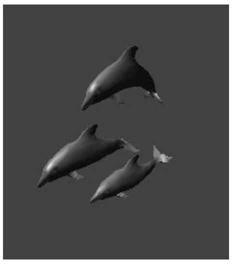
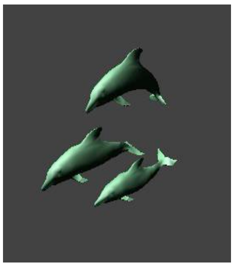
Universität Bielefeld

Virtual Reality for Human Computer Interaction

Appearance





Appearance

- Objects have been described so far by their spatial attributes position, location and shape (using vertices, surfaces and transformations).

- The next task is to determine their appearance:
  1. Render type: vertices, lines, surfaces, …
  2. Lighting: Description or model of light-object-eye interaction.
  3. Shading: Algorithmical lighting application during rendering across a primitive.

- The applied methods can be loosely divided as follows:
  1. Local models:
     - Do not take object-object reflections into account.
     - Example: Gouraud and Phong shader using Phong lighting model.
  2. Global models:
     - Take object-object reflections into account.
     - Example: Ray-tracer, Radiosity

- Most Realtime 3D systems currently use local models and texturing...
- …but local models are often extended to capture global attributes, e.g., using

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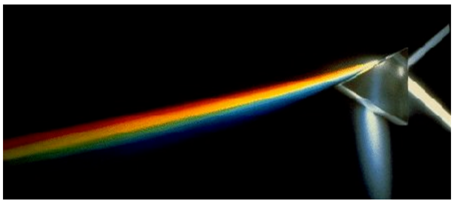
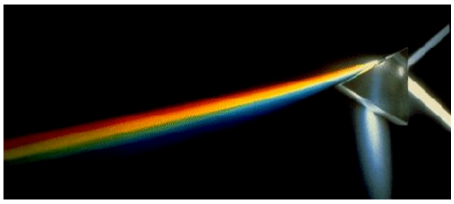


Appearance:

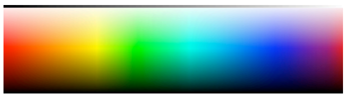
Visual perception
Light and Color

see: (van Dam et al., 1996, pp.563-604)

Achromatic/Colored Light

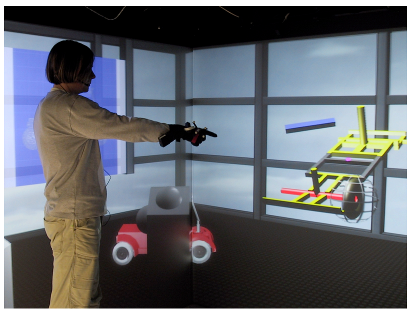


- Achromatic light



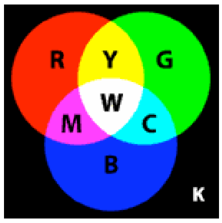
- Chromatic color

- Color models for raster graphics
- Reproducing color



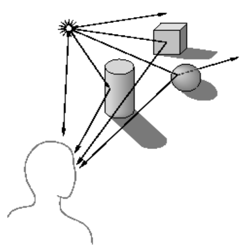
- Using color in computer graphics

Color in Computer Graphics

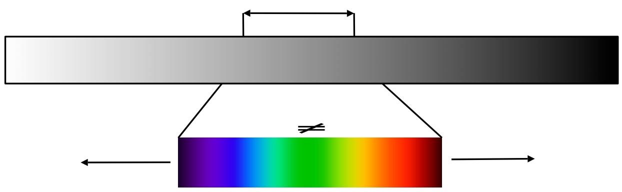


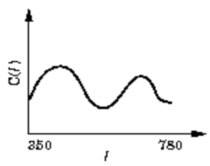
- Physics and measurement for realism
  - what does coding an RGB triple mean?
- Perception and aesthetics for selecting appropriate user interface colors
  - why a bright red and orange striped bedroom is a bad idea
  - how to put on matching pants and shirt in the morning
  - role of culture and even age
    - e.g., WIRED magazine
- Color models for providing users with easy color selection
  - systems for naming and describing colors
- Color models, measurement and color gamuts for color media conversion
  - why colors on your screen may not be printable, and vice-versa
  - managing color in systems with computers, monitors, scanners, and printers
  - color awareness
    - a highly interdisciplinary field that is often unpredictable and downright bizarre
- Useful background for rendering; provides a good introduction to signal processing
  - also used for image processing and anti-aliasing

What Creates Colors?



- Interaction between Light, Objects, Eyes
- What is Light?
  - Electromagnetic Radiation of a Specific Spectrum Range
- Light is a distribution C(l) of intensities l at each wavelength





Color difficulties

- Color is an immensely complex subject, drawing on physics, physiology, psychology, art, and graphic design
- Many theories, measurement techniques, and standards for colors, yet no one theory of human color perception is universally accepted
- Color of object depends not only on object itself but also on light source illuminating it, on color of surrounding area, and on human visual system (the eye/brain mechanism)
- Some objects reflect light (wall, desk, paper), while others also transmit light (cellophane, glass)
  - surface that reflects only pure blue light illuminated with pure red light appears black
  - pure green light viewed through glass that transmits only pure red also appears black

Achromatic/Chromatic Light

- Achromatic light: intensity (quantity of light) only
  - called intensity or luminance if measure of light's energy or brightness
    - the psychophysical sense of perceived intensity
  - gray levels (e.g., from 0.0 to 1.0)
  - seen on black and white TV or display monitors
- Chromatic light
  - visual color sensations
    - brightness/intensity
    - chromaticity/color
      - hue/position in spectrum (red, green, yellow . . .)
      - saturation/vividness
  - generally need 64 to 256 gray levels for continuous-tone images without contouring

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Gamma

- **Gamma** (γ) is a measure of the nonlinearities of a display
  - *Nonlinearity*: the response (output) is not directly proportional to the input (term often used incorrectly to refer to nonlinearity of image data)
- Example: PC monitors have a gamma of roughly 2.5, while Mac monitors have a gamma of 1.8, so Mac images appear dark on PC's:

- Problems in graphics
  - need to maintain color consistency across different platforms and hardware devices (monitor, printer, etc.)
  - even the same type/brand of monitors change gamma value over time
  - proper design, use of color software like ColorBlind ®

Gamma

- Nonlinearities are pervasive
  - hardware
  - ***human visual systems***
- How to distribute 256 different intensities?
  - don't want, for example, first 128 in [0, 0.1] and second 128 in [0.9, 1.0]
    - would create a visible gap from 0.1 to 0.9
  - but equal distribution of 256 in [0,1.0] ignores important characteristic of the human eye
    - Eye sensitive to *ratio*: perceives intensities 0.10 and 0.11 as differing just as much as the intensities 0.50 and 0.55
- Yet want predictability
- First, we deal with nonlinearity of the human visual system, then with nonlinearity of CRT (LCD is different)

Gamma correction

- To achieve equal steps in brightness, space logarithmically rather than linearly, so that: $\frac{I_{j+1}}{I_j} = \frac{I_j}{I_{j-1}} = r$
- Use the following relations: $I_0 = I_0,\ I_1 = rI_0,\ I_2 = rI_1 = r^2 I_0,\ I_3 = rI_2 = r^3 I_0, \ldots,$
  $I_{255} = r^{255} I_0 = 1$
- Therefore: $r = (1/I_0)^{1/255},\ \ I_j = r^j I_0 = (1/I_0)^{j/255} I_0 = I_0^{(255-j)/255} \quad (13.2)$
  $for\ 0 \le j \le 255$
- In general for *n*+1 intensities: $r = (1/I_0)^{1/n},\ \ I_j = I_0^{(n-j)/n} \quad for\ 0 \le j \le n \quad (13.3)$
- Thus for: $n = 3$ (4 intensities) and $I_0 = 1/8,\ r = 2,$
  intensity values of 1/8, 1/4, 1/2 and 1

Display of Intensities

- *Dynamic range*: ratio of maximum to minimum intensities, i.e., $1/I_0$
- Typical on CRT anywhere from 40:1 to 200:1 => I_0 between .005 and .025:
  for I_0 = 0.02, EQ (13.2) yields r = 1.0154595 …
- First few, last two of 256 intensities from EQ (13.1):
  0.0200, 0.0203, 0.0206, 0.0209, 0.0213, 0.0216, …, 0.9848, 1.0000
- Pixel values are NOT intensities: need *gamma correction* to compensate for nonlinearities
- Non-linearities in CRT

  $I = kN^{\gamma} \quad (13.4)$

  N = number of electrons in beam, proportional to grid voltage, which is proportional to pixel value V

  k and γ are constants

  γ is typically in the range of 2.2 to 2.5
- Therefore, for some other constant k:

$$I = KV^{\gamma}, \quad or \quad V = (I/K)^{1/\gamma} \quad (13.5)$$

Display of Intensities

- To display intensity I, find nearest I_j from a table or: j = **ROUND($\log_r(I/I_0)$)**
- Then $I_j = r^j I_0$
- And $V_j = \mathrm{ROUND}((I_j / K)^{1/\gamma})$
  - if <u>no</u> look-up table, load V_j in pixel
  - if look-up table, load j in pixel, V_j in entry j
- Number of intensities needed for appearance of continuous intensity depends on ratio:
  - need r = 1.01 for I_j and I_j**+1** to be indistinguishable:

$$r = (1 / I_0)^{1/n} \quad \text{or} \quad 1.01 = (1 / I_0)^{1/n}$$

  - solve for n:

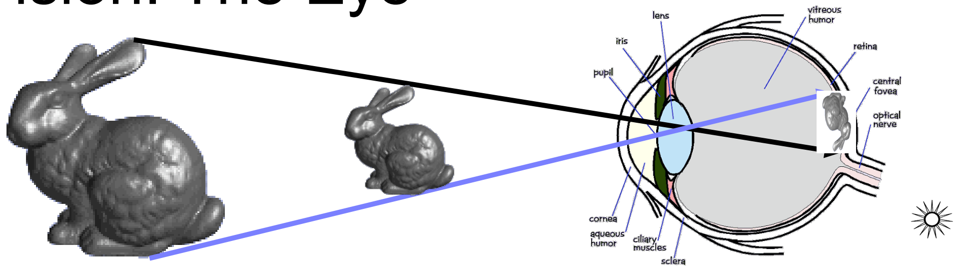
$$n = \log_{1.01}(1 / I_0); \quad 1 / I_0 \text{ is dynamic range} \qquad (13.10)$$

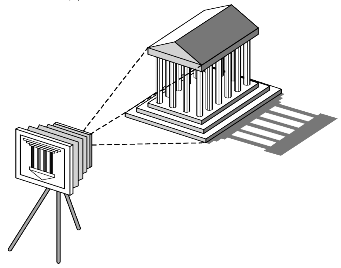
Display of Intensities

Display Media	Typical Dynamic Range	No. of Intensities, n
CRT	50-200	400-530
Photographic prints	100	465
Photographic slides	1000	700
Coated paper printed in B/W	100	465
Coated paper printed in color	50	400
Newsprint printed in B/W	10	234

- ink bleeding and random noise considerably decreases n in practice
- Note: a medium's dynamic range (number of intensities) not same as gamut (number of visible colors it can display)

Vision: The Eye



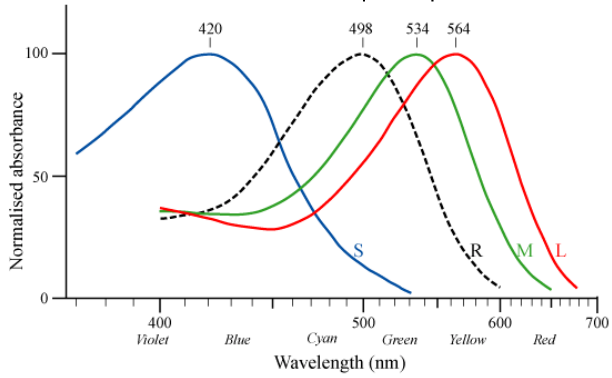


- The eye can be viewed as a dynamic, biological camera: it has a lens, a focal length, and an equivalent of film.
- The lens must focus directly on the retina for perfect vision.
- But age, malnutrition and disease can unfocus the eye, leading to near- and farsightedness
- The retina functions as the eye's "film".
  - It is covered with cells sensitive to light. These cells turn the light into electrochemical impulses that are sent to the brain.
  - There are two types of cells, ***rods*** and ***cones***

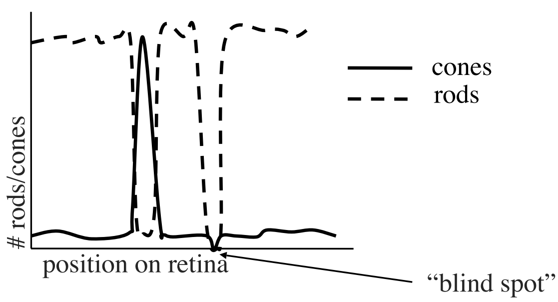
Vision: Rods and cones

- Rods:
  - Sensitive to most visible frequencies (brightness).
  - About 125 million in eye.
  - Located outside of *fovea*, or center of retina.
  - Used in low light (theaters, night) environments, result in achromatic (b&w) vision.
- Cones:
  - L cones are sensitive to long wavelengths (λ)(red), M to middle λ's (green), and S to short λ's (blue).
  - About >6 million in eye.
  - Highly concentrated in fovea, with S cones more evenly distributed than the others (but only about 12% are S cones).
  - Used for high detail color vision.

rod/cone normalized absorption spectrum:



rod/cone distribution:



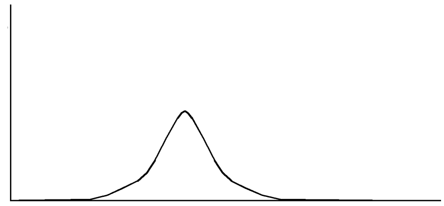
Vision: Sensitivity vs. Acuity

- *Sensitivity*
  - is a measure of the dimmest light the eye can detect.
- *Acuity*
  - is a measure of the smallest object the eye can see.
- These two capabilities are in competition:
  - In the fovea
    - cones are closely packed.
    - Acuity at its highest, sensitivity at its lowest.
  - Outside the fovea
    - acuity decreases rapidly.
    - Sensitivity increases correspondingly.

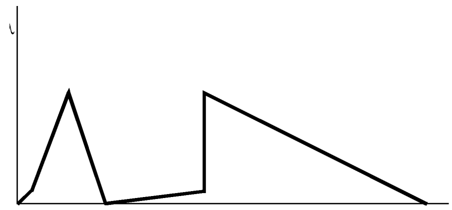
Blind spot examples

Stimuli response

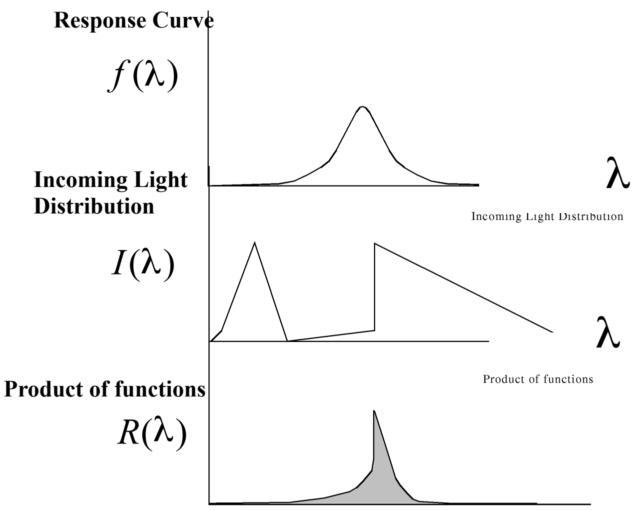
- We draw a frequency response curve like this:
- …to indicate how much a receptor responds to light of uniform intensity for each wavelength



- To compute response to incoming band (frequency distribution) of light, like this:
- …we multiply the curves, wavelength by wavelength, to compute receptor response to each amount of stimulus across spectrum



Stimuli response



Gray area under product curve represents how much receptor "sees," i.e., total response to incoming light

- Let's call this receptor red, then

red perception $= \int R(\lambda) d(\lambda) = \int I(\lambda) f(\lambda) d\lambda$

- Response curve also called filter because it determines amplitude of response (i.e., perceived intensity) of each wavelength
- Where filter's amplitude is large, lets through most of incoming signal
  → strong response
- Where filter's amplitude is low, filters out much/most/all of signal
  → weak response
- This is much like impulse response and filtering you'll see in Image Processing

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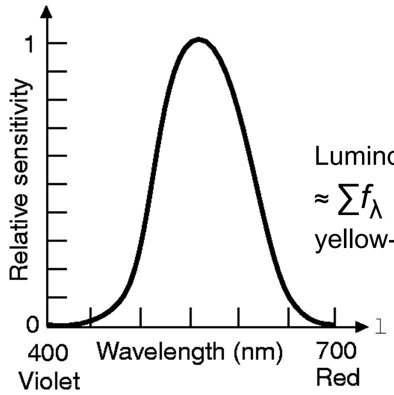
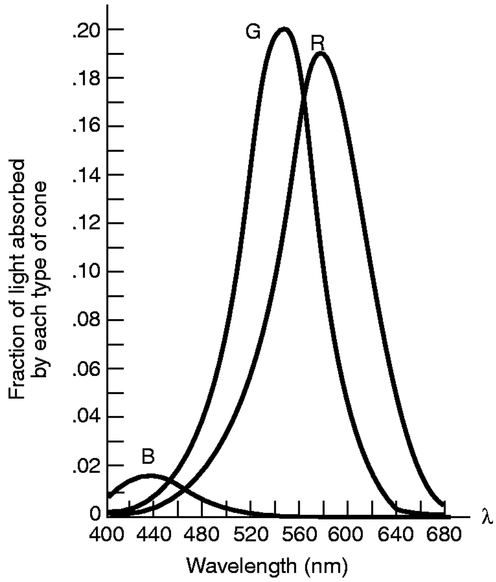
Tristimulus Theory



Luminous Efficiency Function
≈ $\sum f_\lambda$ (peak sensitivity at yellow-green (550nm))

Spectral-response functions of f_λ each of the three types of cones on the human retina (not normalized)



- Tristimulus theory does not explain color perception, e.g., not many colors look like mixtures of RGB (violet looks like red and blue, but what about yellow?)

Triple Cell Response Applet:

http://www.cs.brown.edu/exploratories/freeSoftware/repository/edu/brown/cs/exploratories/applets/spectrum/triple_cell_response_guide.html

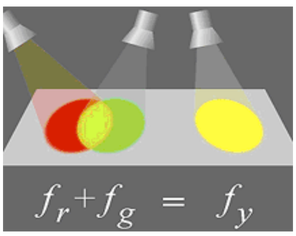
Vision

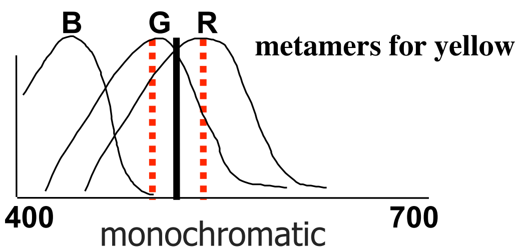
Chromatic adaption

- If color is just light of a certain wavelength, why does a yellow object always look yellow under different lighting (e.g. interior/exterior)?
- This is the phenomenon of ***color constancy***.
- Colors are constant under different lighting because the brain responds to **ratios** between the R, G and B cones, and **not magnitudes**.

Metamers

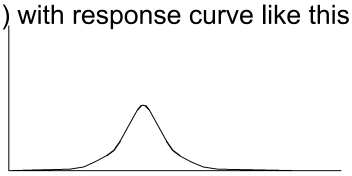
- Colors are represented to the brain as ratios of three signals:
  - possible for different frequency combinations to appear as the same color.
- These combinations are called metamers. *This is why RGB color works!*



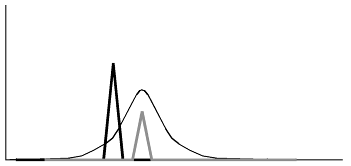


Metamers

- Imagine a creature with **one receptor** type ("red") with response curve like this:

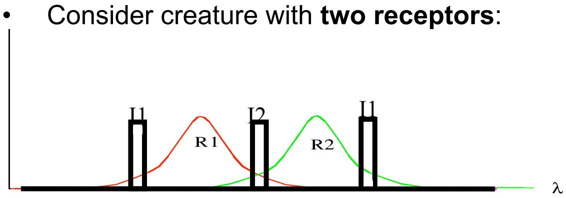


- How would it respond to each of these two light sources?



- Both signals will generate same amount of "red" perception. They are metamers
- One receptor type cannot give more than one color sensation (albeit with varying brightness)

- Consider creature with **two receptors**:



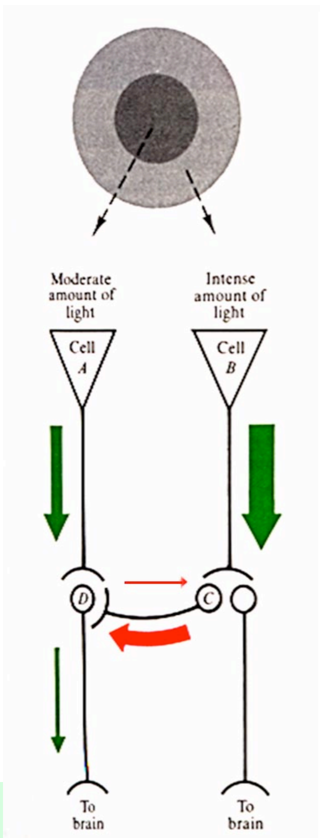
- In principle, an infinite number of frequency distributions can simulate the effect of I2, e.g., I1
- In practice, for I*n* near base of response curves, amount of light required becomes impractically large.
- For three types of receptors, potentially infinite color distributions (metamers) that will generate identical sensations
- Conversely, no two monochromatic lights can generate identical receptor responses and therefore all look unique
- Thomas Young in 1801 postulated that we need 3 receptor types to distinguish gamut of colors represented by triples H, S, V (hue, saturation, value)

Lateral inhibition

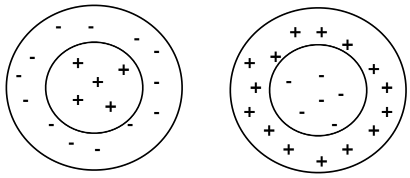
- Receptor cells, A and B, stimulated by neighboring regions of stimulus.
- A receives moderate light. A's excitation stimulates next neuron on visual chain, cell D, which transmits message toward brain.
- Transmission impeded by cell B, whose intense excitation inhibits cell D. Cell D fires at reduced rate.
- Intensity of cell $c_j = I(c_j)$ is function of c_j's excitation $e(c_j)$ inhibited by its neighbors with attenuation coefficients a_k that decrease with distance. Thus,

$$I(c_j) = e(c_j) - \sum_{k \neq j} \alpha_k e(c_k)$$

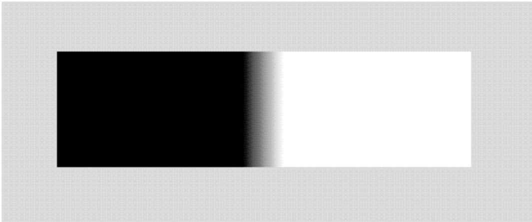
- At boundary more excited cells inhibit their less excited neighbors even more and vice versa. Thus, at boundary dark areas even darker than interior dark ones, light areas are lighter than interior light ones.
- Nature's edge detection

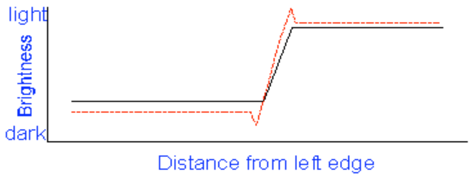


Lateral inhibition

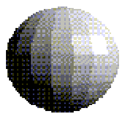


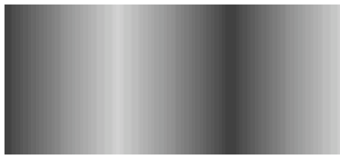
- The light striking rods and cones in the retina is not summed uniformly:
  - The nerves that combine the signals from the rods or cones sum with a center/surround opponency.
  - This results in Mach-bending



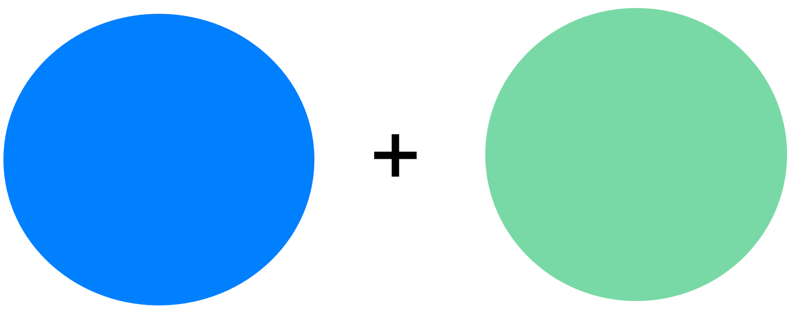


- **Mach-bends**: Perceptual artifacts caused by the eye's lateral inhibition which appear at any discontinuity or drastic change in the rate of shading.
  - When one receptor responds to a high intensity, it inhibits its neighboring receptors' responses.
  - Receptors on the bright side of a discontinuity receive less inhibition from the dark side.
  - Receptors on the dark side of a discontinuity receive more inhibition from the light side.
- ➢ Imaginary dark and light lines appear at facet boundaries. Flat shading of more facets does not necessarily look smoother.





Color afterimage example



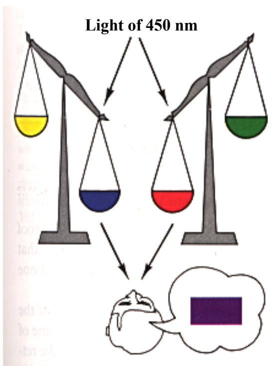
Stare at the plus sign for about 30 seconds (as you do this you probably will see some colors around the blue and green circles).

Color afterimage example

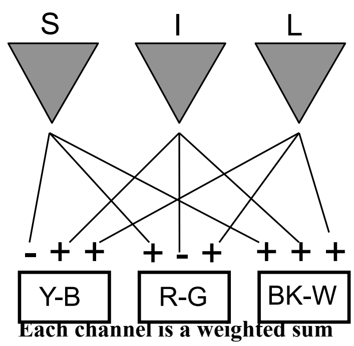
You probably saw a yellow and desaturated reddish circle.

Hering's chromatic opponent channels

- Additional neural processing
  - three receptor elements have excitatory and inhibitory connections with neurons higher up that correspond to opponent processes
  - one pole activated by excitation, other by inhibition
- All colors can be described in terms of 4 "psychological color primaries" R, G, B, and Y
- However, a color is never reddish-greenish or bluish-yellowish: idea of two "antagonistic" opponent color channels, red-green and yellow-blue
- The blue/yellow and red/green pairs are called complementary colors. Mixing the proper shades of them in the proper amounts produces white light.



Hue: Blue + Red = Violet



Each channel is a weighted sum of receptor outputs – linear mapping

Vision: Beyond the Eye

- Beyond the eye, visual signals move through different processing stages in the brain.
- There seem to be two main pathways
  - *Magnocellular*: low-resolution, motion sensitive, and primarily achromatic pathway
  - *Parvocellular*: high-resolution, static, and primarily chromatic pathway
- Color vision is processed in three dimensions.
  Perceptual terms: *hue, saturation,* and *luminance*
  - *Hue*: In colorimetry: the dominant wavelength of the light entering the eye
  - *Saturation*: In colorimetry: exitation purity, inversely related to the amount of white light in the light entering the eye (e.g. red, fully saturated; pink, not fully saturated)
  - *Luminance*: the intensity of the light entering the eye (e.g. light with a dial)
    - *Lightness*: luminance from a reflecting object. In colorimetry: luminance
    - *Brightness*: luminance from a light source. In colorimetry: luminance
- *Chromaticity*: the hue and saturation of light (not luminance)