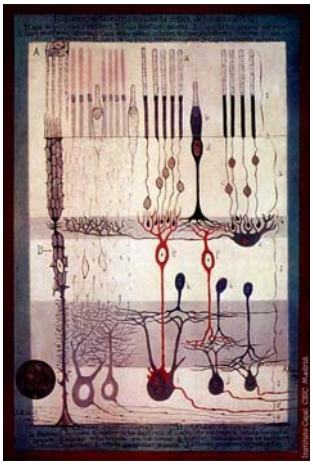
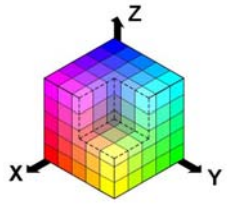
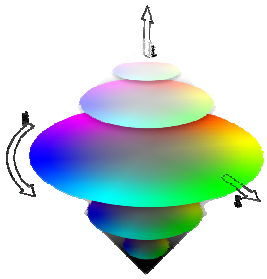
The Human Visual System and Color Models



S. Ramón y Cajal, Structure of the Mammalian Retina, 1900

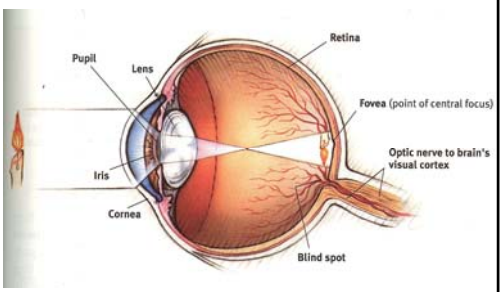




Geog. 581 Satellite Digital Image Analysis
By Dylan Carmody

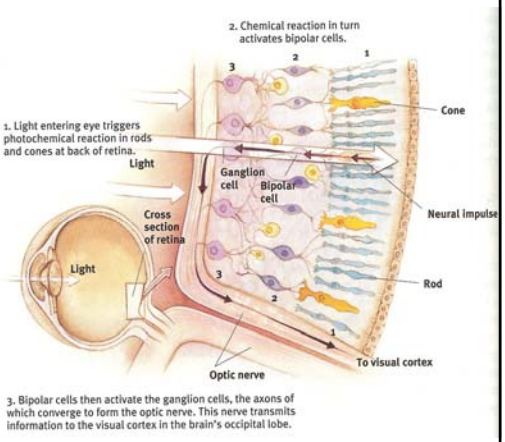
Basics of the Eye

- Light enters the cornea, which protects the more delicate parts of the eye and bends light to help provide focus.
- Light passes through the pupil, which is an adjustable opening.
- The pupil's size is determined by the iris, which expands and contracts depending on how much light needs to be let into the pupil and can also be subject to mood changes.
- The lens then focuses the incoming light rays onto the photosensitive retina in the back of the eye. Due to the shape of the lens the image is reversed and turned upside down.
- The fovea is the central point of focus on the retina.



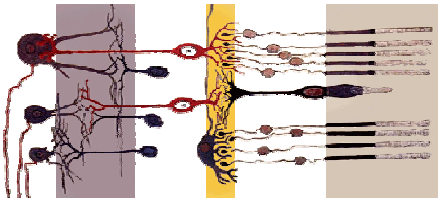
The All-Seeing Retina

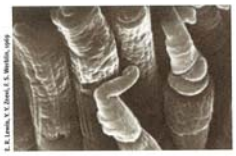
- The retina is also made up of the layers of neurons where the visual processing of images is begun.
- The retina contains the photoreceptive cells that we know as rods and cones.
- The rod and cone cells contain light sensitive chromophores, such as retinal.
- Retinal has different molecular shapes and when light is absorbed by retinal it changes shapes, setting off a sequence of events that eventually lead to the electrical impulses that are sent through the optic nerve to the visual cortex.



Rods

- There are around 100 million rod cells in the retina and they are completely absent from the fovea.
- Rod cells function in low-levels of illumination and are responsible for the monochromatic vision known as scotopic vision, which is how we see at night.
- Rods are highly sensitive to light and can respond to light from a single photon.
- They do not provide any color information, instead providing information on the intensity of the lighting.

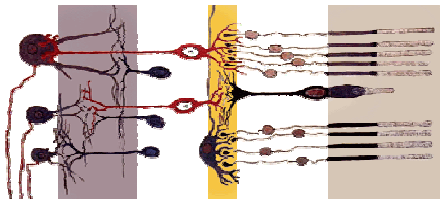




Rod-shaped rods and cone-shaped cones
As the scanning electron microscope shows, rods and cones are well-named. The rods are more sensitive to light than are the color-sensitive cones, which is why the world looks colorless at night.

Cones

- There are about 5 million cone cells in the retina and they are primarily located in the fovea.
- Cones give us the ability to distinguish color (photopic vision), saturation, and to a lesser extent intensity of light.
- Cone cells require tens to hundreds of photons to become activated.
- Cones allow for finer detail and more rapid images to be seen than rods because their repsonse times to stimuli are much faster than for rod cells.
- The number of “blue”-sensitive cones is much less than the other two types.



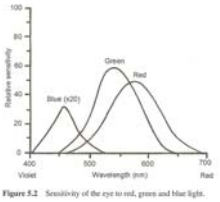
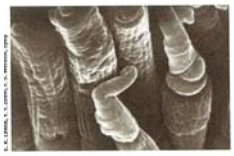


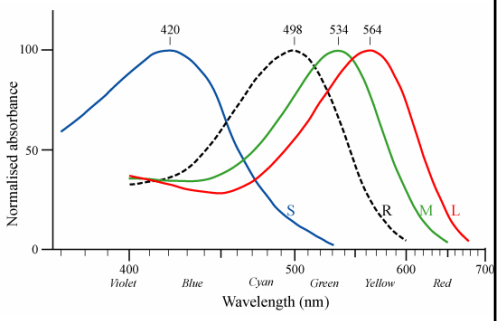
Figure 5.2 Sensitivity of the eye to red, green and blue light.



Rod-shaped rods and cone-shaped cones
As the scanning electron microscope shows, rods and cones are well-named. The rods are more sensitive to light than are the color-sensitive cones, which is why the world looks colorless at night.

Response Curves of Rods and Cones

- Rod cells are more sensitive to light in the blue wavelengths, peaking at about 498 nm and are completely insensitive to light beyond the 640 nm range.
- Humans generally have three types of cones which have three different response curves (tristimulus theory).
  - The “red” or long-wavelength (L) cones peak response is to light at 564 nm, which is actually yellowish-green light.
  - The “green” or medium-wavelength (M) cones peak response is to light at 534 nm, which is bluish-green light.
  - The “blue” or short-wavelength (S) cones peak response is to light at 420 nm, which is a blue-violet wavelength.
- Color vision is probably due to the ratio of incoming light detected by the three types of cone cells rather than due to the absolute information from each type of cone cell.



Working Together We See Everything

- An achromatic image captures brightness variations in a scene and is formed by using all of the incoming energy of the reflected light that an eye can detect. Spatial detail is very easily discerned.

Black And White Only

- A purely chromatic image contains no information about variations in brightness and only contains data about hue and saturation. Spatial detail is very poor in these pictures.

Color Only

- A normal full color image contains all types of data: brightness, hue, and saturation.

Full Color

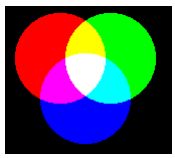
Showdown

Rods vs. Cones

Rods	Cones
Around 100 Million	Around 5 Million
Used for night vision	Used for day vision
Highly sensitive to light; sensitive to scattered light (they have more pigment than cones)	At least 1/10th of the rods' light sensitivity; sensitive only to direct light
Loss causes night blindness	Loss constitute legal blindness
Low spatial resolution with higher noise	High spatial resolution with lower noise
Not present in the fovea	Concentrated in the fovea
Slower response to light; rods need to be exposed to light over time	Quicker response to light; can perceive more rapid changes in stimuli
Stacks of membrane-enclosed disks are unattached to the cell membrane	Disks are attached to the outer membrane
One type of photosensitive pigment (monochromatic stimulus)	Three types of photosensitive pigment in humans (trichromatic stimulus)
Confer achromatic vision, with more emphasis on detecting motion	Confer color vision, with more emphasis on detecting fine details
Have more pigment than cones, so can detect lower light levels	Have less pigment than rods, require more light to detect images

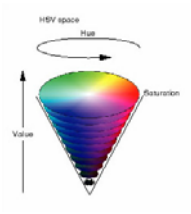
Color Models

- RGB

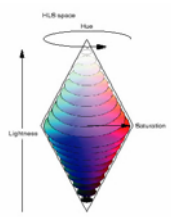


- CMYK

- HSV or HSB

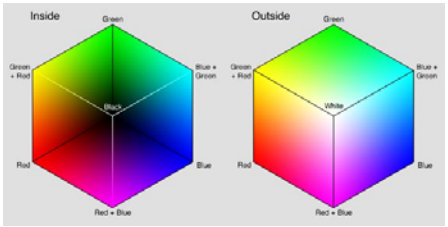


- HSL (HLS) or HSI



RGB
– Red, Green, Blue

- The RGB color model is an additive model. Meaning that when two of the primary colors are added in equal parts they will make one of the secondary colors, i.e. blue and red together make magenta.
- Adding all three colors in equal parts makes a grayscale, no colors makes black and maximum of all three makes white.
- The RGB model is the one that TVs and computer monitors use to display color.
- Computers interpret the RGB cube using 24-bits, 8 for each primary color. 8 bits allows for 256 intensities of each color when multiplied together this gives us 16,777,216 (256^3) colors.



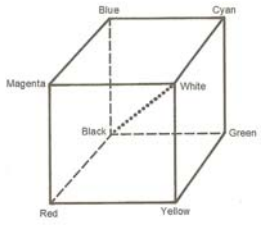
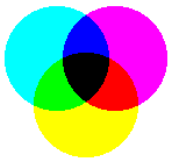


Figure 5.3 Red-green-blue colour cube.

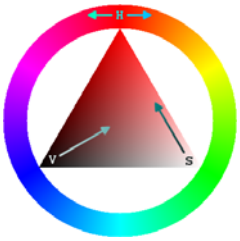
CMY(K)
– Cyan, Magenta, Yellow, (Key (Black))

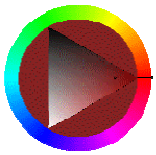
- The CMYK model is a subtractive color model. Meaning that the colors that are seen are from the part of light that is not absorbed.
- Magenta and yellow absorb green and blue, respectively, leaving red to be seen.
- White is the absence of colors whereas black is the presence of all three in equal amounts.
- Black is used in printing because it is cheaper than using the colored pigments and also because it rarely happens that the other pigments are pure enough to produce black when added together.

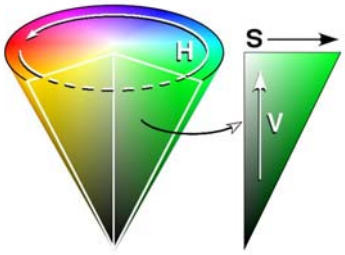


HSV or HSB
– Hue, Saturation, Value or Brightness

- In the HSV color space each color is represented by it's Hue, Saturation, and Value or Brightness.
- Hue is the color type and is represented by an angular position off the center of the circle.
- Saturation also known as purity is the level of grayness present, the less saturated the more gray a color appears. And is shown as the distance from the circles center.
- Value or Brightness is the perception of luminance and is shown as the height along the axis.

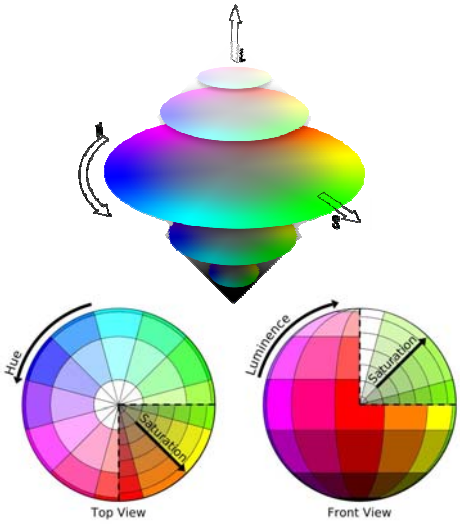




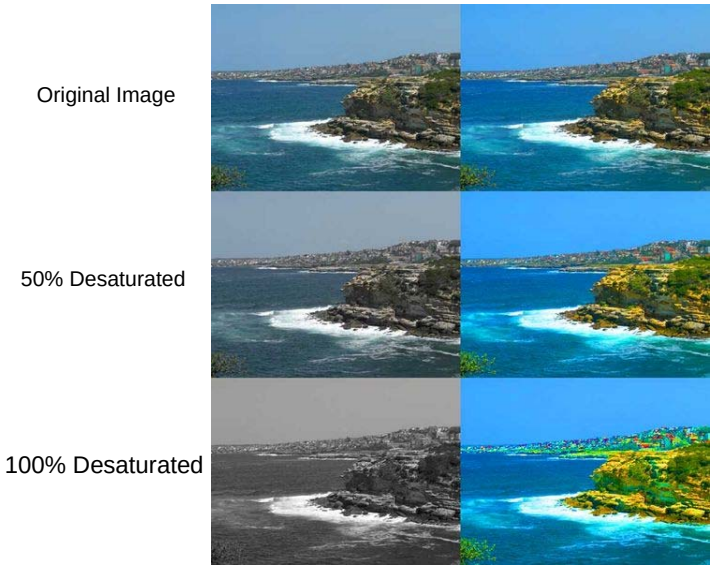


HSL (HLS) or HSI
- Hue, Saturation, Lightness (Luminance) or Intensity

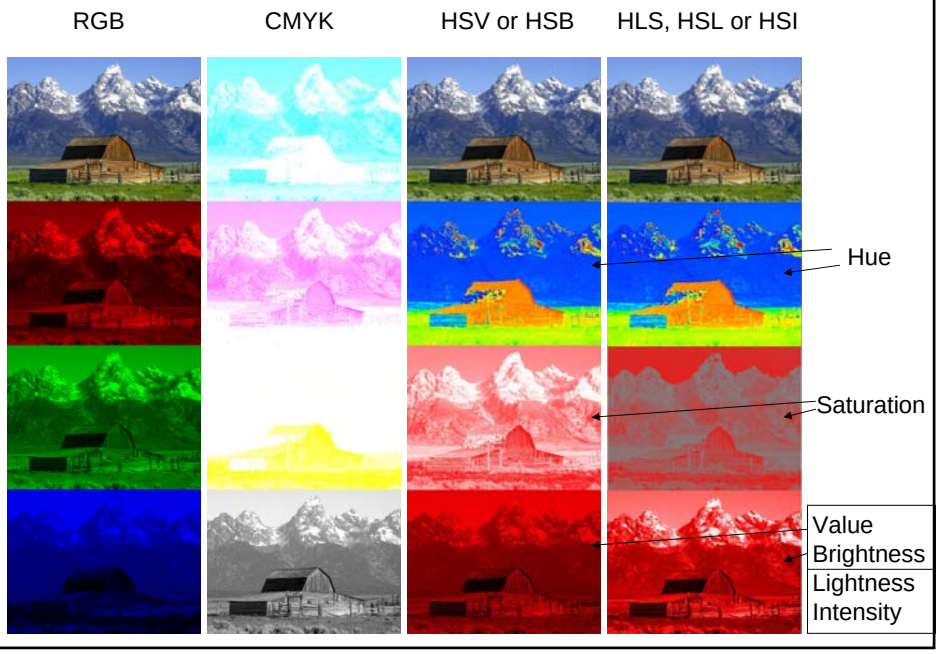
- In the HSL (HLS) or HSI color model each color is represented by it's Hue, Saturation, and Lightness (Luminance) or Intensity.
- HSL is very similar to HSV. The angular parameter corresponds to Hue, distance from the axis corresponds to Saturation, and distance along the black-white axis corresponds to Lightness (Luminance) or Intensity.
- The Saturation in the HSL component always goes from fully saturated color to the equivalent gray (in HSV, with V at maximum, it goes from saturated color to white).
- The Lightness in HSL always spans the entire range from black through the chosen hue to white (in HSV, the V component only goes half that way, from black to the chosen hue).

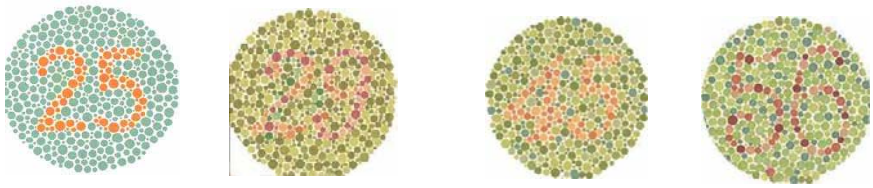


Saturation



A Comparison of Models





The End