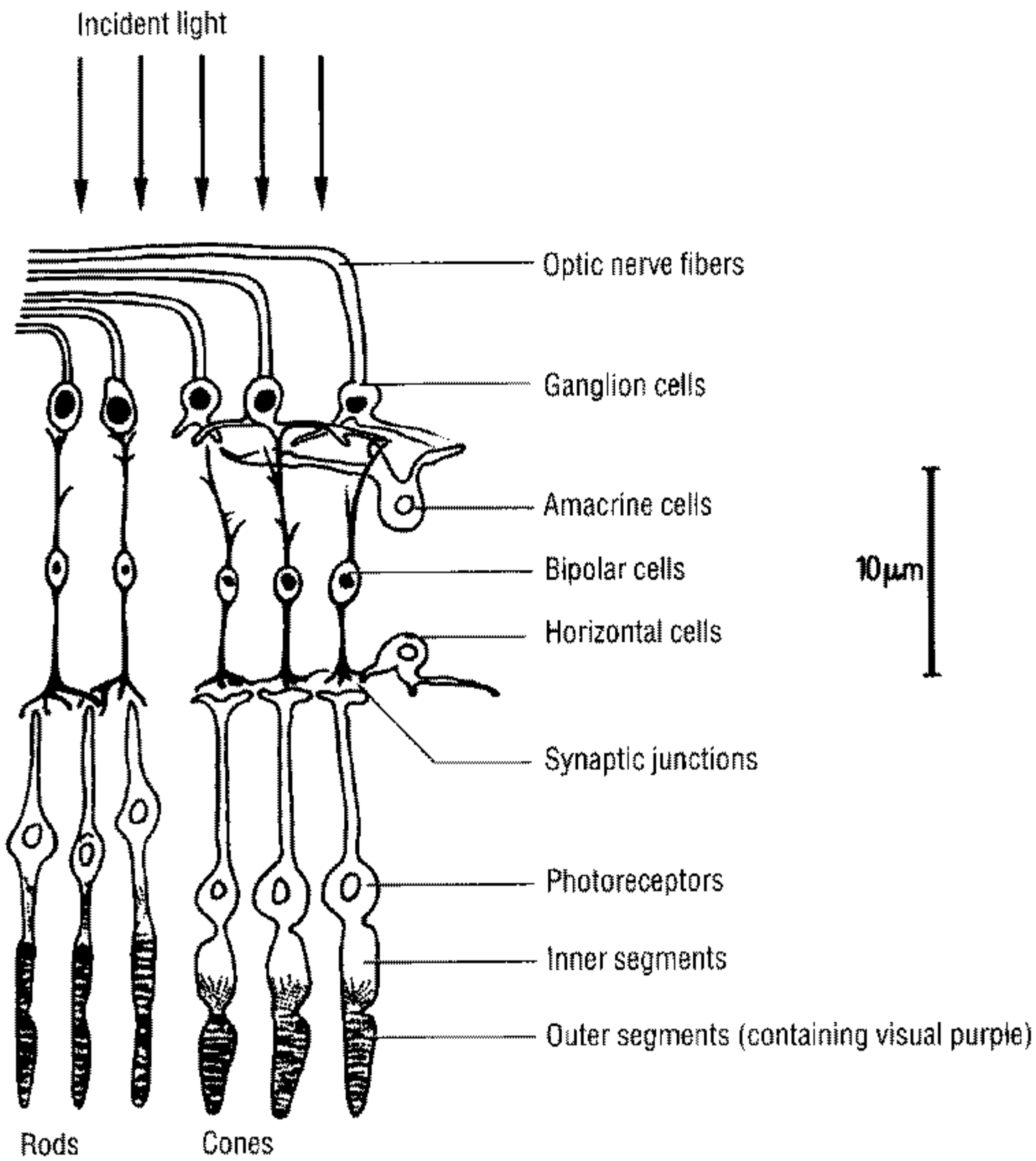
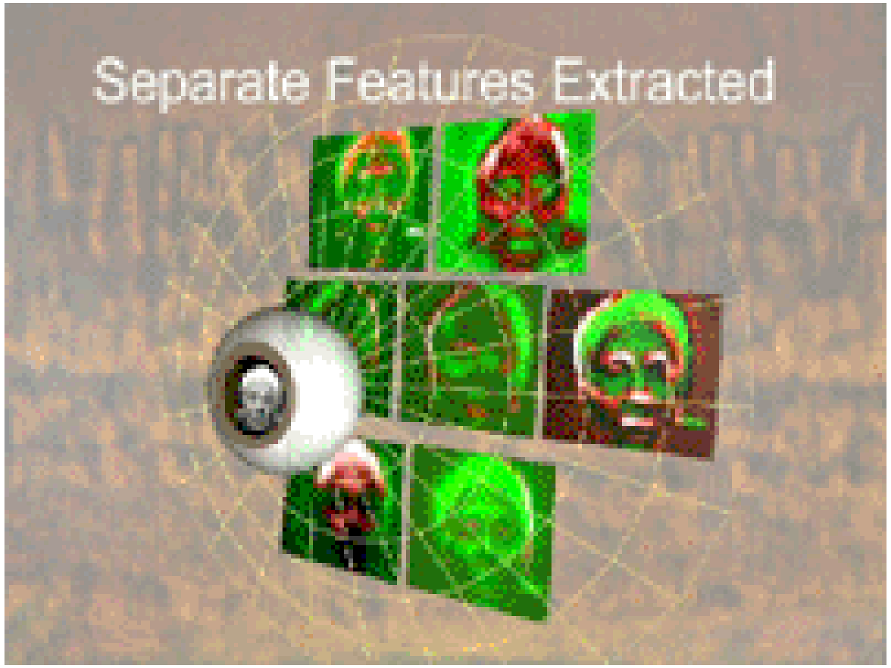


Fig. 1.9
Diagrammatic representation of the structure and relative position of the active elements of the retina



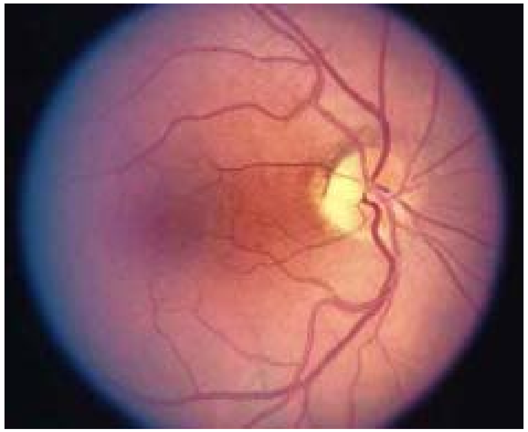
Seven of the dozen separate movies that the
eye extracts from a scene and sends to the brain (*Roska*).

There are only 10 output channels from the eye to the brain.

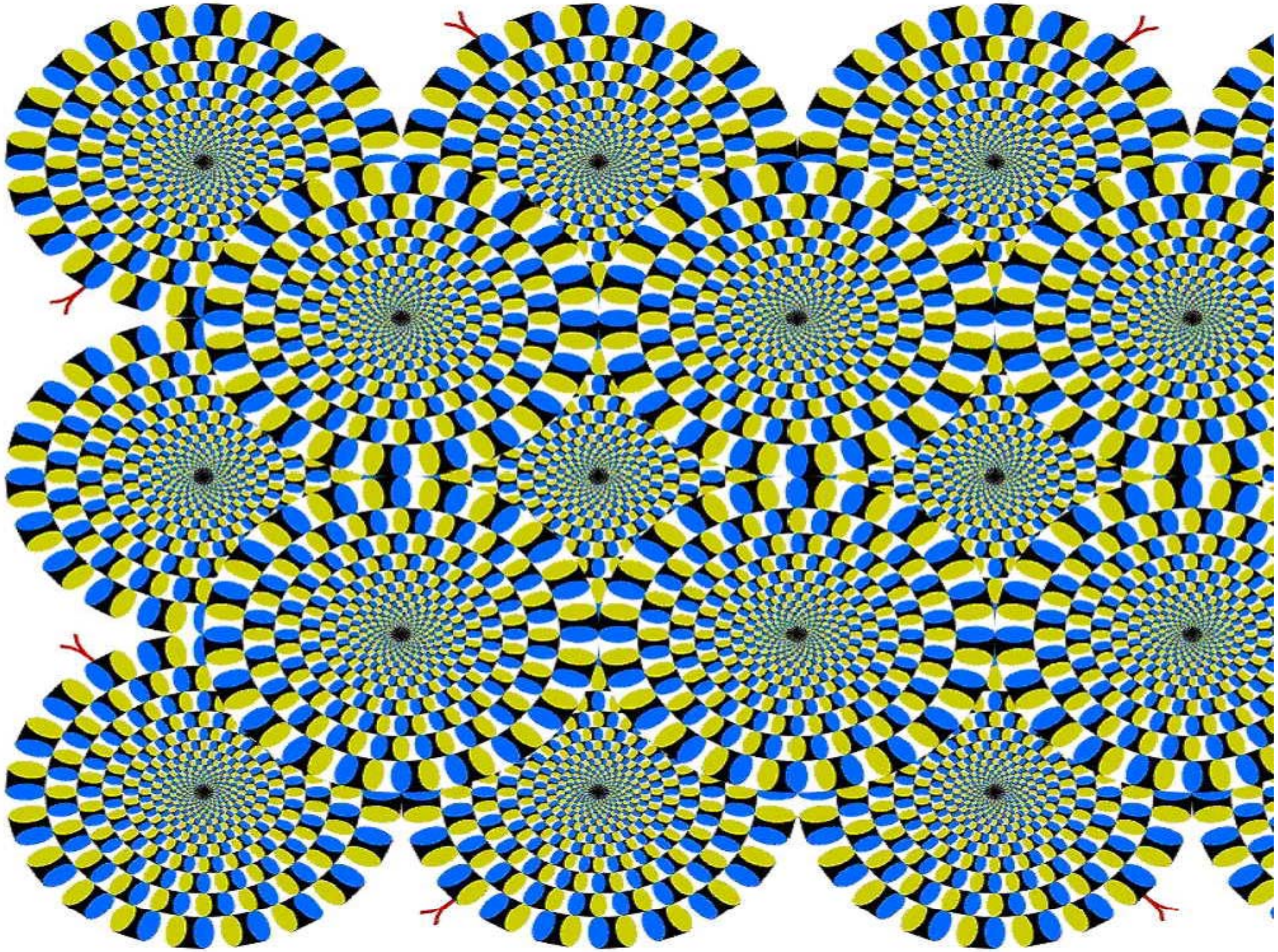
"These 10 pictures of the world constitute all the information we will ever have about what's out there, and from these 10 pictures, which are so sparse, we reconstruct the richness of the visual world," Werblin said. "I'm curious how nature selected these 10 simple movies and how it can be that they are sufficient to provide us with all the information we seem to need."

Even though we think we see the world so fully, what we are receiving is really just hints, edges in space and time. Each representation emphasizes a different feature of the visual world - an edge, a blob, movement - and sends the information along different paths to the brain .

<u>Question</u>: Do we see what is there (veridical perception)?
Or do we see what is on the retina?
Or do we see what we expect to see?
Or…?



Cortical processing



…or how do we fill in the gaps?

Why specify color numerically?

- Accurate color reproduction is commercially valuable
  - Many products are identified by color (“golden” arches);
- Few color names are widely recognized by English speakers -
  - About 10; other languages have fewer/more, but not many more.
  - It’s common to disagree on appropriate color names.
- Color reproduction problems increased by prevalence of digital imaging - eg. digital libraries of art.
  - How do we ensure that everyone sees the same color?

Color standards are important in industry

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AMS USDA

Fruit and Vegetable Programs

AMS USDA SEARCH

Processed Products Standards and Quality Certification

Visual Aids and Inspection Aids Approved For Use in Ascertaining Grades of Processed Fruits and Vegetables (Photo)

- Frozen Red Tart Cherries
- Orange Juice (Processed)
- Canned Tomatoes
- Frozen French Fried Potatoes
- Tomato Products
- Maple Syrup
- Honey
- Frozen Lima Beans
- Canned Mushrooms
- Peanut Butter
- Canned Pimientos
- Frozen Peas
- Canned Clingstone Peaches
- Headspace Gauge
- Canned Applesauce
- Canned Freestone Peaches
- Canned Ripe Olives

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UNITED STATES DEPARTMENT OF AGRICULTURE

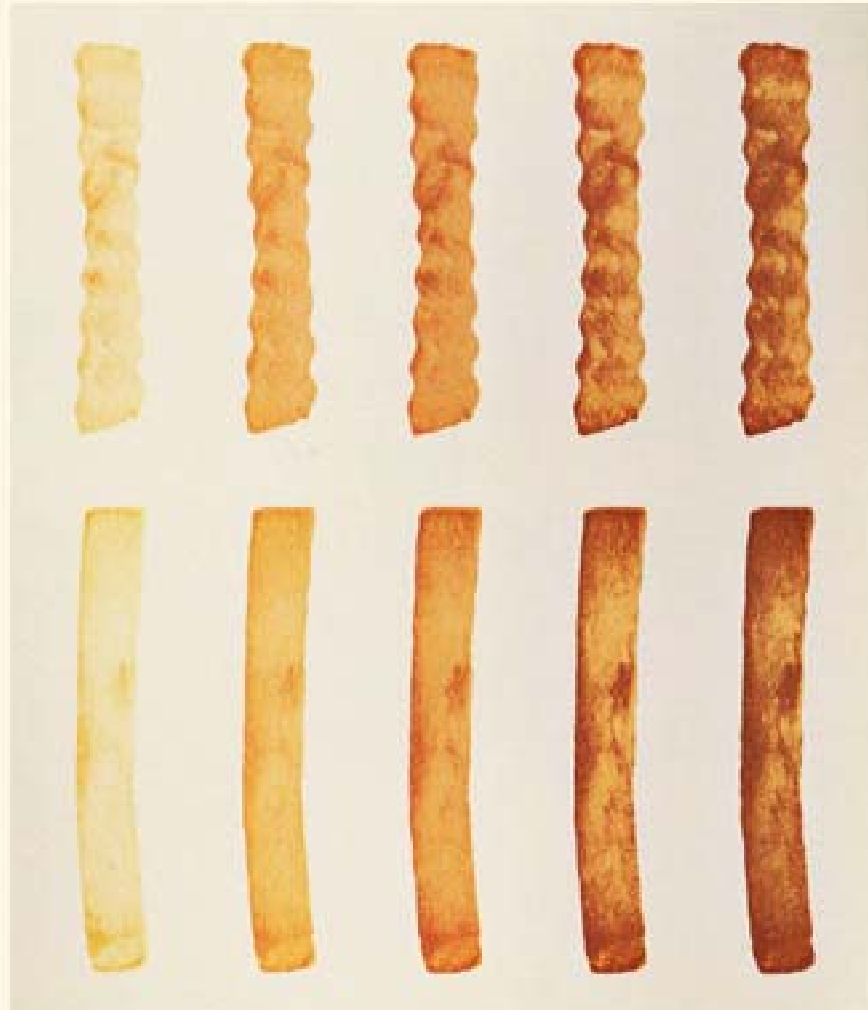
COLOR STANDARDS

for

FROZEN FRENCH FRIED POTATOES

FOURTH EDITION, 1988

MUNSELL COLOR
BALTIMORE, MARYLAND
64-1



An assumption that sneaks in here

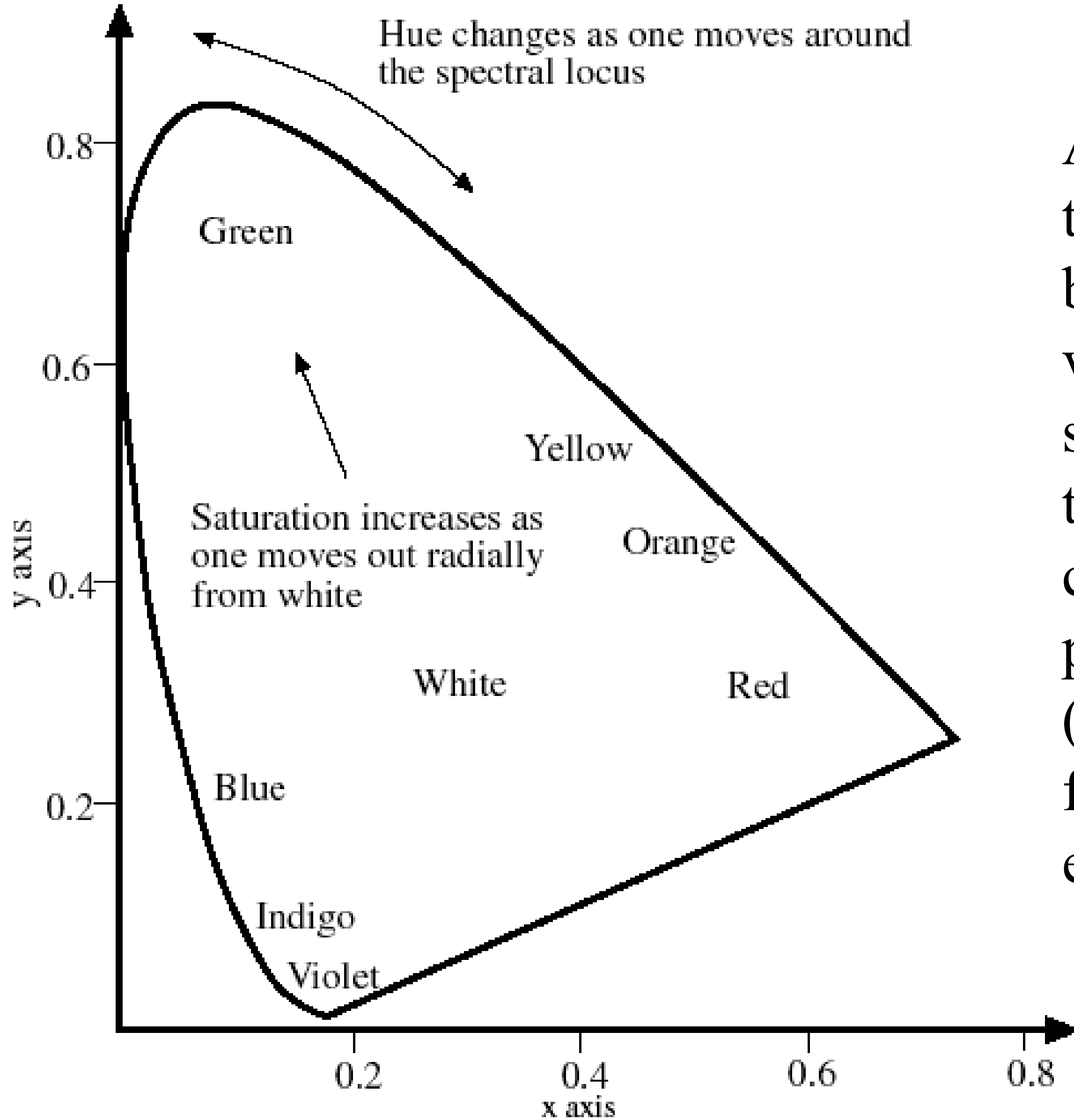
- We know color appearance really depends on:
  - The illumination
  - Your eye's adaptation level
  - The colors and scene interpretation surrounding the observed color.

- But for now we will assume that <u>the spectrum of the light arriving at your eye completely determines the perceived color</u>.

CIE XYZ color space

- Commission Internationale d'Eclairage, 1931
- "…as with any standards decision, there are some irratating aspects of the XYZ color-matching functions as well…no set of physically realizable primary lights that by direct measurement will yield the color matching functions."
- "Although they have served quite well as a technical standard, and are understood by the mandarins of vision science, they have served quite poorly as tools for explaining the discipline to new students and colleagues outside the field."

Foundations of Vision, by Brian Wandell, Sinauer Assoc., 1995

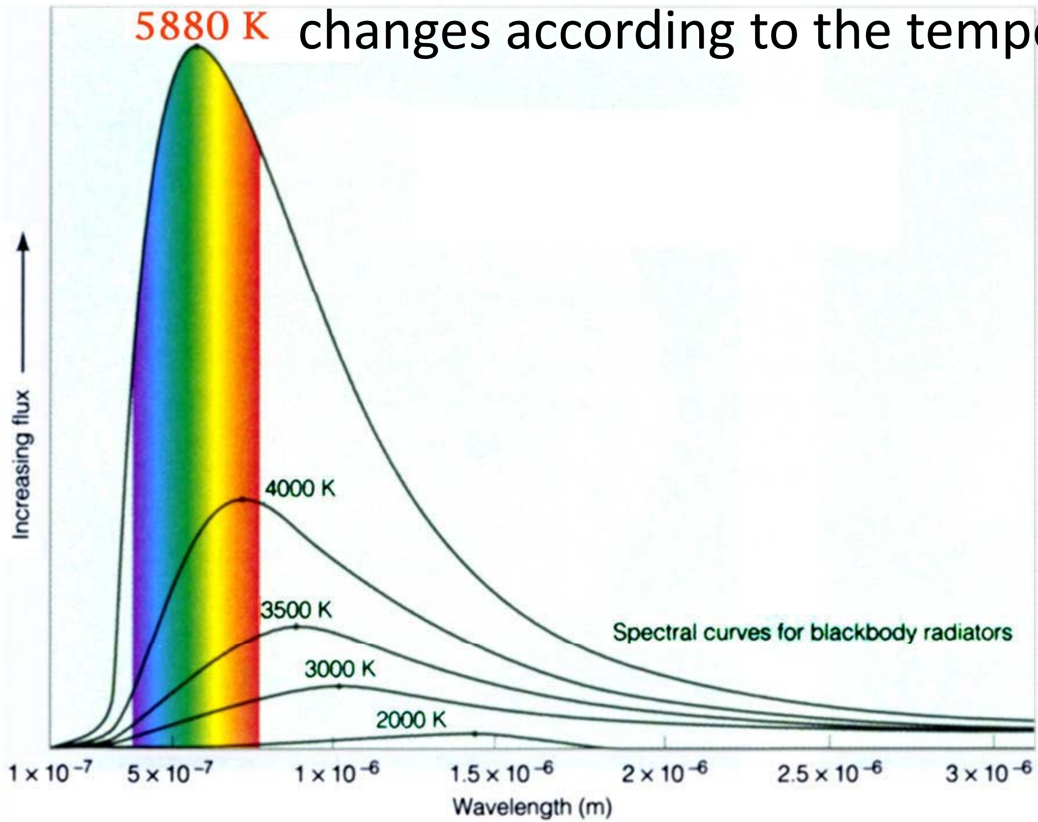


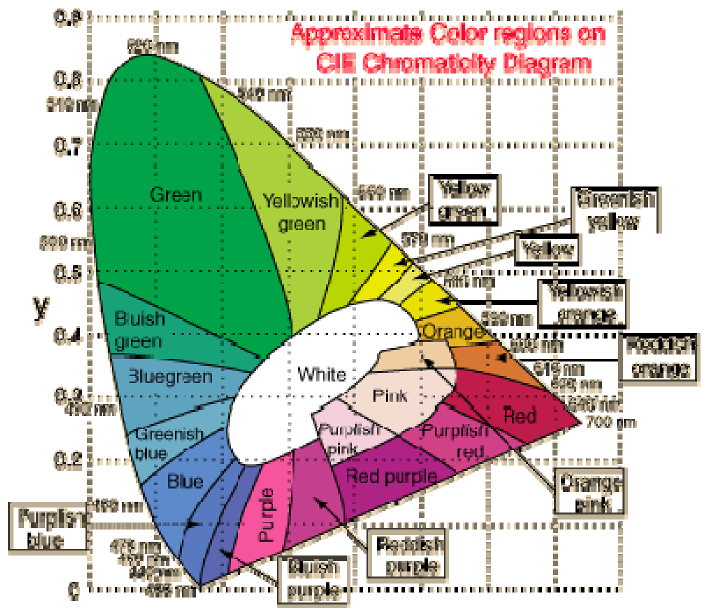
A qualitative rendering of the CIE (x,y) space. The blobby region represents visible colors. There are sets of (x, y) coordinates that don't represent real colors, because the primaries are not real lights (so that the color matching functions could be positive everywhere).

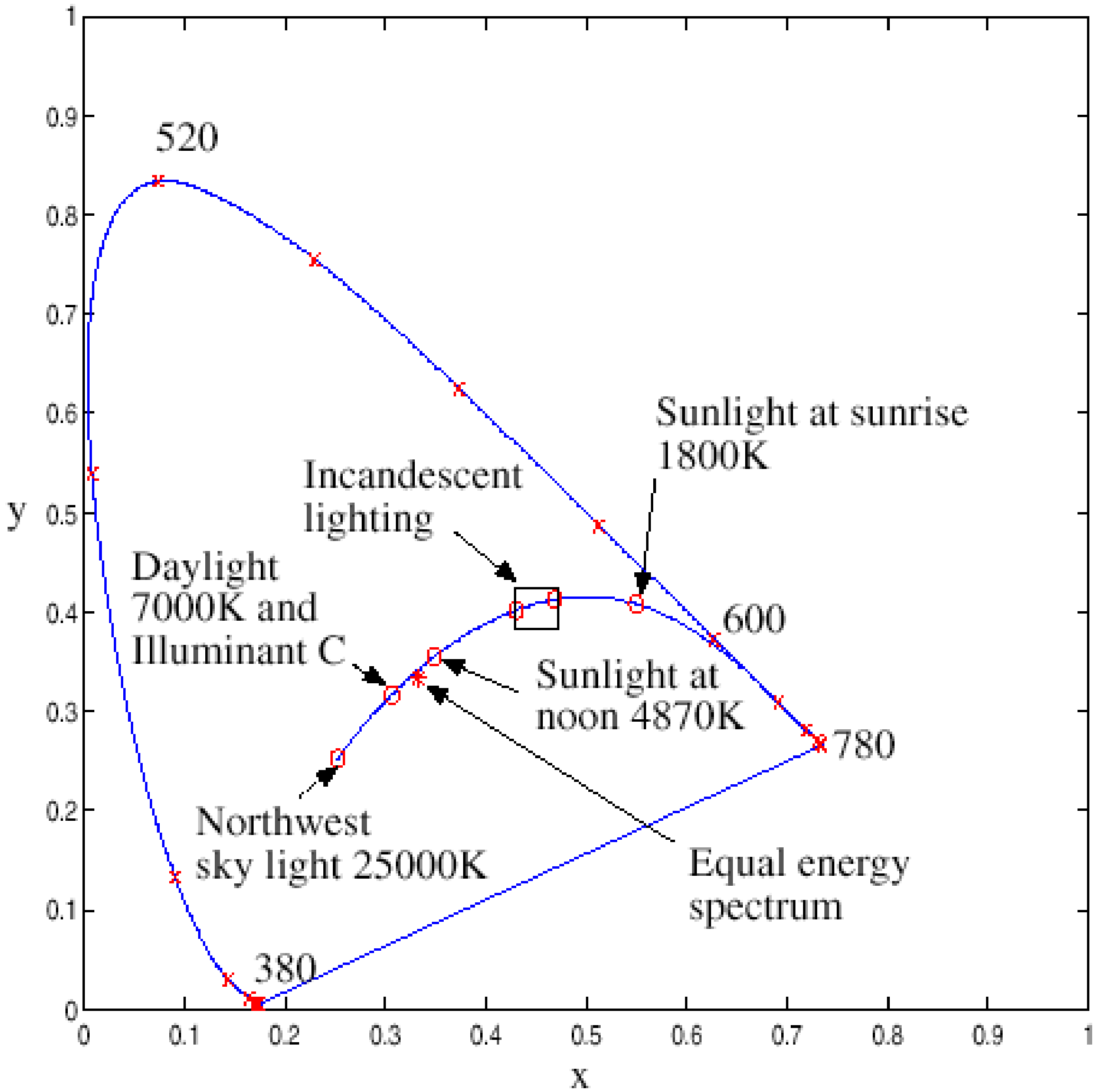
Forsyth & Ponce

- Some objects that radiate their own light are hot; this is called incandescence. If you heat an iron bar sufficiently, it begins to radiate light of its own, where at
- about 3000°C, it glows red - is said to be "red hot.“
- about 6000°C, it glows white - is said to be "white hot."

(In fact, such a heated iron bar radiates many wavelengths of light at different intensities. In other words, it exhibits a spectral curve, which changes according to the temperature of the bar.)





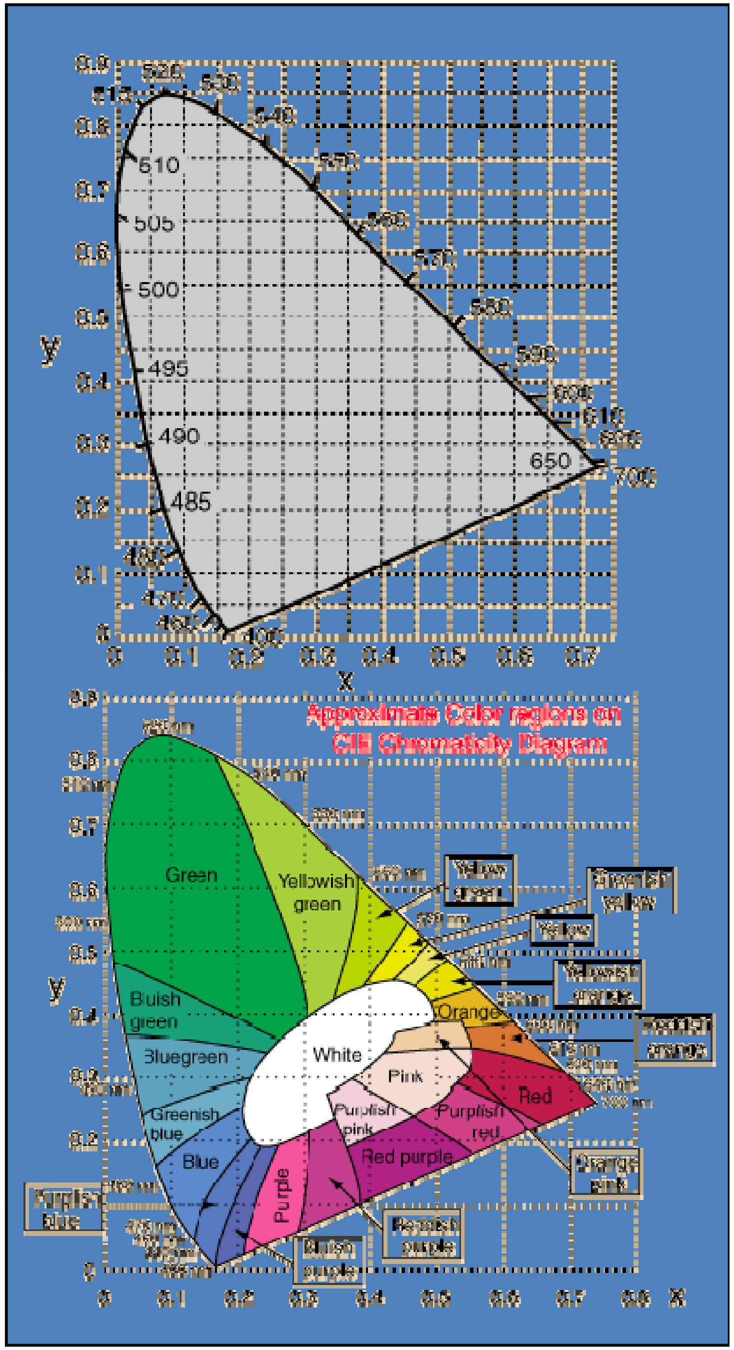


A plot of the CIE (x,y) space. We show the spectral locus (the colors of monochromatic lights) and the black-body locus (the colors of heated black-bodies). I have also plotted the range of typical incandescent lighting.

Forsyth & Ponce

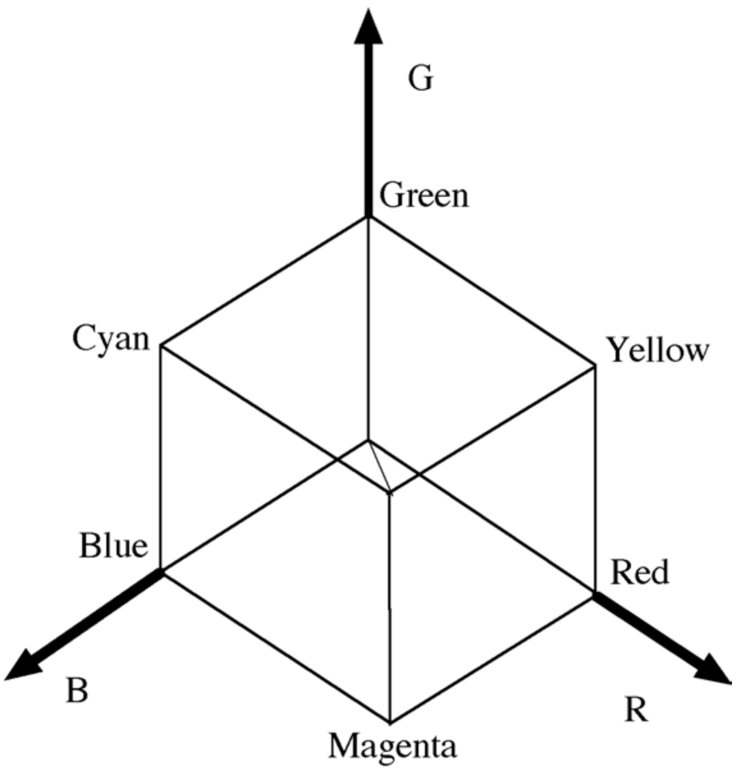
What’s wrong with these?

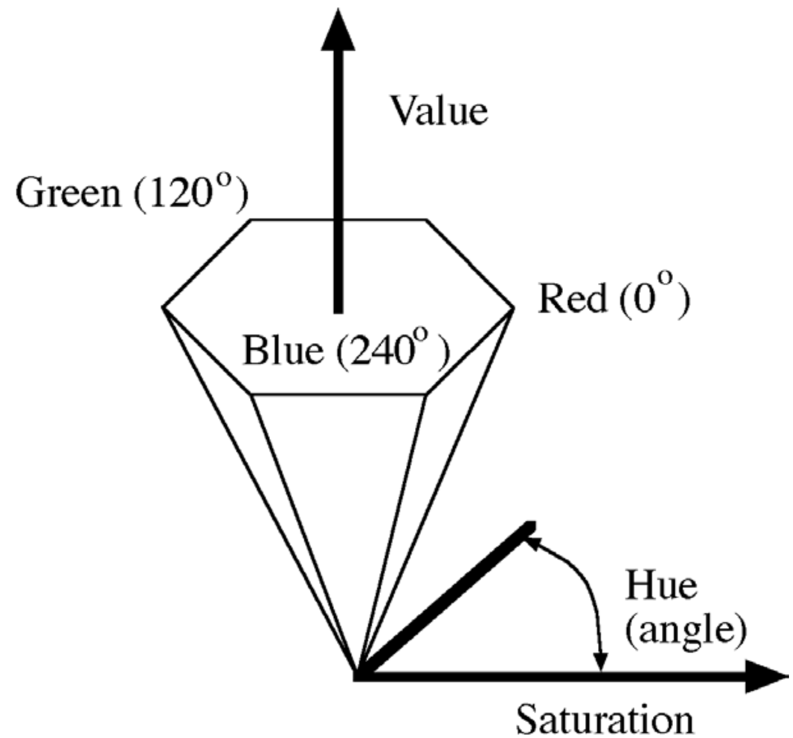
- They do not describe the way light interacts in reality, but simplify it according to how the human eye perceives



Some other color spaces…

HSV hexcone



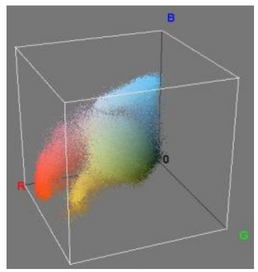


Forsyth & Ponce

Colours in RGB, HSV and HSL colour spaces (and HSI and HSB)

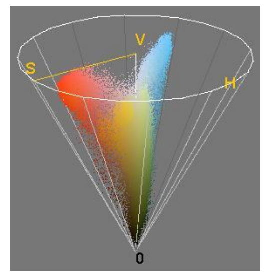
=

RGB



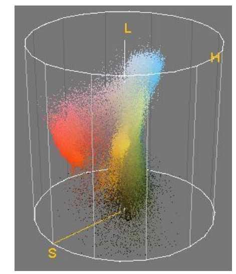
or

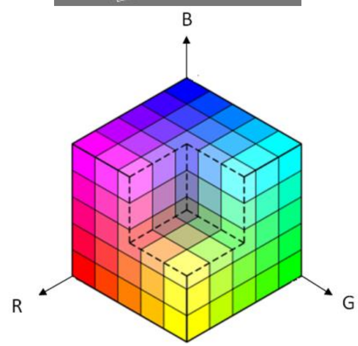
HSV



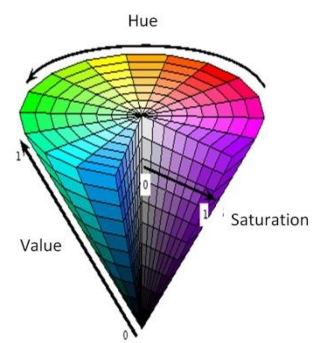
or

HSL

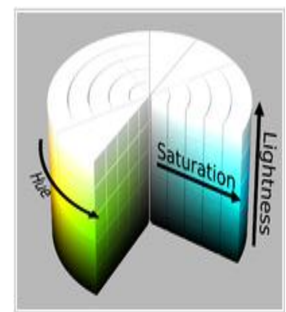




RGB



HSV

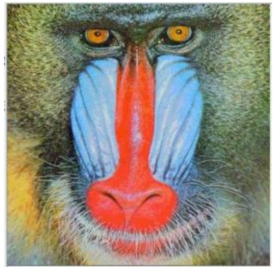


HSL

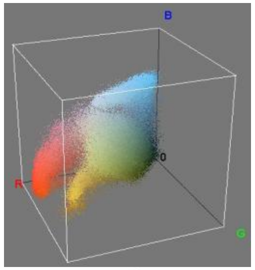
H=Hue, S=Saturation, V=Value, L=Level, I=Intensity, B=Brightness

Colours in RGB, HSV and HSL colour spaces (and HSI and HSB)

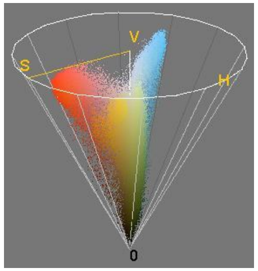
RGB HSV HSL



=



or



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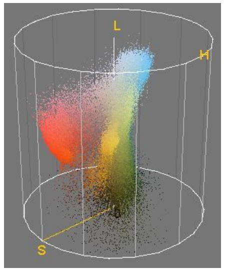

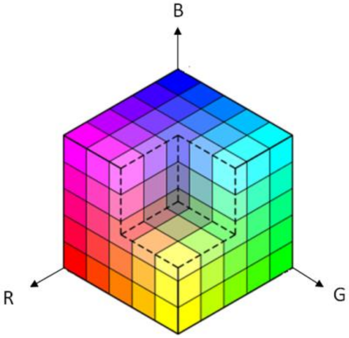

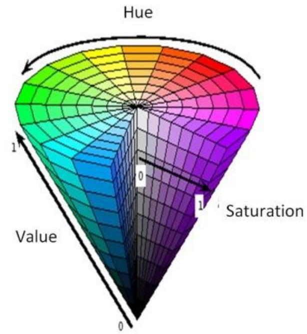

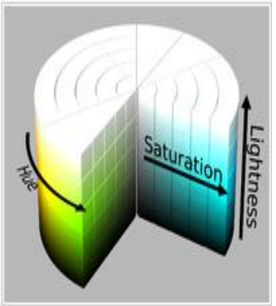

RGB HSV HSL

H=Hue, S=Saturation, V=Value, L=Level, I=Intensity, B=Brightness

Flaws:

- HSV=HSB – but $V_{blue}=V_{white}$ even though V_{blue} is 10% luminance of V_{white}
- HSL=HSI – but $S_{(R+G+0.9B)}=S_G$ even though $S_{(R+G+0.9B)}$ has almost no chroma/saturation

So use CIE's most recent colour model, CIECAM02 = $J_{(lightness)}$ $C_{(chroma)}$ $H_{(hue)}$