LIGHT AND COLOR, Fall 2008

Color: Chapter 9

1. Subtractive processes

a) *Filters*: colored objects that absorb (*subtract*) some colors & transmit others.

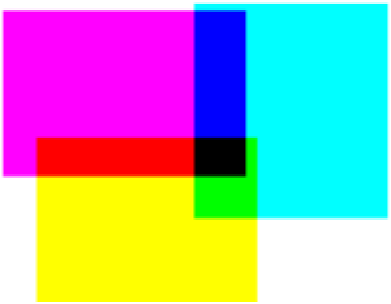
Concepts of transmission and subtraction: MISCONCEPTION that filter adds color to white light.

Filter subtracts light.

Where does subtracted light go? It is absorbed in the filter.

b) Color mixing by *subtraction*

Results of magenta, yellow and cyan *filters* overlapping.



c) *Transmittance* curves.

A transmittance curve is a property of a filter. Different for each filter.

Shows fraction of incident light transmitted at each wavelength when you send broadband light through the filter. Rest is absorbed.

Subtractive mixing of filters requires knowledge of the transmission curves of the filters. Simplest case is ideal filters.

d) Ideal filters

Transmits either all or nothing at each wavelength

Figure 9.14

e) Simple subtractive rules

Any two RGB filters subtractively mix to black, because they let through mutually exclusive wavelengths.

Yellow, magenta and cyan are the subtractive primaries

The yellow filter subtracts blue from white light, etc.: Y = W - B, M = W - G, C = W - R.

Hence, Y + M = R, Y + C = G, M + C = B.

Practical example of stage lighting. Need red filter for spotlight but only have greens, blues, cyans, yellows and magenta

f) Color of *everyday reflected object* depends on at least TWO factors:

Reflection properties of the object and intensity distribution of incident light.

A rose *only reflects* red wavelengths. When the rose is illuminated by incident white light comprised of a mixture of red, green and blue it appears red because it *absorbs* the green and blue wavelengths rather than *reflecting* them. This is a subtractive process

g) *Reflectance* curves

Colored objects reflect some wavelengths more or less than others.

Reflectance curve tells us something about the reflection *properties* of a single-colored *object*, such as a shirt or folder or of a single-colored region of a picture

The reflectance curve gives shows the percentage of light at each wavelength reflected from the object or region. The reflectance curve *doesn't tell us anything* about the illuminating source of light. The colors that are subtracted are at the low portions of the reflectance curve.

These colors are absorbed by the colored object.

h) *Rules* for finding the effect of different light sources on a colored object such as a folder, shirt or a region of a picture

How to pick the color of your tie, dress, kitchen, etc. *by looking at it under the right light*

You need to know the *color* of the light (it's *intensity-distribution curve*) AND

You need to know the *subtractive* properties of the object (it's *reflectance* curve)

You can then find the *color* of the reflected light (intensity-distribution curve)

This is the color that the object appears to have in that light.

To find that color- Multiply the source's *intensity distribution curve* by the objects *reflectance curve*:

How to multiply curves (Both curves should be zero to one on the y-axis for simplicity).

Multiply each pair of y-values to get the new y at each x.

[Intensity-distribution curve of incident light] x [reflectance curve of object] = [intensity distribution curve of reflected light].

i) Practical consequences.

Yellowish appearance of a photo of a living room taken indoors using incandescent (yellowish) light instead of a flash. Note the psychological adjustment we make when we are viewing the same living room in that indoors yellowish light. The colors of the living room seem normal in spite of the yellowish light -- we adjust to the different light source. This is *color constancy*.

However when we view the photo in daylight we can make comparisons of the color in the picture with other colors outdoors and we notice the yellowish appearance of the photo

Don't expect clothes bought in store with fluorescent light to have same color outdoors. (Figs. 9.18, 9.19)

2. Color temperature of a light source.

a) Various white light sources can be characterized by the temperature of a black body needed to match the light source (e.g., incandescent bulb). This is called the color temperature and can be located as a specific color on the CIE Chromaticity diagram.

See Figure 9.21 hotter temperatures mean cooler colors.

Used in commercial photography to characterize light sources. Cannot just make the light dimmer because the color changes.

3. Water colors- the artist's filters

a) Water colors act like filters

The light goes through the wash once on the way to the paper and once on the way back.

Color is *subtracted* each way.

Mixing two watercolors under these conditions is a subtractive process.

b) Rules for determining the apparent color of a region of water color.

If light source is broad-band white and paper is broadband white, the color is determined by the *transmittance curve* of the wash acting twice (multiply the curve by itself).

This is just like finding the color of white light passed through a pair of identical filters.

If the light source is broad-band white but the paper below the water-color is colored, the apparent color will be different.

Multiply the *transmittance curve* of the water color by the *reflectance curve* of the paper and then by the *tranmittance curve* again to get the apparent color.

4. Printer's specification of color

a) Cyan, magenta and yellow (CMY) are called the *subtractive* primaries.

A large number of color sensations (but not all) can be formed by subtractive mixing of cyan, magenta and yellow inks (or filters).

b) Printers preparation of colored pictures for publications.

Printers inks reflect a bit of incident light from the top surface (more than from water colors).

Fig. 9.22 shows a ray of this top-reflected light entering the eye

Fig. 9.22 also shows a different ray – corresponding to the transmitted and bottom-reflected light which ALSO enter the eye

The top-reflected ray *mixes* with the transmitted and bottom-reflected ray. This mixing is additive, so the entire process is both subtractive and additive.

The overall process, however, is mainly subtractive, due to the transmission of light throught ink.

c) Printers use subtractive primaries plus black

Printer's primary colors are CMY – cyan, magenta and yellow.

Need black because of insufficient subtraction of the three subtractive primaries overlapping. (*Four-color* process)

Four plates are used to print a color picture, one for the cyan, one for the magenta, one for the yellow, and one for the black.

The colored images from these plates are superimposed to get the final picture.

5. Media colors and methods - how many colors can be used?

a) Fig. 9.23- the *gamut* of media colors

Printer's colors have the narrowest range.

TV colors are next.

Color slides are best, but there are still many colors from the chromaticity diagram which are not reproduced.

6. Halftones

Need to produce light, less saturated colors

Cannot dilute inks because would need a plate for each desaturated color ink. Instead, less ink is put down on a given area as in Fig. 9.24.

Smaller dots produce lighter, less saturated color due to *partitive* (additive) mixing.

Larger dots produce more saturated color.

Half-tones superimposed cause both subtractive and additive (partitive) mixing, depending on whether the dots are overlapping or next to each other.

Color Processing: Chapter 10

1. Trichromacy of color vision

a) One kind of cone or one kind of rod alone cannot produce color vision

b) Normal person has 3 different types of cones in retina.

S-cones which respond mainly to short wavelength light (bluish hues).

I-cones, which respond mainly to intermediate wavelength light (greenish hues).

L-cones, which respond mainly to long wavelength light (reddish hues).

c) Response curves are different for each type of cone (Fig. 10.5)

For each cone, a different broad *resonance* curve describes the *response*, or amount of light absorbed by that cone at different wavelengths.

Note that at virtually every wavelength the eye's response to a spectral light generally involves *more* than one type of cone.

Our perception of any "color" is based on the relative responses of *all three kinds of cones*

2. Opponent processing

a) Psychological primaries

All hues can be verbally described in terms of combinations of 4 *psychological primaries*:

Blue (used to describe "unique" 475 nm spectral blue)

Green (used to describe "unique" 500 nm spectral green)

Yellow (describes "unique" 580 nm spectral yellow)

Red (there is no spectral color corresponding the psychological primary red – it is more like magenta)

These are NOT the additive primaries NOR the subtractive primaries.

All other hues on the chromaticity diagram (*spectral and nonspectral*) can be described perceptually ("named") in terms of only *two psychological primaries*

Orange is yellowish red

Purple is reddish blue

Cyan is greenish blue, etc

b) Opponent processing of psychological primaries

Our naming of colors suggests *opposition* between psychological primaries yellow and blue and between red and green in perceiving colors.

Neural connections of three types of close-by cones to nerve cells can explain *opponent processing*.

Each of the three different cones (S, I and L) is thought to be connected to each of three different nerve cells in the retina in a different way. (Fig. 10.11)

The ambient signal of a "y-b nerve cell" is enhanced by light on I and/or L cones, but inhibited by light on S cones

This is called *yellow-blue chromatic channel* when talking about the process independently of the nerve-cell interpretation. If the net result is an enhanced signal from the nerve cell to the brain the light is interpreted as yellowish. If the net result is a decreased signal from the nerve cell to the brain the light is interpreted as bluish

The ambient signal of an "r-g" nerve cell is enhanced by light on S and/or L cones but inhibited by light on I cones. This is called a *red-green chromatic channel*

If the net result is an enhanced signal from the nerve cell to the brain the light is interpreted as redish. If the net result is a decreased signal from the nerve cell to the brain then the light is interpreted as greenish

A third nerve cell, the "w-bk" nerve cell is excited when light falls on any of the three different cones This is called the *white-black channel* It relays lightness information to the brain via the mechanisms of lateral inhibition discussed in Chapter 7

c) The response of the *chromatic channels* can be understood in terms of *sectors* on a *chromaticity diagram* (Fig. 10.12)

Two crossed lines on the chromaticity diagram divide it into 4 sectors which correspond to the activity in the *chromatic channels*

They cross at *white* where there is as much blue response as yellow and as much green as red (think of unique red as magenta, which is complementary to green)

The line labeled y-b connects the psychological primary yellow (580 nm) to the psychological primary blue (475 nm)

The line labeled r-g connects the psychological primary green (500 nm) to the psychological primary "red" (not a wavelength color)

For related reasons the r-g line divides yellowish colors (above it) from bluish colors (below it) – see book

3. Color deficiencies people can have

a) *Monochromacy* (only one type of color receptor)

b) *Dichromacy* (deficiency in which only two spectral colors are sufficient for a person to match any color)

Protanopia: (can be explained by L-cones lacking). This is a form of red-green color blindedness – bluish-green, red and grey all look the same

Deuteranopia (can be explained by I-cones lacking). Hence, this is also a form of red-green color blindednes – green, bluish-red and grey all look the same

Tritanopia (can be explained by S-cones lacking). Hence, this is a form of yellow-blue color blindedness

Tetartanopia (no cones lacking but y-b channel lacking). Also a form of yellow-blue color blindedness

c) *Trichromacy* (three spectral colors needed to match any color)

Three types of cones as well as rods are present and functioning but either

response curves are shifted from normal or connections between one type of cone and pooling nerve cell may be defective.

Protanomaly, *Deuteranomaly* (most common deficiency), *Tritanomaly*, *Neuteranomaly*

4. Spatial processing of color

a) Chromatic lateral inhibition (Figs. 10.16 and 10.17)

Red appears *redder* when viewed right next to green. This is called *simultaneous color contrast*

b) *Simultaneous color contrast* suggests lateral inhibition

Due to spatial opponency of *chromatic channels*. "Lateral" means "on the side," or "next to spatially."

c) *Double-opponent cells* are opponent in terms of both color and spatial location (explain Fig 10.16 and 10.17)

Center-surround configuration of r-g and y-b receptive fields just like for edge processing

However now the center of an r-g receptive field is excited by red and inhibited by green and the surround is inhibited by red and excited by green .

d) *Color constancy* is associated with this chromatic lateral inhibition

Color constancy means that we continue to see the different colors in a scene accurately whether we are viewing the scene by artifical light, daylight or the setting sun (i.e., three somewhat different colored light sources illuminating the same scene)

This is because the chromatic retinal fields don't register any change in the pooling cell neuron signal to the brain if the same color is in the center and the surround.

5. Temporal processing of color

a) *Negative afterimages* make you see the complement of the colors in the image shown to you and then taken away

b) *Positive afterimages* also occur in their original color (at least initially)

Scattering and Polarization: Chapter 13

1. Scattering

a) Rayleigh scattering scatters short wavelength components of light to the side

Reason sky is blue and sunsets are red.

2. Polarization

a) Polarization refers to the direction of the electric forces in the waveform.

These force fields are *always* perpendicular to the ray direction but they can still be in a variety of directions (i.e. lie in different polarization “planes” containing both the ray and the electric force field)

b) *Unpolarized* light its plane of polarization always jumping around

c) Plane *polarized* light has its waveform and electric forces lying in a plane which may be vertical, horizontal or anything in between

d) The electric forces in polarized or unpolarized light may be decomposed into 2 “components” polarized in two perpendicular directions such as vertical and horizontal.

These two components are completely equivalent to the original electric force arrows in the light ray in every way. They are essentially the “shadow” forces of the original force and their “arrow lengths” can vary in time and along the ray just as the original electric forces along the ray can vary in time and along the ray. Hence, unpolarized light traveling in a certain (ray) direction can be broken up into components of light polarized in the vertical plane and the horizontal plane or any other pair of perpendicular planes containing ray and electric fields.

e) Scattered light is polarized in a plane which depends on the viewing angle.

f) Reflected light is polarized in a plane parallel to the surface it is reflected from – especially near the *Brewster* angle.

Hence, sunlightlight reflected off flat snow or water is horizontally polarized – the electric fields lie in the horizontal plane (and are always perpendicular to the ray)

3. Polaroid filters

a) Polaroid filters are composed of long molecules laid out parallel to each other embedded in glass or plastic.

b) They absorb (and hence block) any component of light with its electric force fields parallel to the long molecules and let through any component of light with its electric force fields peprpendicular to the long molecules.

c) A polaroid filter can make the blue sky darker or eliminate glare off a surface if it is rotated so that it blocks the polarization of the scattered or reflected light going through it to a camera.

d) *Unpolarized* light going through a polaroid filter or sunglass will be polarized when it comes out the other side because the filter will absorb the component of the electric field of the unpolarized light which is parallel to the long molecules and let through the other component.

e) Light passing through two (crossed) polaroid filters each of whose long molecules are at right angles to the other will be almost completely blocked.

f) If a third filter is put in between the crossed polaroid filters light will be able to go through the three filters.

To understand this resolve the polarized light which goes through the first filter into components parallel and perpendicular to the second filter and then again for the third filter.

g) Polaroid filters used in viewing 3D color movies let one polarization through for the left eye and the perpendicular polarization through for the right eye in order to supply the different image to each eye necessary for 3D binocular vision.