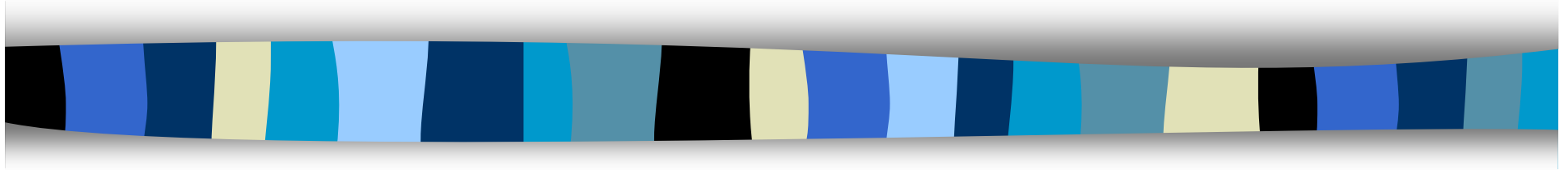


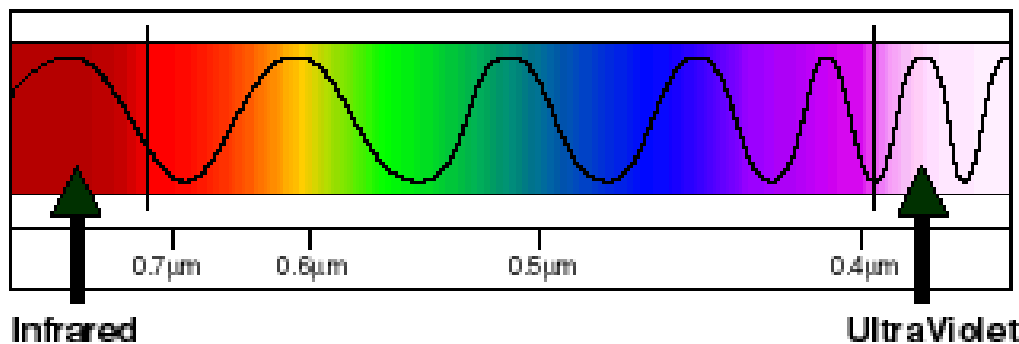
Color and Color Model



Physics of Light

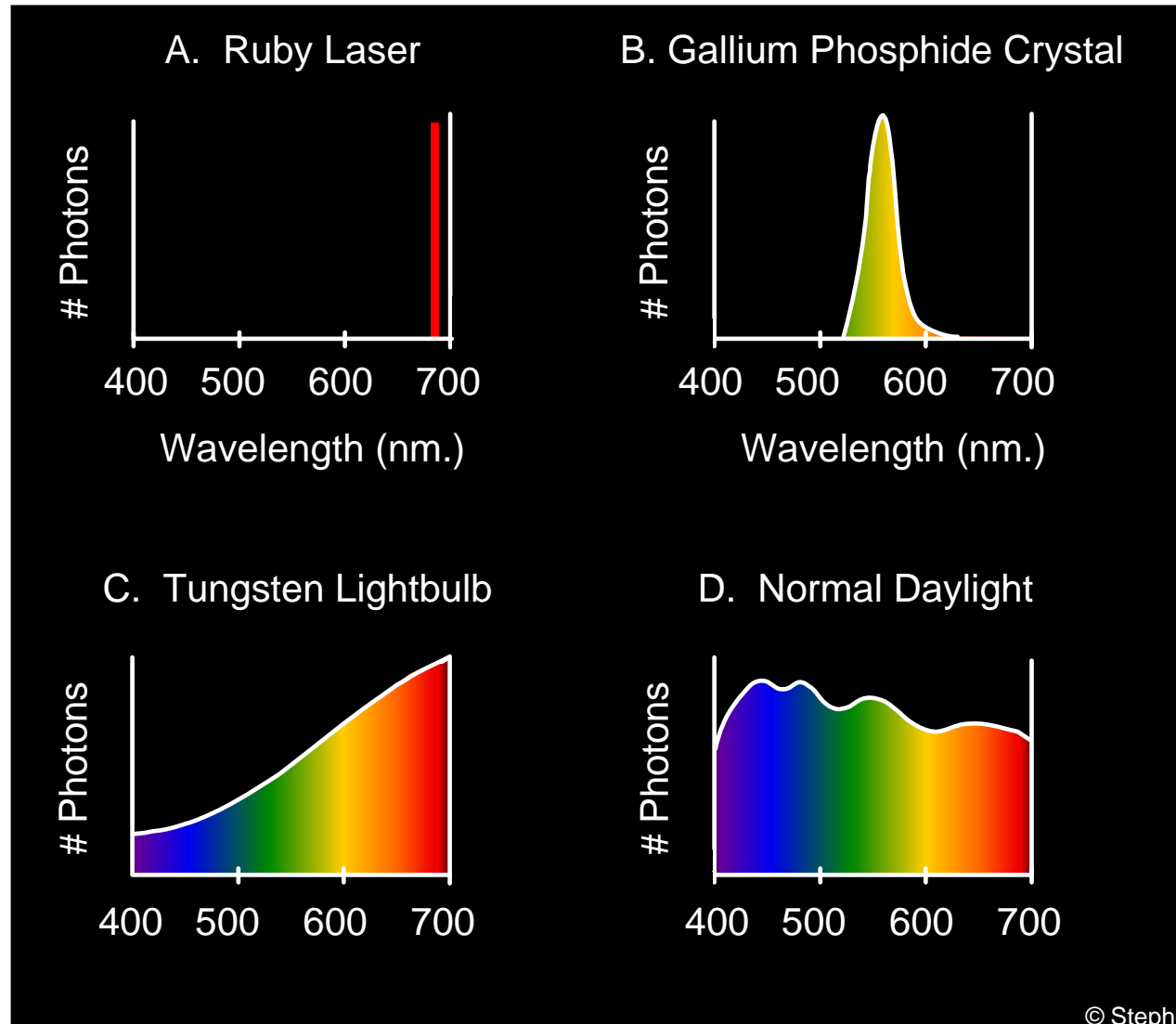
- Electromagnetic spectrum:
red (700nm)-violet (400nm)
- *Dominant wavelength*: color (색상, hue) of the light

Visible Light Region
of the Electromagnetic Spectrum



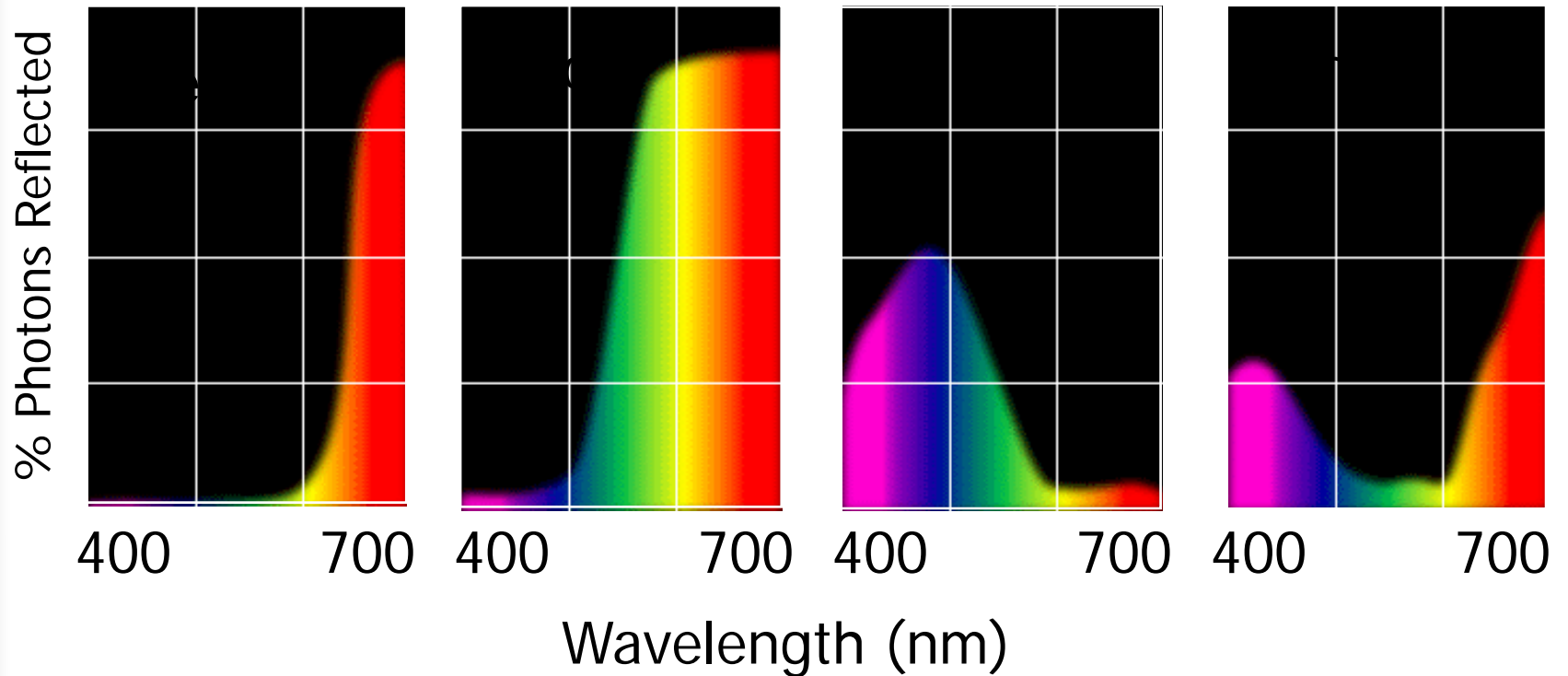
The Physics of Light

Some examples of the spectra of light sources



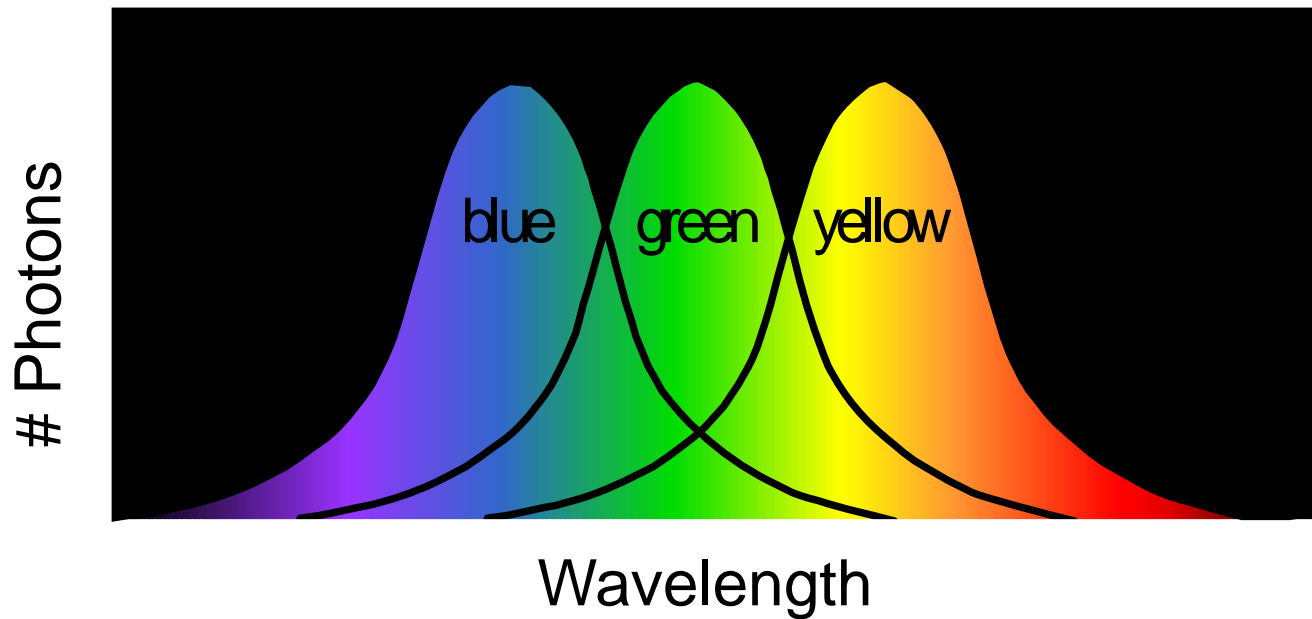
The Physics of Light

Some examples of the reflectance spectra of surfaces



Psychophysical Correspondence

Mean ↔ Hue

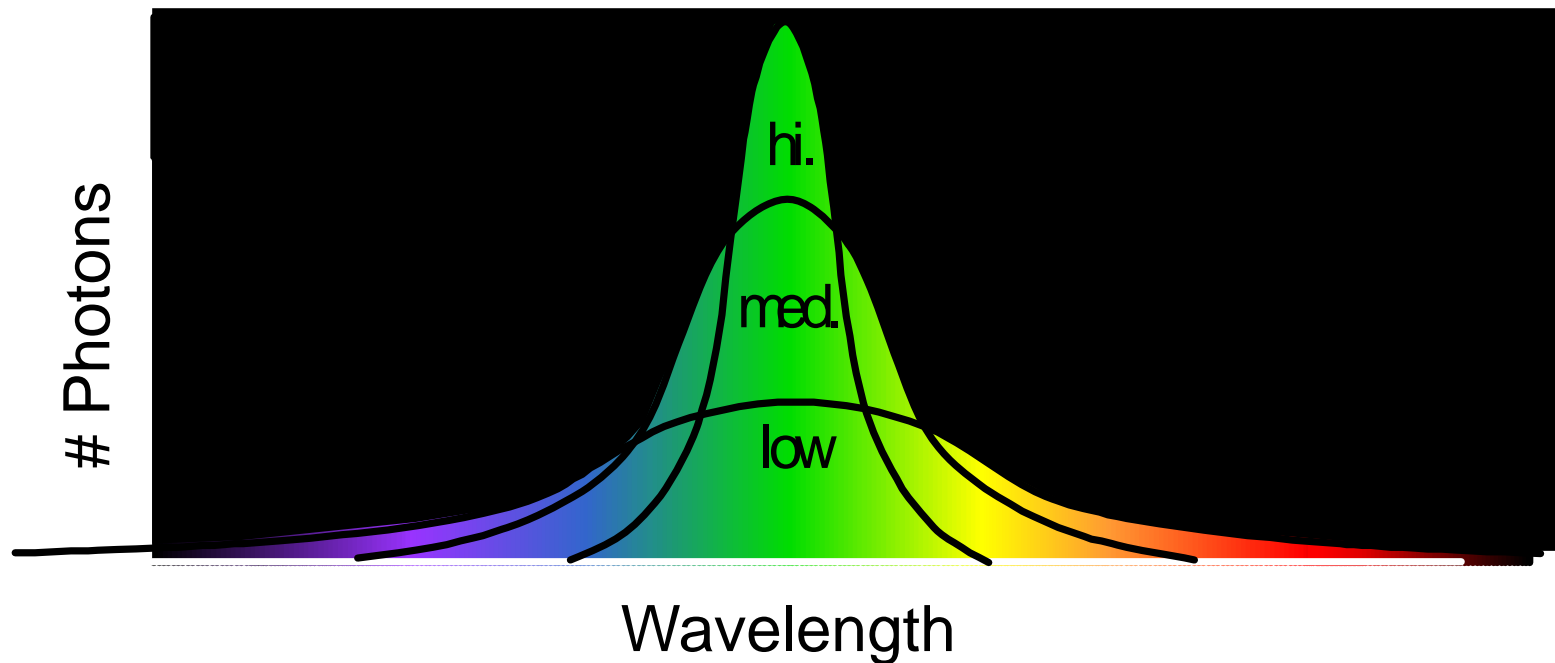


Hue: the perceptual attribute associated with elementary color names.



Psychophysical Correspondence

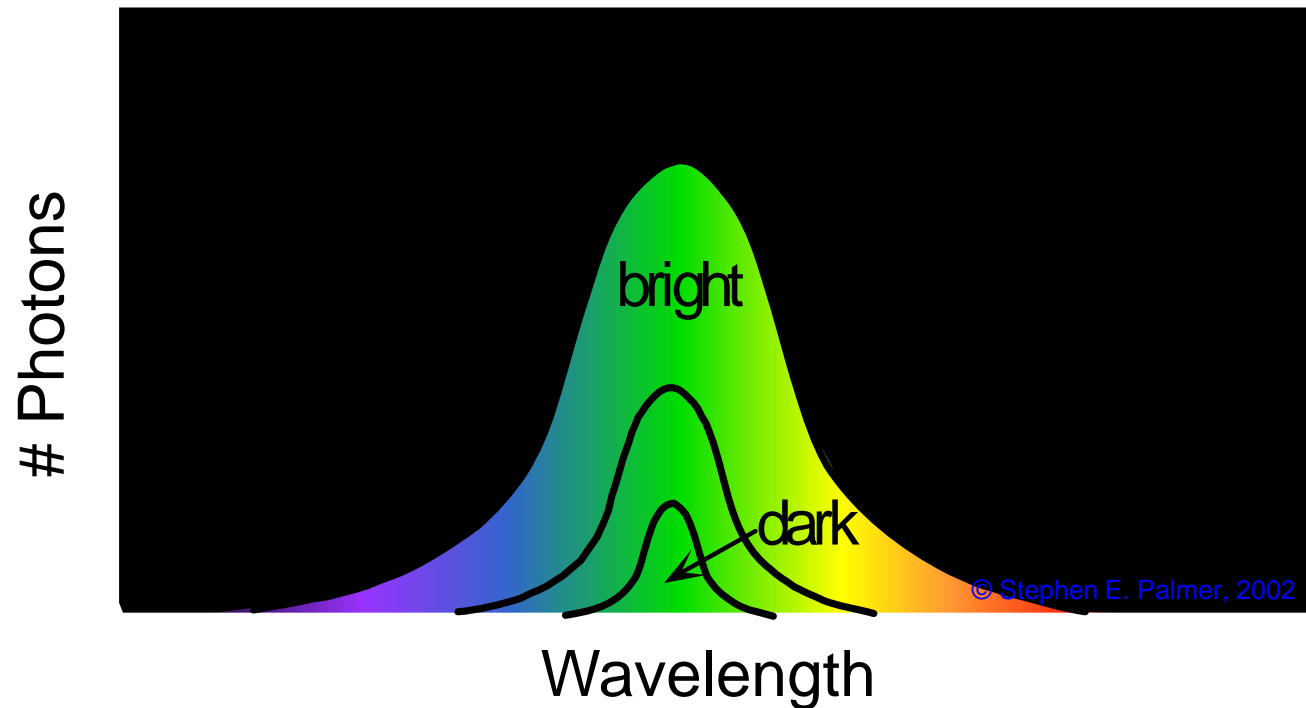
Variance \longleftrightarrow Saturation



Saturation (채도, purity, chroma): how much a color is not mixed with white light.

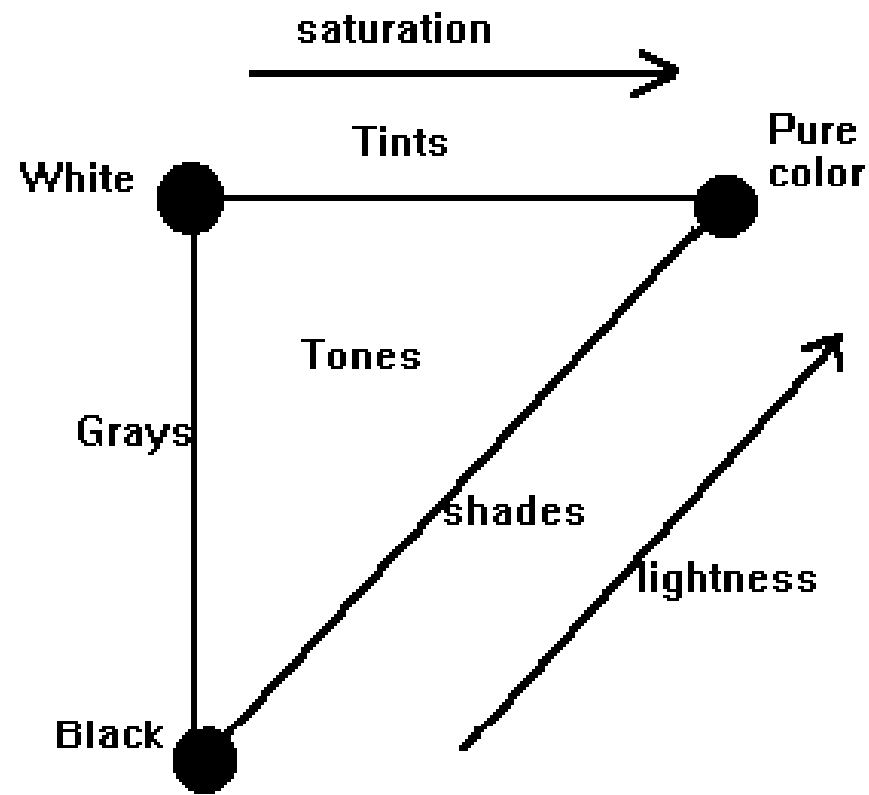
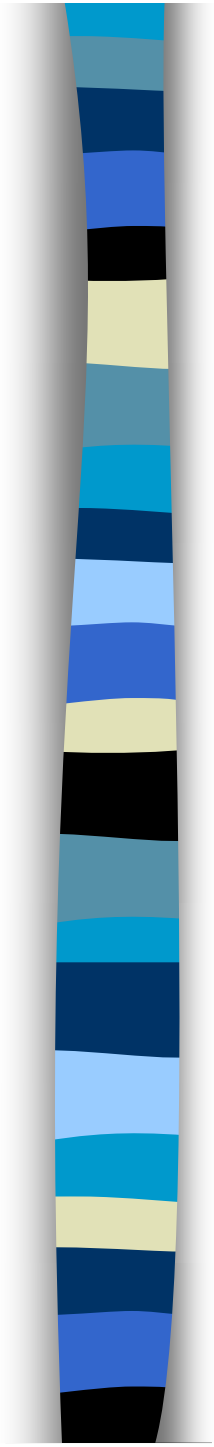
Psychophysical Correspondence

Area ↔ **Brightness**



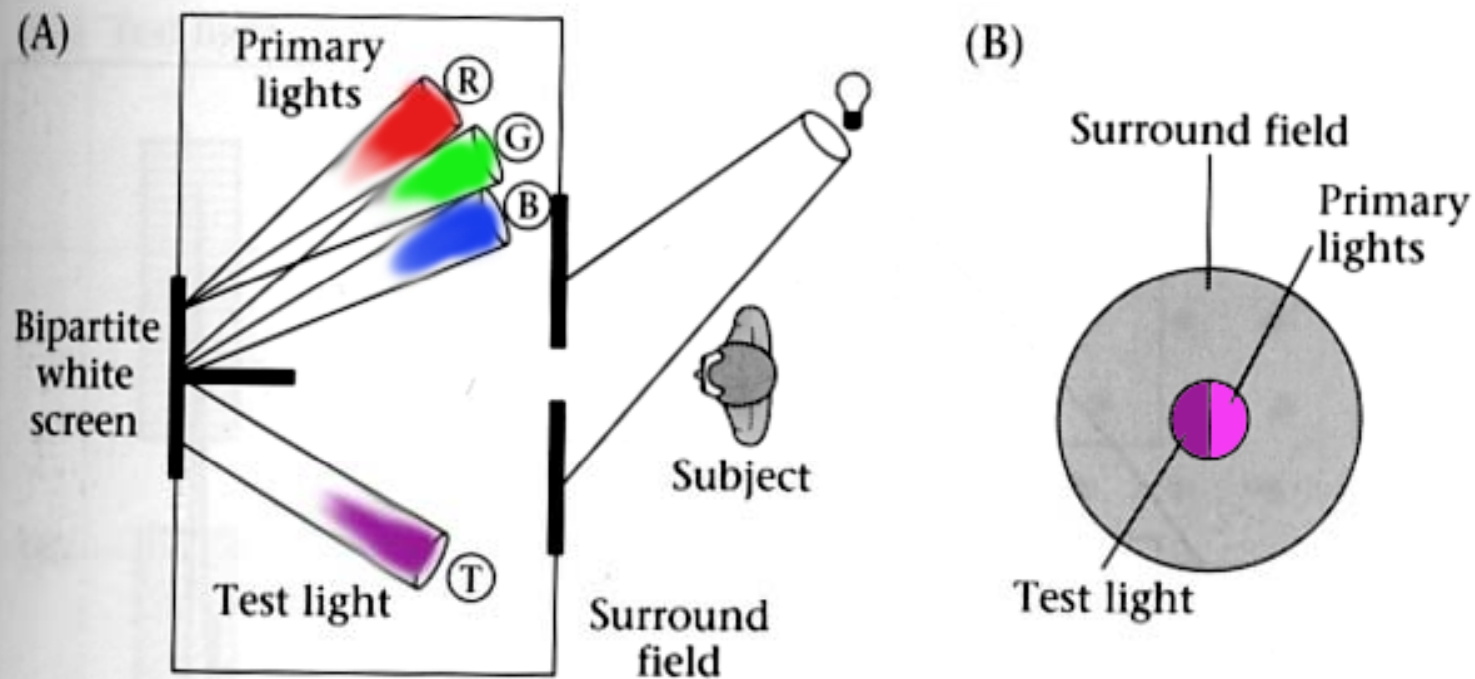
Luminance : the physical measure of *brightness*.
Luminance is the amount of visible *light* leaving a point on a surface in a given direction.

Properties of light



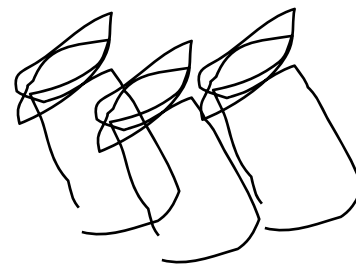
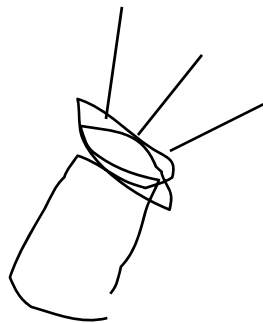
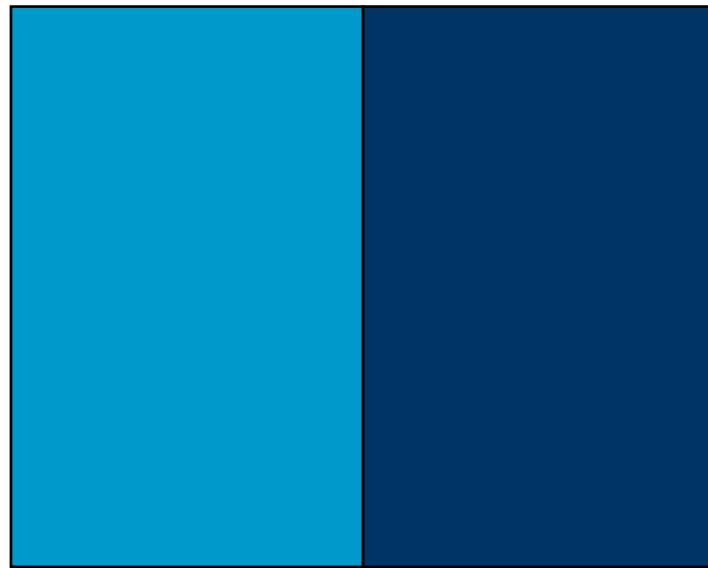
Color Matching

$$Q_\lambda = r(\lambda)R + g(\lambda)G + b(\lambda)B$$

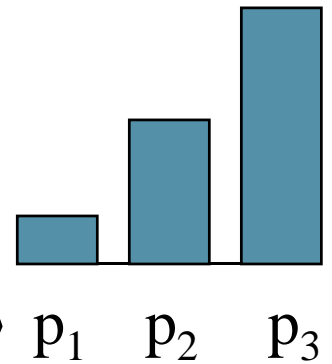
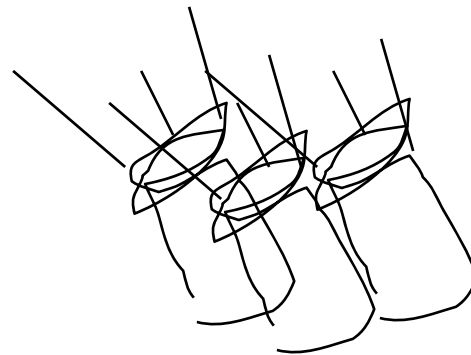
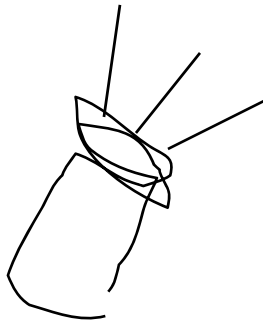
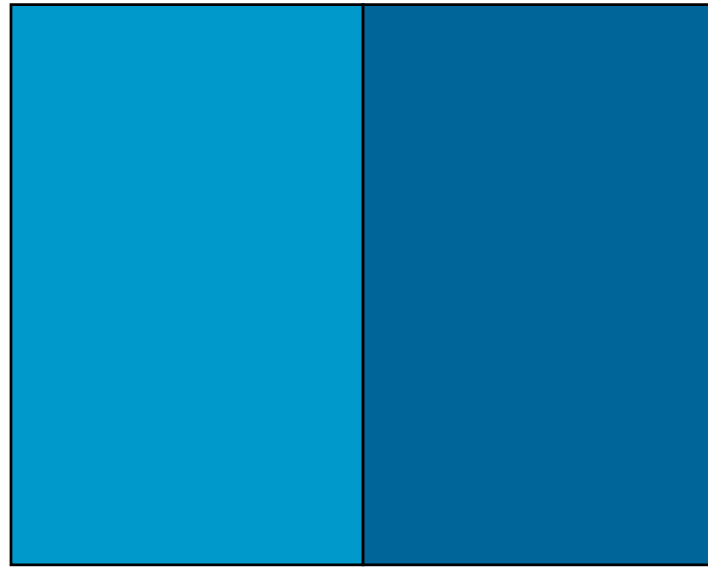


4.10 THE COLOR-MATCHING EXPERIMENT. The observer views a bipartite field and adjusts the intensities of the three primary lights to match the appearance of the test light. (A) A top view of the experimental apparatus. (B) The appearance of the stimuli to the observer. After Judd and Wyszecki, 1975.

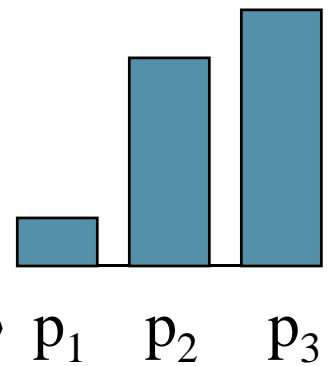
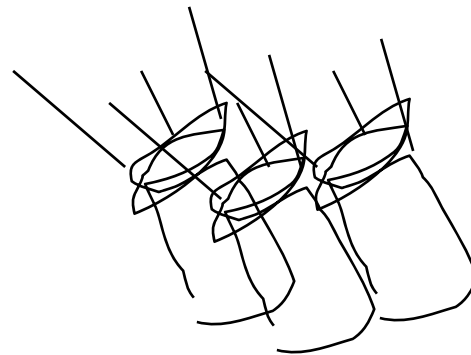
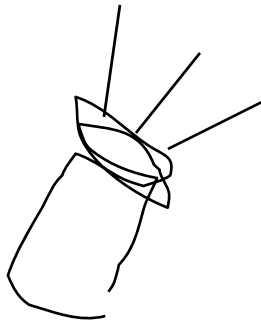
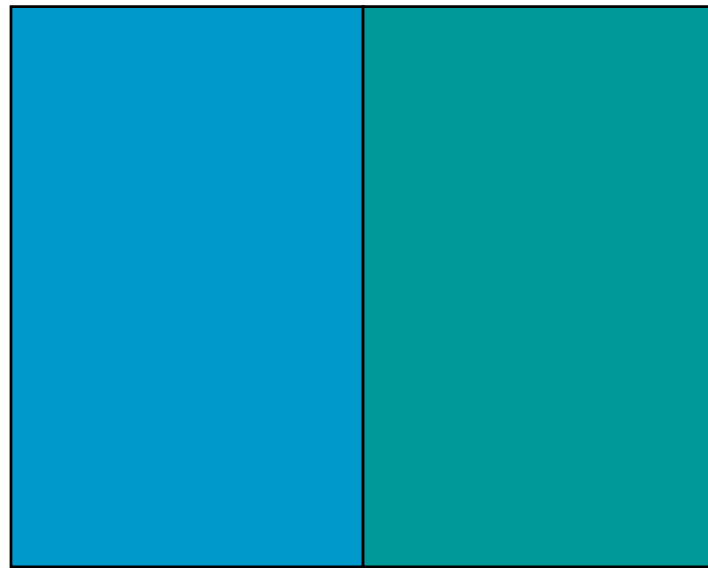
Color matching experiment 1



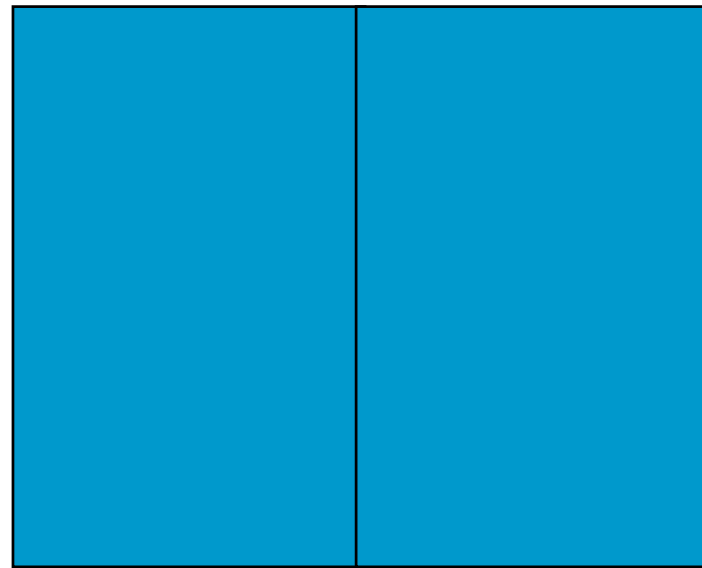
Color matching experiment 1



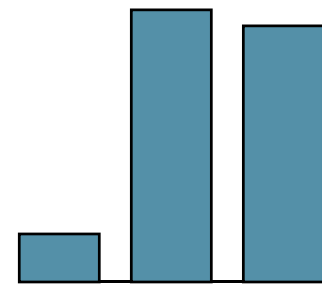
Color matching experiment 1



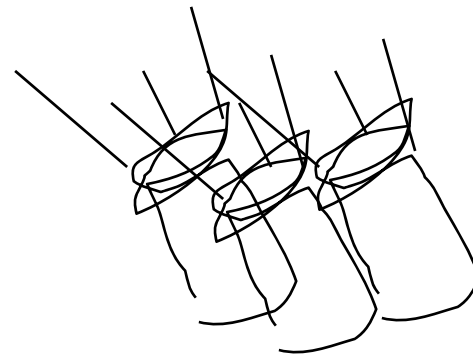
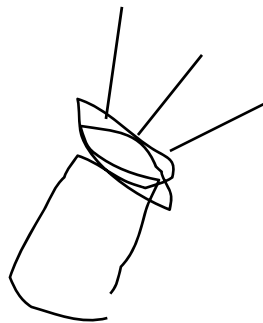
Color matching experiment 1



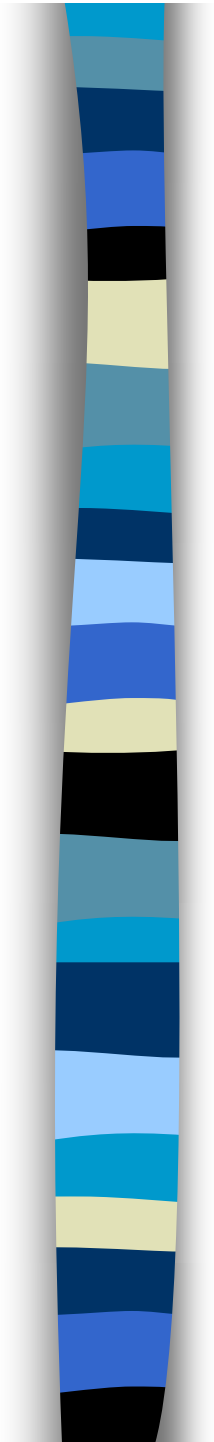
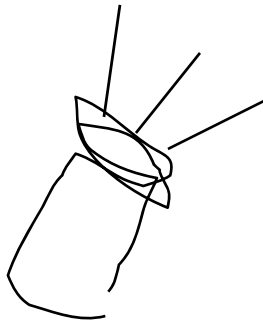
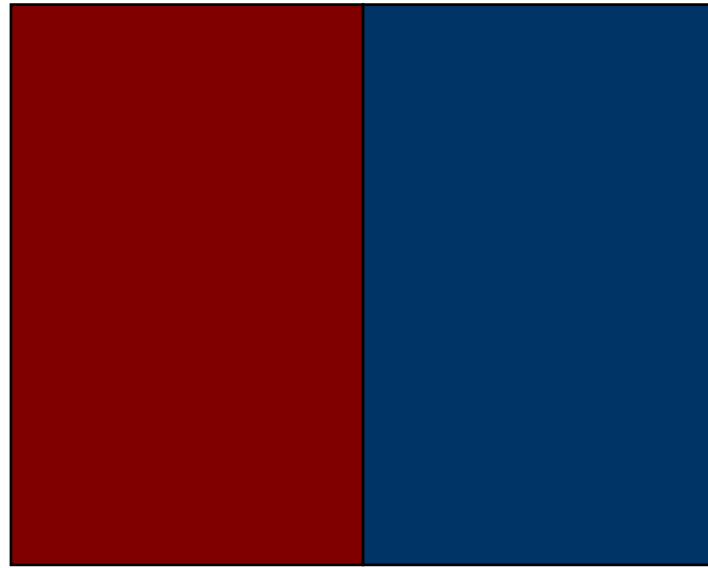
The primary color amounts needed for a match



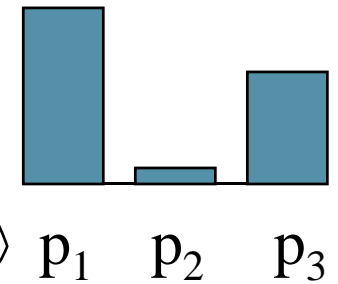
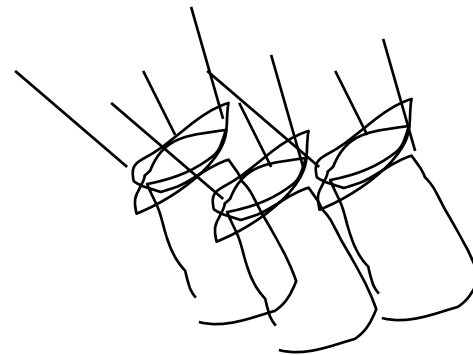
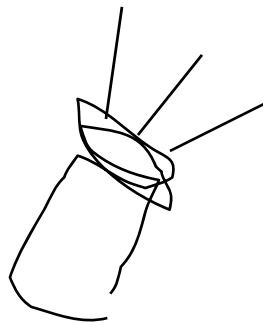
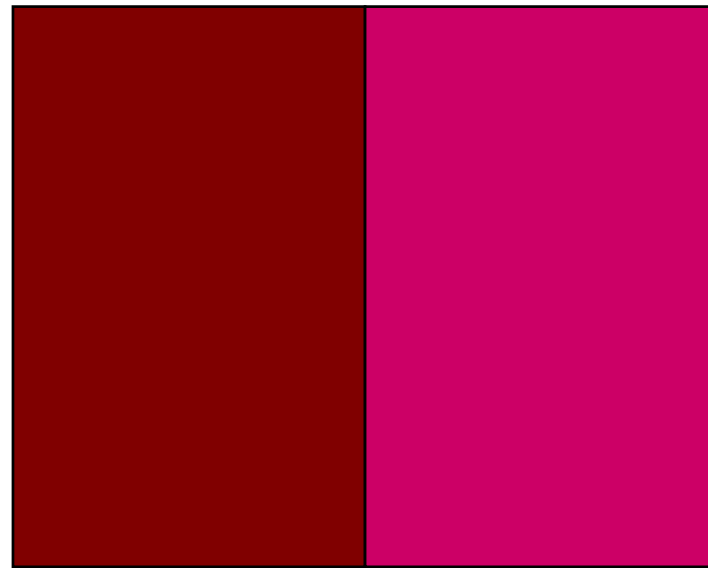
p_1 p_2 p_3



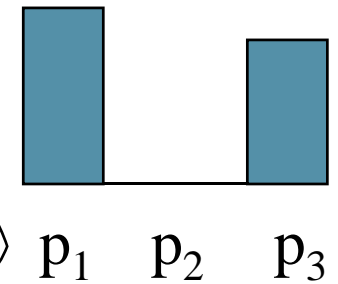
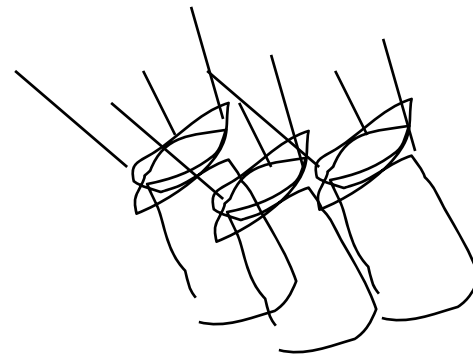
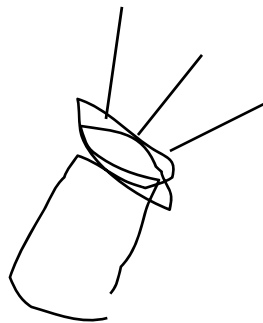
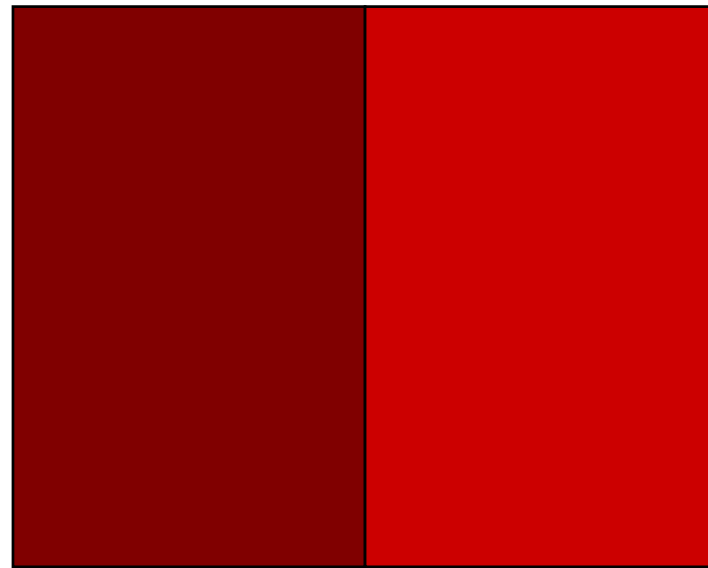
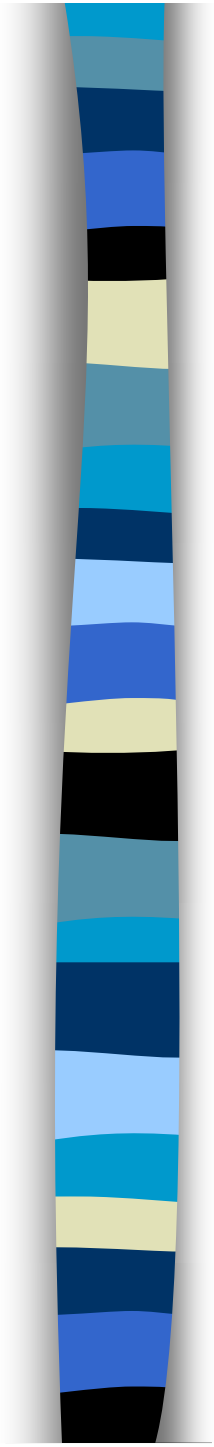
Color matching experiment 2



Color matching experiment 2

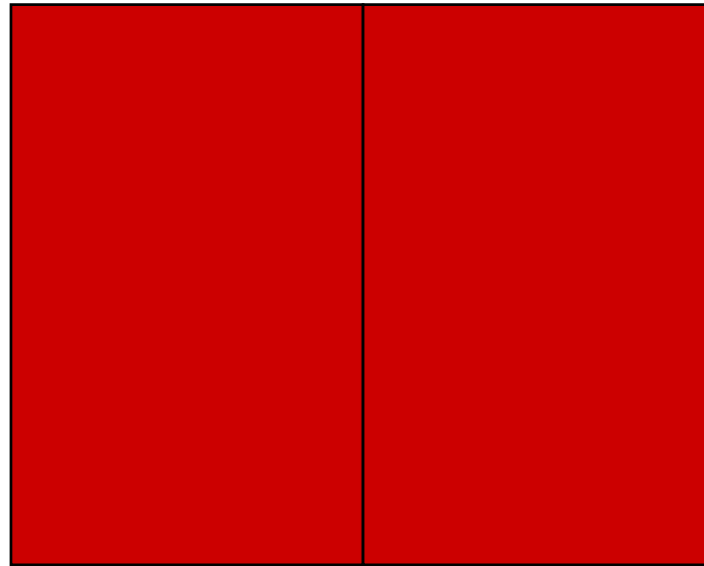


Color matching experiment 2

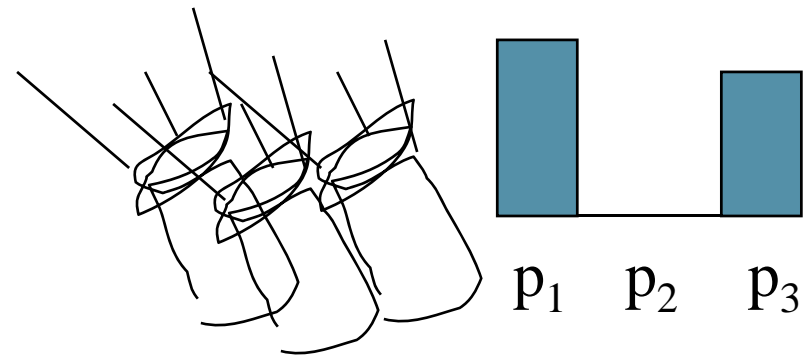
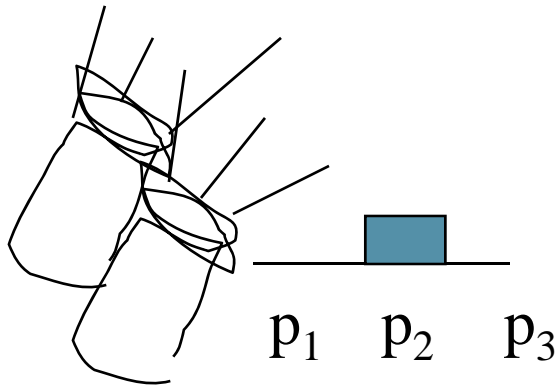
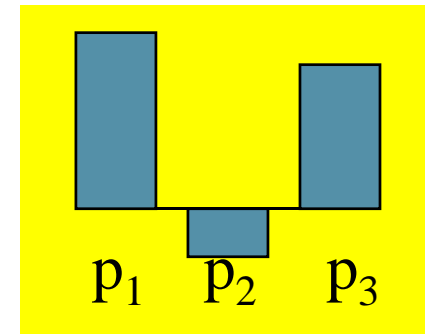


Color matching experiment 2

We say a "negative" amount of p_2 was needed to make the match, because we added it to the test color's side.

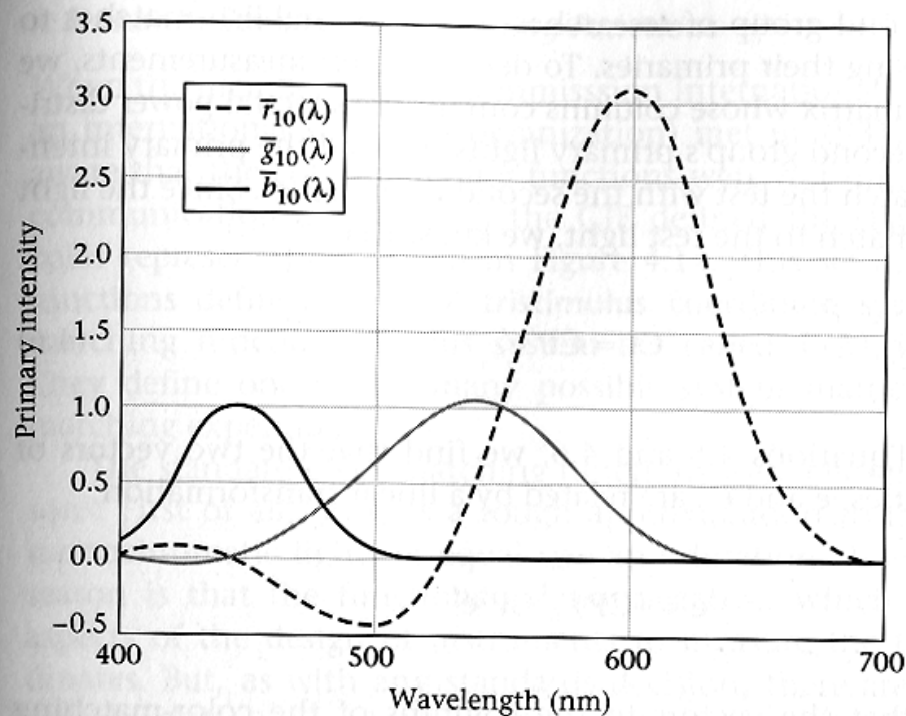


The primary color amounts needed for a match:



CIE XYZ space

- The dominant international standard for color specification (1931, by CIE)
- When we use R,G,B color, we have negative primaries



- $p_1 = 645.2 \text{ nm}$
- $p_2 = 525.3 \text{ nm}$
- $p_3 = 444.4 \text{ nm}$

4.13 THE COLOR-MATCHING FUNCTIONS ARE THE ROWS OF THE COLOR-MATCHING SYSTEM MATRIX. The functions measured by Stiles and Burch (1959) using a 10-degree bipartite field and primary lights at the wavelengths 645.2 nm, 525.3 nm, and 444.4 nm with unit radiant power are shown. The three functions in this figure are called $\bar{r}_{10}(\lambda)$, $\bar{g}_{10}(\lambda)$, and $\bar{b}_{10}(\lambda)$.

test light wavelengths indicating that

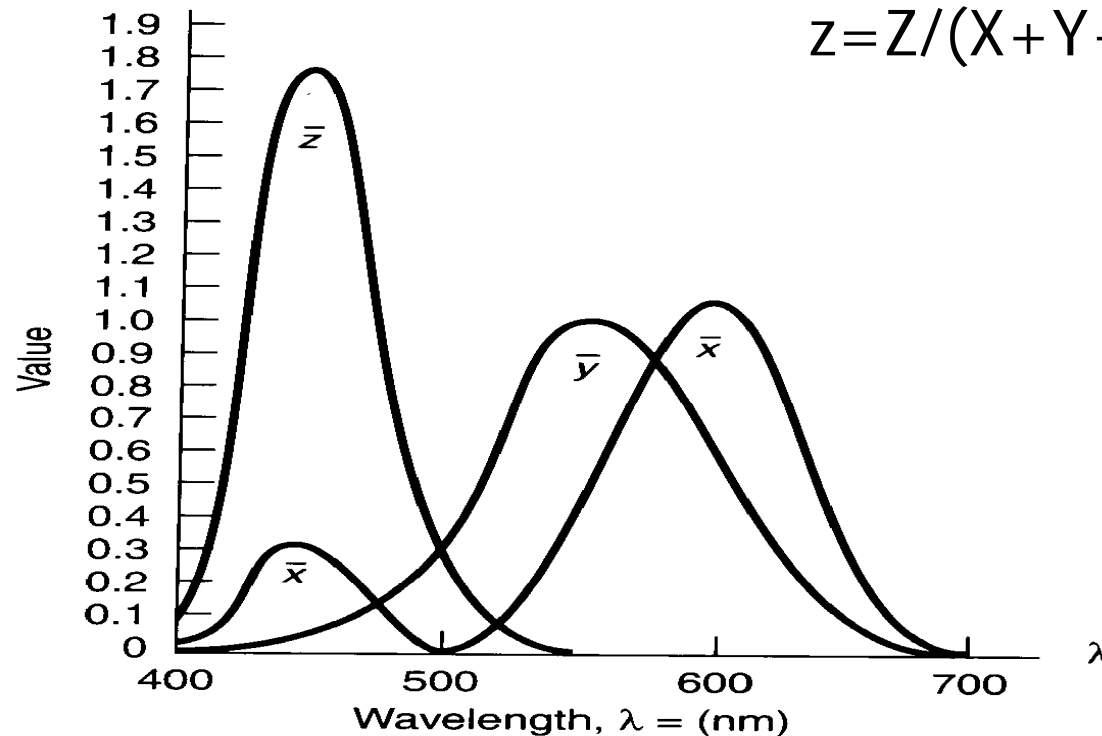
CIE XYZ space

- Color matching functions are positive everywhere, but primaries are “imaginary” (require adding light to the test color’s side in a color matching experiment).

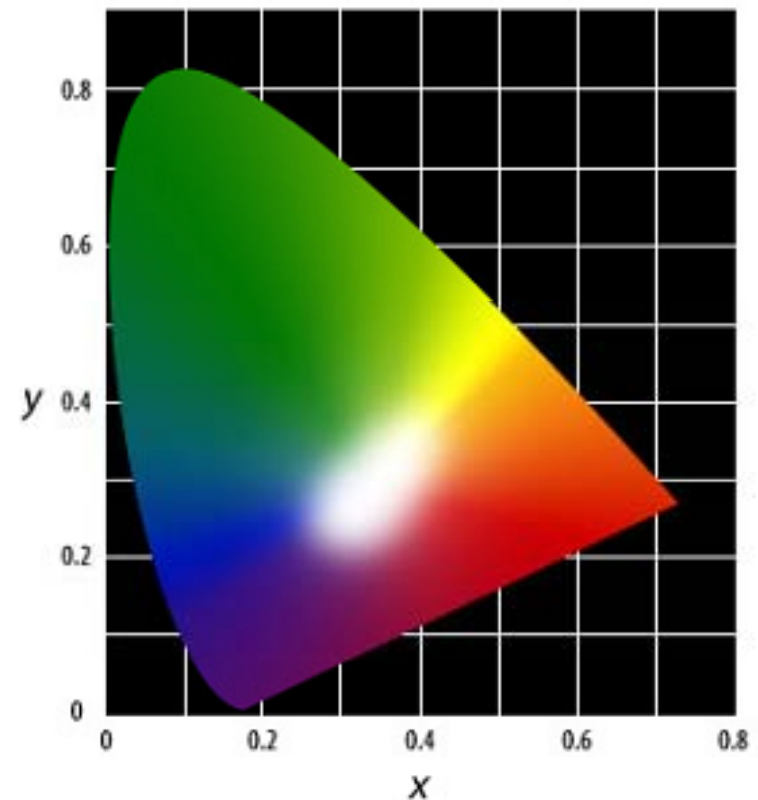
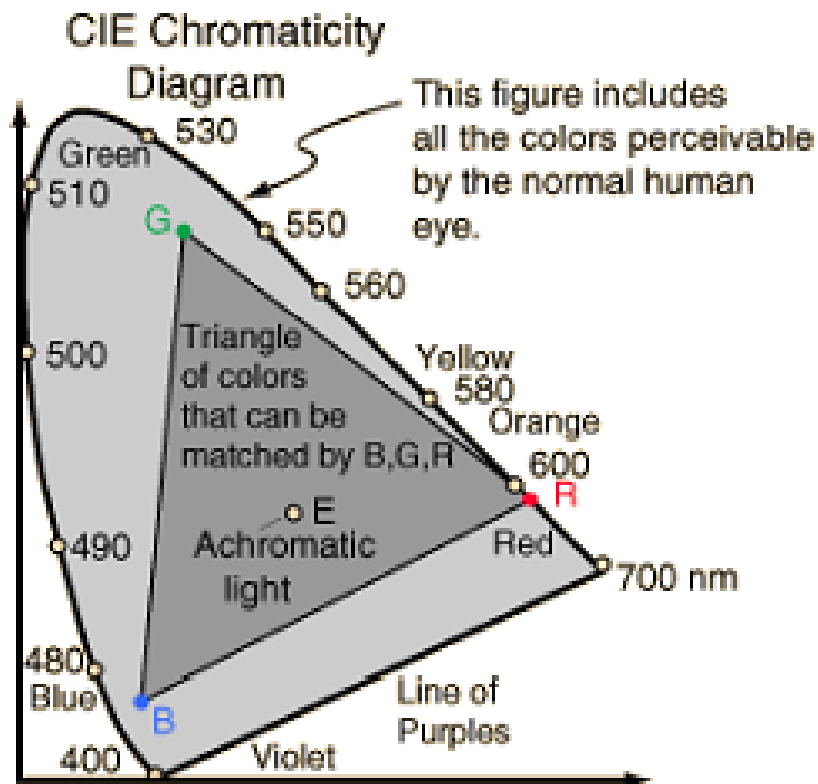
Usually compute x , y , where $x = X/(X+Y+Z)$

$$y = Y/(X+Y+Z)$$

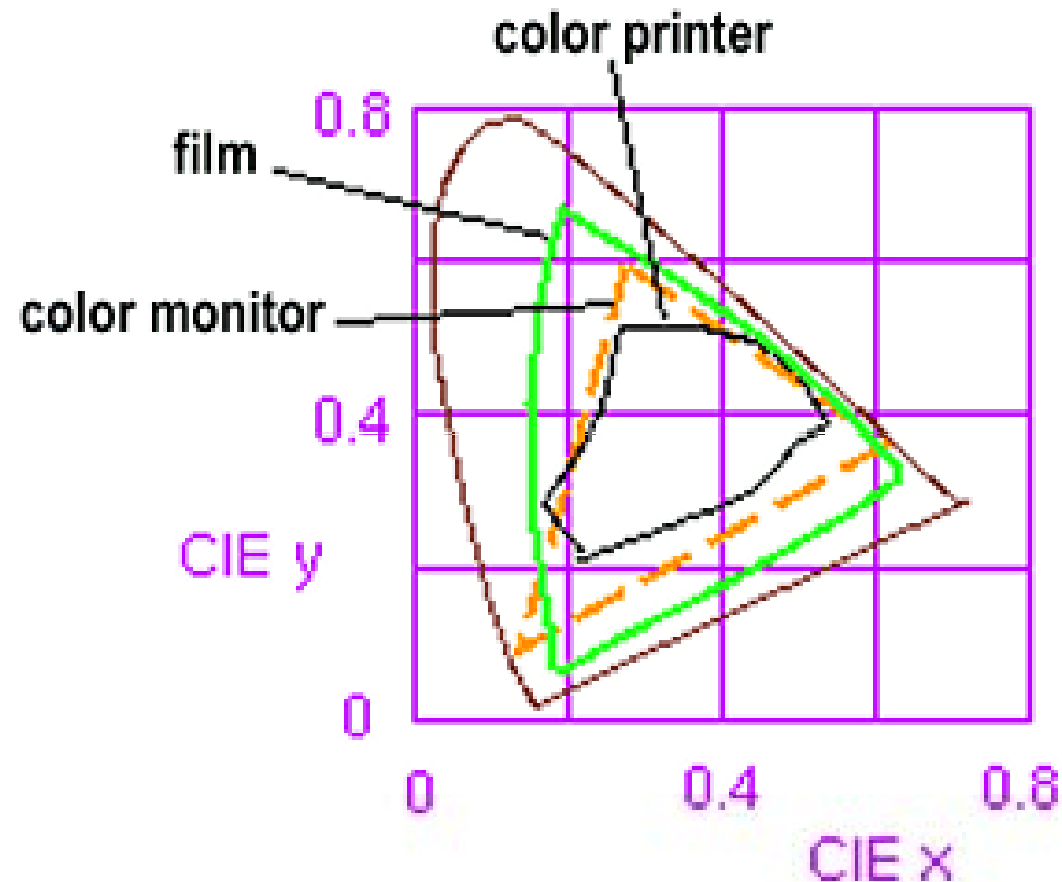
$$z = Z/(X+Y+Z)$$



- All real colors can be represented as positive combinations of x , y since $x+y+z=1$
- CIE chromaticity diagram encompasses all the perceivable colors in 2D space (x,y) by ignoring the luminance Y .



- ***Color gamut*** : range of colors a color model can describe
- CIE color model is useful for comparing color gamuts for different sets of primaries.



Complementary Colors

- ***Complementary colors*** : together produce white color.
- Illuminant C (Average sunlight)

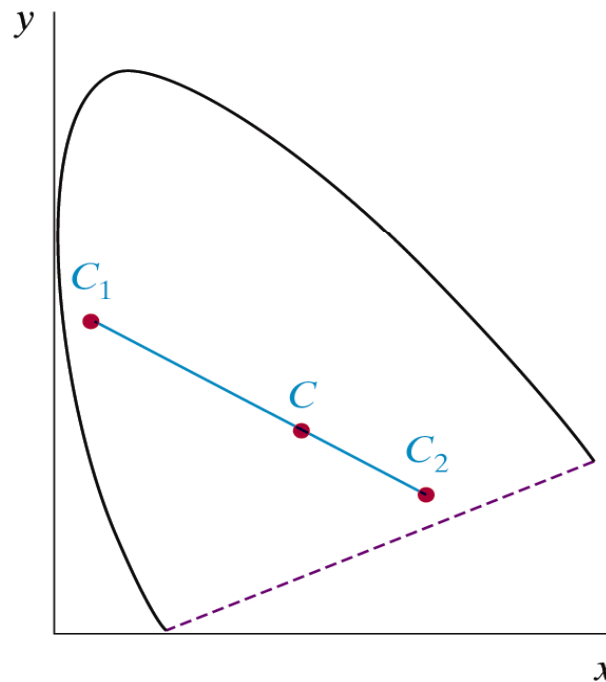
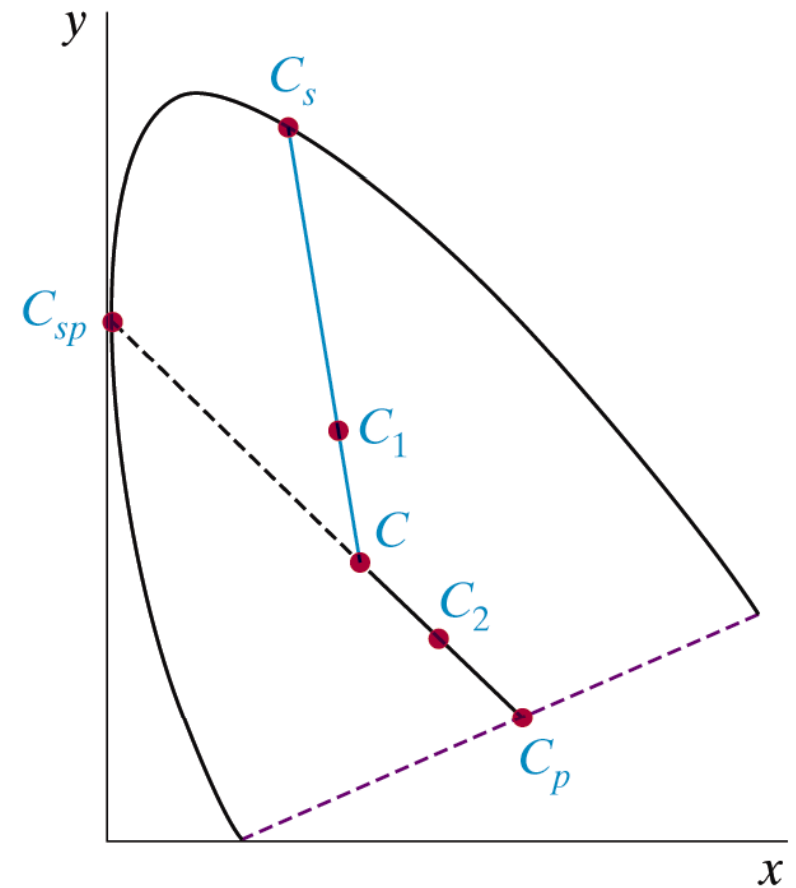


Figure 12-9

Representing complementary colors on the chromaticity diagram.

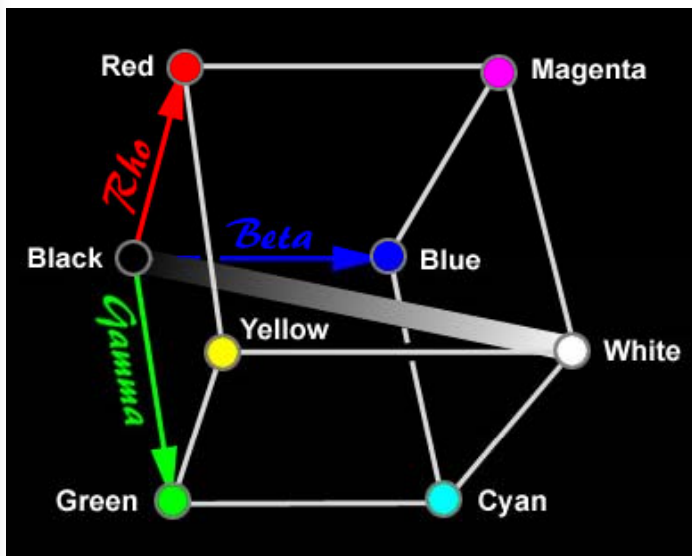
Dominant Wavelength

- The spectral color which can be mixed with white light in order to reproduce the desired color
- The dominant color of C_2 is C_p .



RGB Color Model

- Red, Green, Blue
- Used in display devices
- Based on the tri-stimulus theory
- Human eyes perceive colors by the response of three different types of cones on the retina.
- *Grays and saturation?*

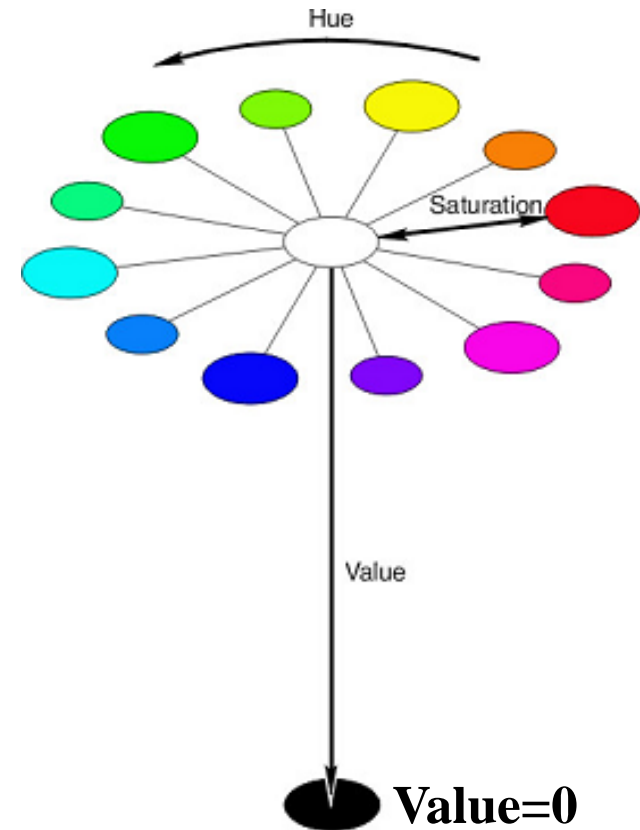


$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.24 & -1.54 & -0.50 \\ -0.97 & 1.88 & 0.04 \\ 0.06 & -0.20 & 1.06 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.41 & 0.36 & 0.18 \\ 0.21 & 0.72 & 0.07 \\ 0.02 & 0.12 & 0.95 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

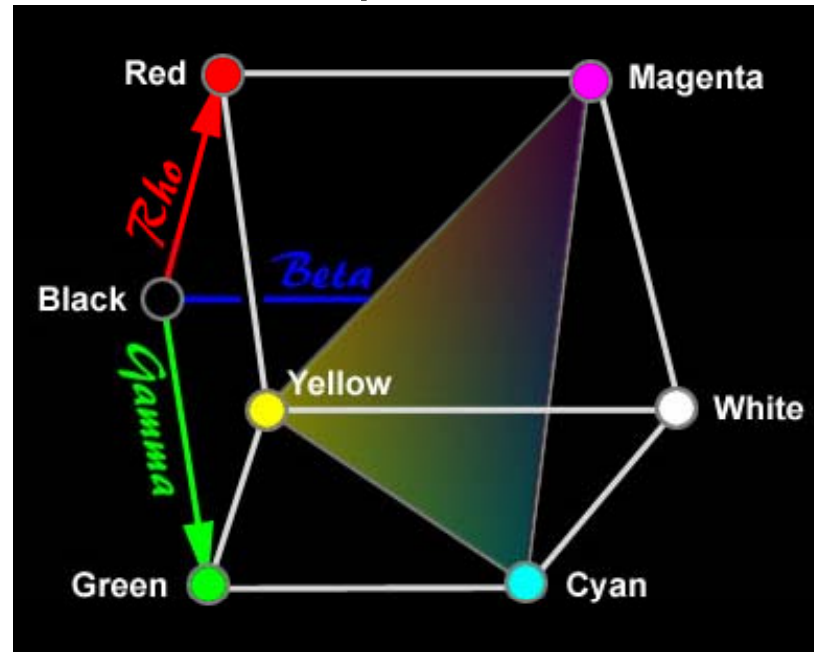
HSV color model

- Hue, Saturation, Value
- Color gamut is inside the hexcone
- Value 0 - 1 represents the relative brightness
- RGB color cube viewed along principal diagonal is Value = 1.0 plane



CMY color model

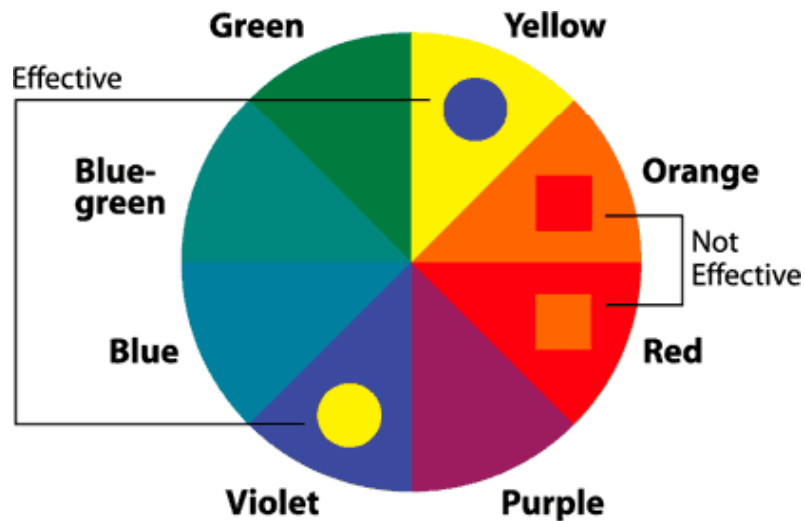
- Subtractive model (colors of pigments are subtracted)
- Used in color output devices



- **CMYK** color model
 - K for black ink for reducing the amount of ink

Effective Use of Color on a Visual Display

- Opponent colors go well together.
 - red-green, yellow-blue ← good
 - red-yellow, green-blue ← poor





Effective Use of Color on a Visual Display

- Avoid the simultaneous display of highly saturated (pure), spectrally extreme colors.
 - visual refocusing caused by mixing extreme color pairs causes fatigue
 - avoid red-blue, yellow-purple
 - [solution: avoid pairs (add white)]
- Avoid adjacent colors that differ in the amount of blue.
 - Short-wavelength photo-pigment does not contribute to the perception of brightness.
 - Edges are indistinct



Effective Use of Color on a Visual Display

- Pure blue should be avoided for text, thin lines, and small shapes.
 - Fovea is blue-blind.
 - Blue is absorbed in eye.
 - Can't focus on blue.
 - Blue is an excellent background color.
 - Raster points less noticeable in blue
 - Blue perceived clearly in peripheral vision



Effective Use of Color on a Visual Display

- Text should be printed with the highest possible contrast.

Effective

**Not as
effective**

Effective Use of Color on a Visual Display

- Exaggerate lightness differences between foreground and background colors
- Avoid using colors of similar lightness adjacent to one another, even if they differ in saturation or hue.





Effective Use of Color on a Visual Display

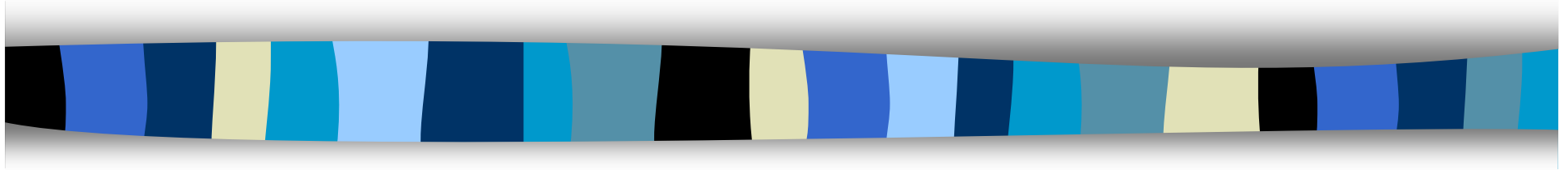
- It is difficult to focus upon edges created by color alone.
 - Use brightness difference to enhance edge.
- Avoid red and green in the periphery of large-scale displays.
 - Retinal periphery is insensitive to reds and greens
 - Should not be used on the outer limits of a display, particularly for small symbol and shapes
 - Yellows and blues are good peripheral colors



Effective Use of Color on a Visual Display

- For color-deficient observers, avoid single-color distinctions.
 - For color mixture series, vary two color components, not one
 - Monochromatic display not a solution, since reduced brightness sensitivity often accompanies color-deficiency.

Graphical User Interface





User Interface

- the means through which the human and the computer communicate with one another
- Graphical User Interface(GUI) : the user interface using graphical objects such as windows and menus
- ***Designing GUI*** : using some combination of the GUI tools to build an application program in which the human/computer communication is optimized using interactive graphics techniques.
- The principle of user interface design is to hide the complexity of interface implementation from the user, and prevent the user from being overwhelmed by the details of a system.



User Interface Design Stages

1. Define the problem the customer wants solved
2. Model the operator
3. Perform task analysis
4. Define the computer objects and functions that correspond to the task domain
5. Design the appearance and behavior of the user interface
6. Evaluate the design



Ten Heuristics For User Interface Design

by [Jakob Nielsen](#)

Visibility of system status

The system should always keep users informed about what is going on, through appropriate feedback within reasonable time.

Match between system and the real world

The system should speak the users' language, with words, phrases and concepts familiar to the user, rather than system oriented terms. Follow real world conventions, making information appear in a natural and logical order.



Ten Heuristics For User Interface Design

User control and freedom

Users often choose system functions by mistake and will need a clearly marked "emergency exit" to leave the unwanted state without having to go through an extended dialogue. Support undo and redo.

Consistency and standards

Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform conventions.



Ten Heuristics For User Interface Design

Error prevention

Even better than good error messages is a careful design which prevents a problem from occurring in the first place.

Recognition rather than recall

Make objects, actions, and options visible. The user should not have to remember information from one part of the dialogue to another. Instructions for use of the system should be visible or easily retrievable whenever appropriate.



Ten Heuristics For User Interface Design

Flexibility and efficiency of use

Accelerators -- unseen by the novice user -- may often speed up the interaction for the expert user such that the system can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.

Aesthetic and minimalist design

Dialogues should not contain information which is irrelevant or rarely needed. Every extra unit of information in a dialogue competes with the relevant units of information and diminishes their relative visibility.



Ten Heuristics For User Interface Design

Help users recognize, diagnose, and recover from errors

Error messages should be expressed in plain language (no codes), precisely indicate the problem, and constructively suggest a solution.

Help and documentation

Even though it is better if the system can be used without documentation, it may be necessary to provide help and documentation. Any such information should be easy to search, focused on the user's task, list concrete steps to be carried out, and not be too large.



**What you will do
with CG?**