PH 301

ENGINEERING OPTICS

Lecture_Vision Optics_22

Ref.:
Geometrical & Physical Optics by R.S. Longhurst

Colour Vision

- Radiations of different wavelength produce different sensations of colour.
- For a normal eye, hues corresponding to various regions of visible spectrum are approximately as follows:

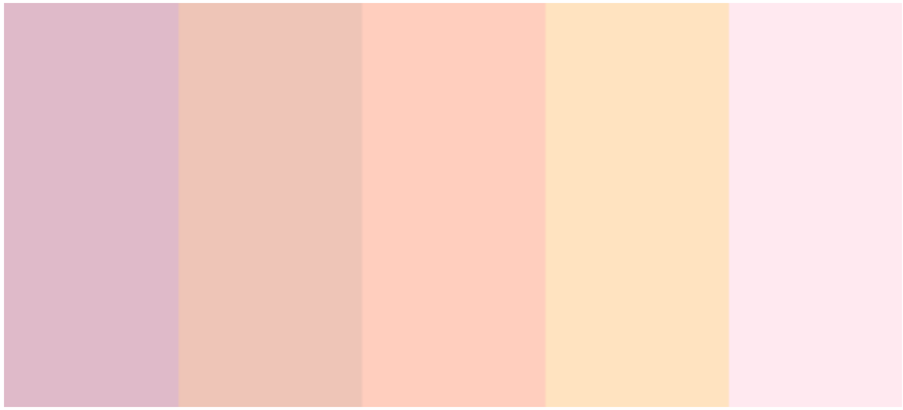
Violet	0.40 µm to 0.45 µm
Blue	0.45 µm to 0.48 µm
Blue-green	0.48 µm to 0.51 µm
Green	0.51 µm to 0.55 µm
Yellow-green	0.55 µm to 0.57 µm
Yellow	0.57 µm to 0.59 µm
Orange	0.59 µm to 0.63 µm
Red	above 0.63 µm

- A stimulus which does not contain a marked excess of any one group of wavelengths produces a sensation of white light.

  White: Colour of a source emitting an equal energy spectrum.

Colour Vision

- If one wavelength is slightly dominant, sensation is of a pale or desaturated colour. As proportion of dominant wavelength is increased the colour is said to become more saturated until, for monochromatic light, complete saturation is reached. Thus, by adding white light to a saturated colour, a desaturated or pale colour is produced.



- A wide range of colours can be produced by an additive mixture of Red (0.70 µm), Green (0.5461 µm), & Blue (0.4358 µm) light.

Colour Vision

- **It is found that a mixture of red & green light gives a fairly saturated orange, yellow, or yellow-green, according to the proportion of red & green employed; a mixture of blue & green gives various blue-greens; & red plus blue gives various purples.**

- **A certain mixture of red, green, & blue matches the colour of an energy source.**

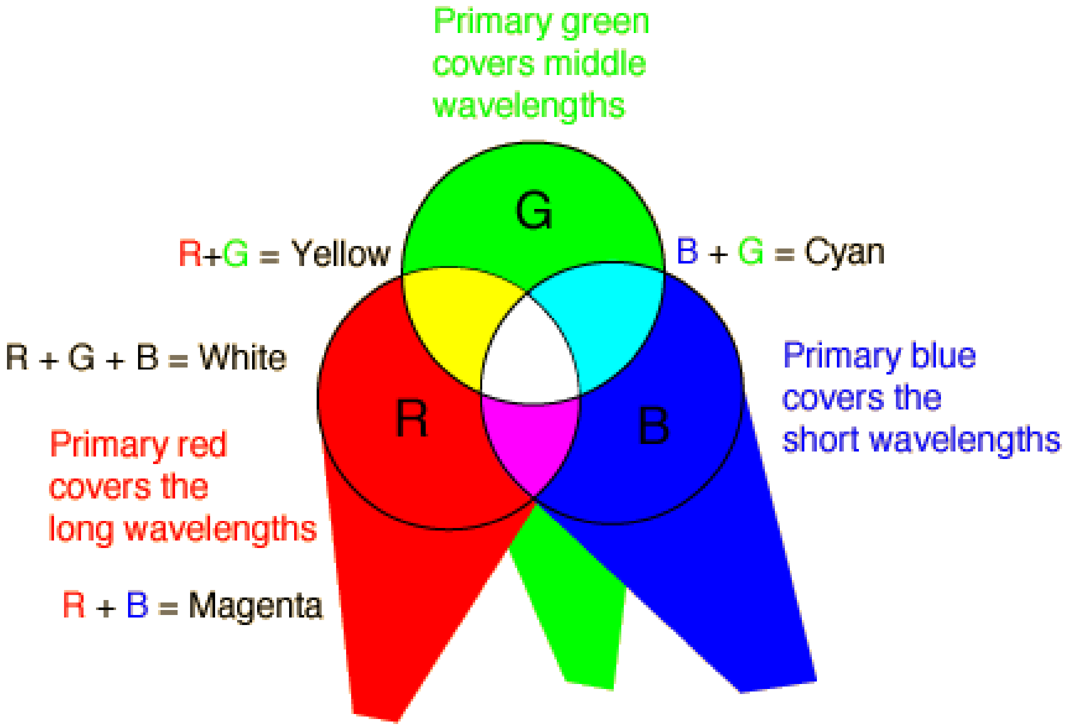
- **If the proportion of one of the three components is increased, one obtains a desaturated red, green, or blue.**

- **If the proportion of any two of the three is greater than that which gives white, the result is a desaturated yellow, blue-green, or purple.**

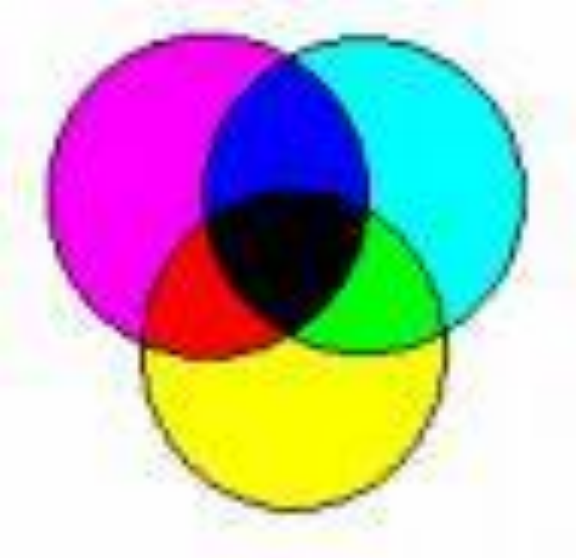
- **Additive mixture of red, green, & blue cannot match very saturated colours.**

Colour Mixing of Light by Addition & Subtraction

Primary & secondary colours



Additive color mixing with red, green and blue additive primary colors.



Colorimetry - Measuring Colour

Importance:

- **Accuracy in matching lights & parts (automobiles)**
- **Reproducible textile colours (clothes, rugs, etc.)**
- **Accurate image reconstruction in printing, photography, TV, computer monitors**

Need for a system for quantifying color for reproduction or representation $\Rightarrow$ Colorimetry

Trichromatic Color Theory

Grassman Laws of linearity & additivity:

1. **Any color can be matched by a suitable mixture of any three stimuli.**
2. **If two colours are matched in turn by mixtures of three stimuli, then sum of two colours will be matched by the sum of two mixtures.**

Colour matching Eqn:

$$C.(C) \equiv R.(R) + G.(G) + B.(B)$$

such that $C = R + G + B$

Unit Eq: $1.(C) \equiv r.(R) + g.(G) + b.(B)$

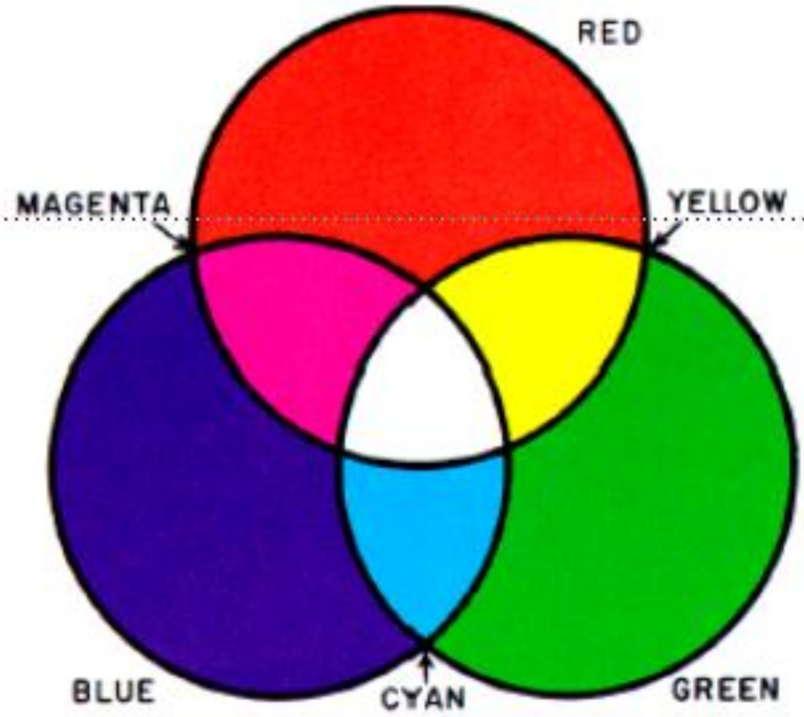
$r = R/(R + G + B)$; $g = G/(R + G + B)$; $b = B/(R + G + B)$

Hence $r + g + b = 1$;

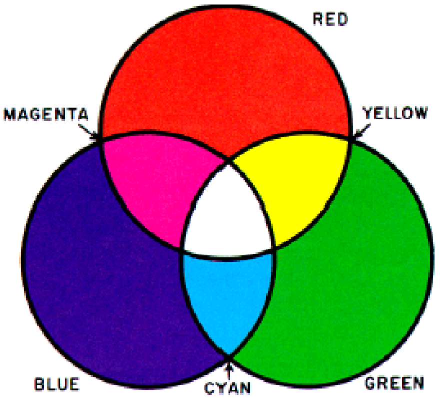
***r*,*g*,*b* are chromaticity co-ordinates to specify any colour**

Additive Color Mixing

- Pick red, green, blue lights
- Add them together
  - 1R = R (red)
  - 1G = G (green)
  - 1B = B (blue)
  - 1G + 1B = C (cyan)
  - 1R + 1B = M (magenta)
  - 1R + 1G = Y (yellow)
  - 1R + 1G + 1B = W (white)
- Create any other color
  - Add different amounts of r, g, b



Additive Primaries

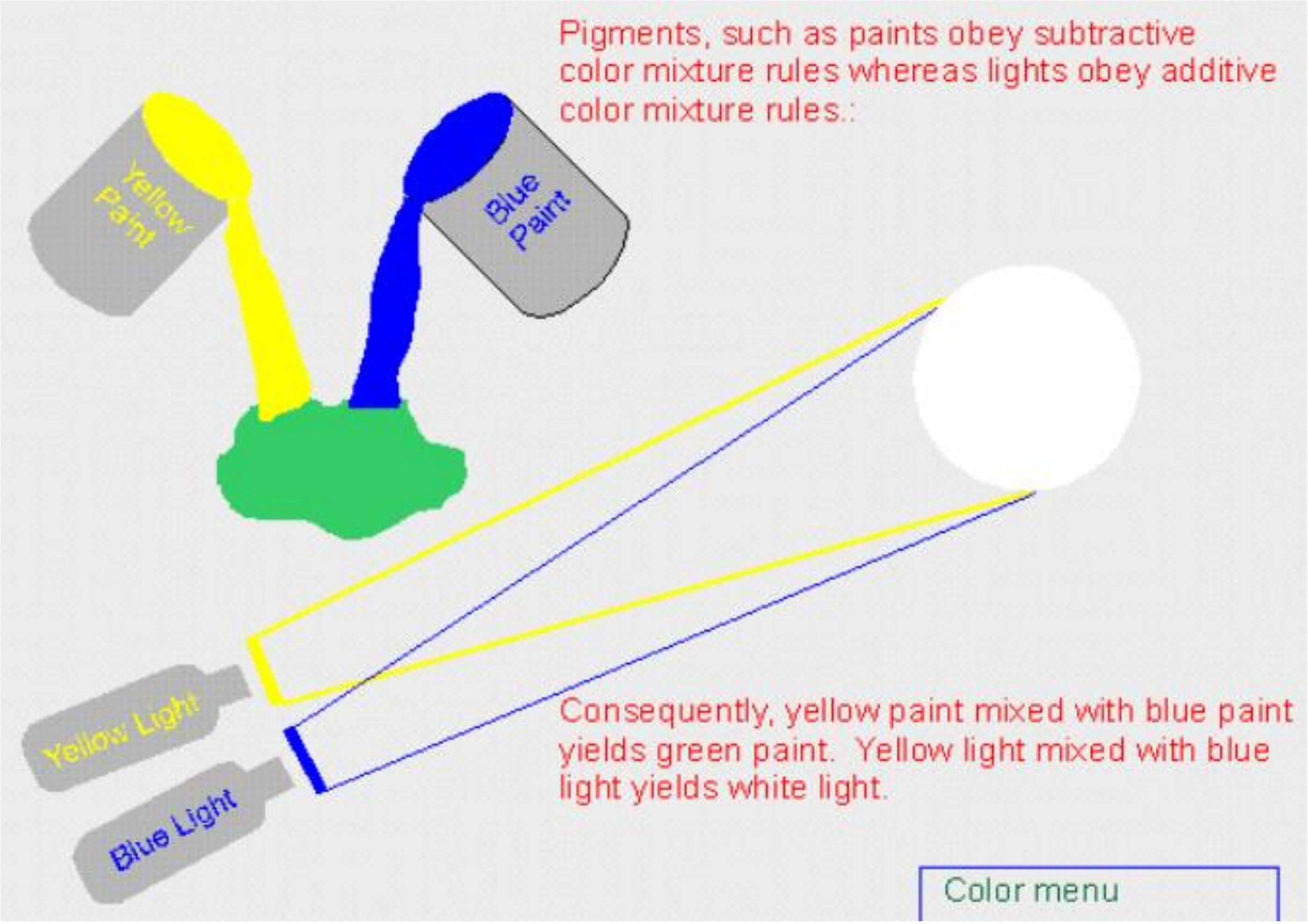


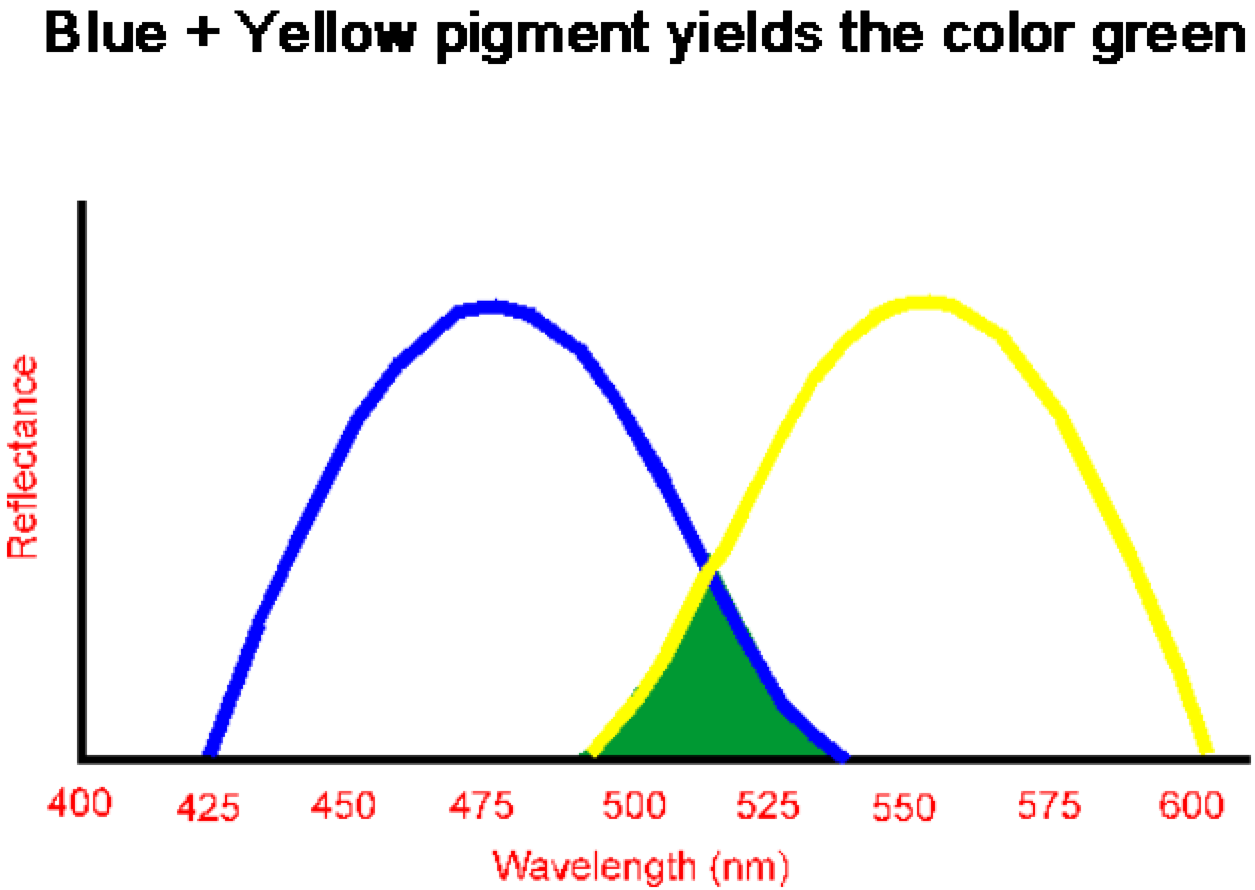
- Additive primaries require active light sources!
- The basis for several technologies:
  - TV monitors
  - Computer monitors (each pixel has r,b,g value)
  - Theater lighting (stage lights)

Subtractive Primaries

- These are Cyan, Magenta and Yellow (C, M, Y)
- Subtract light from external white light source
  - Each primary acts as a filter for light
  - Imagine colors stacked on top of one another
- Simple examples (refer to spectra on previous page)
  - 1C + 1M = B (only blue in common)
  - 1C + 1Y = G (only green in common)
  - 1M + 1Y = R (only red in common)
- Other colors from different amounts of each primary
  - Imagine stacking different thicknesses of each color
- Color technologies dependent on subtractive primaries
  - Color printing
  - Color film

Subtractive & Additive Mixing

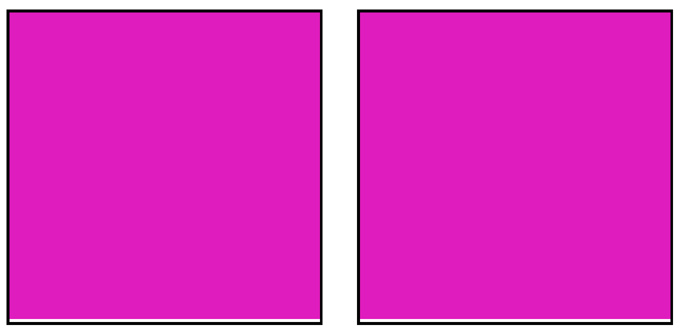




Blue paint & yellow paint both reflect middle (green appearing) wavelengths, but absorb all other wavelengths.

CIE System (1931)

- Based on visual perception measurements
- Basic principle
  - *Any* color stimulus can be matched *exactly* by a combination of three primary lights. Match is *independent of intensity*



Magenta

r=223
g=28
b=189

CIE

- Commission International de l'Eclairage
- Definition of Color Matching Functions for a Standard Colorimetric Observer
- 1931 2° observer
- 1964 10° observer
- Based on a trichromatic color matching experiment.

The CIE 1931 color spaces (XYZ color space) were the first defined quantitative links between distributions of wavelengths in the electromagnetic visible spectrum, & physiologically perceived colors in human color vision.

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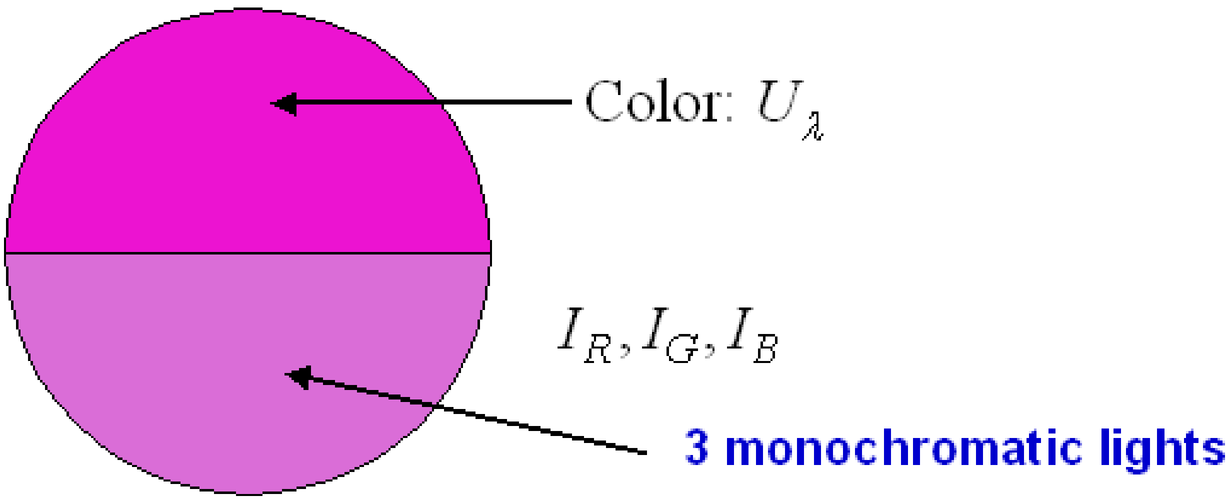
Due to distribution of cones in eye, tristimulus values depend on the observer's field of view. To eliminate this variable, the CIE defined a color-mapping function called the standard (colorimetric) observer, to represent an average human's chromatic response within a 2° arc inside fovea. This angle was chosen owing to the belief that the color-sensitive cones resided within a 2° arc of fovea. Thus CIE 1931 Standard Observer function is also known as the *CIE 1931 2° Standard Observer*.

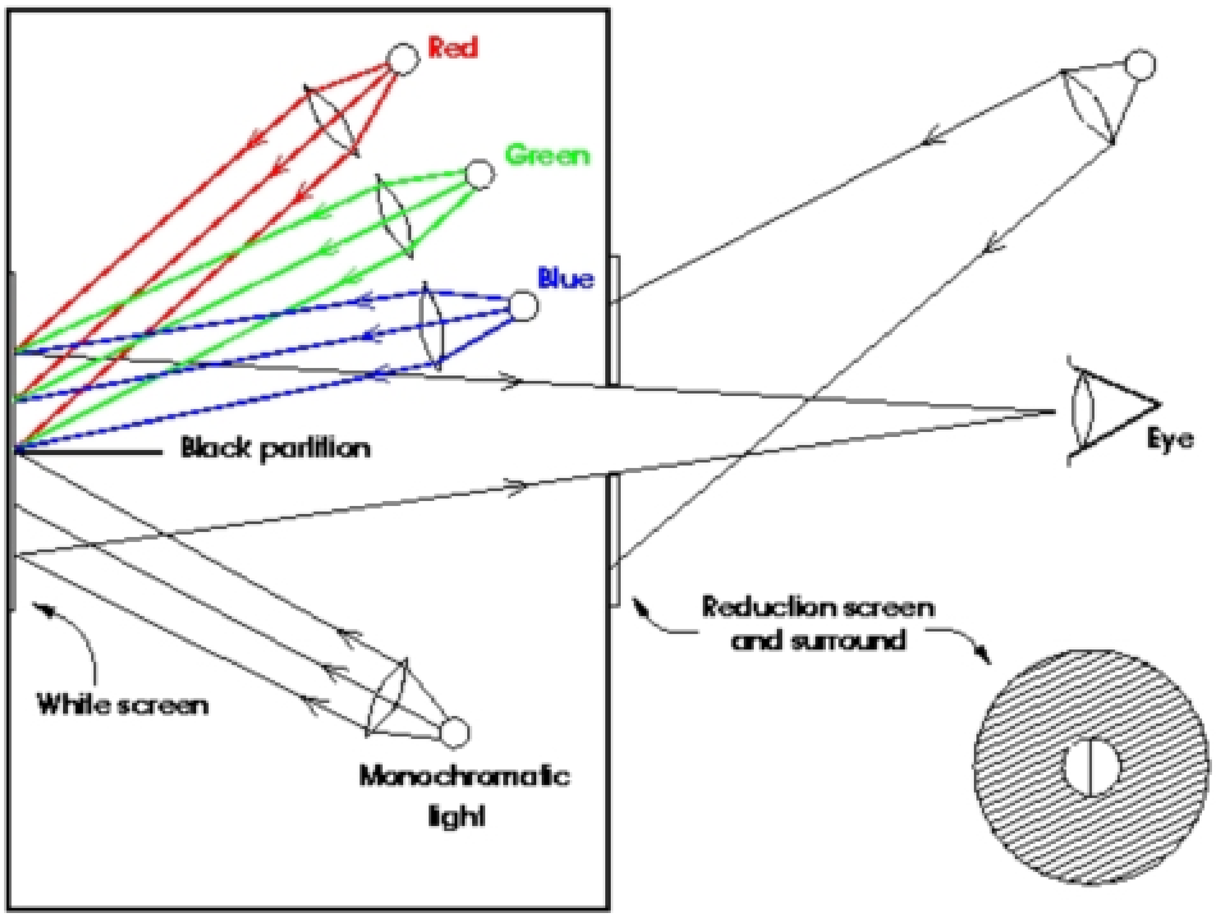
A more modern but less-used alternative is the *CIE 1964 10° Standard Observer.*

Color Matching Experiments

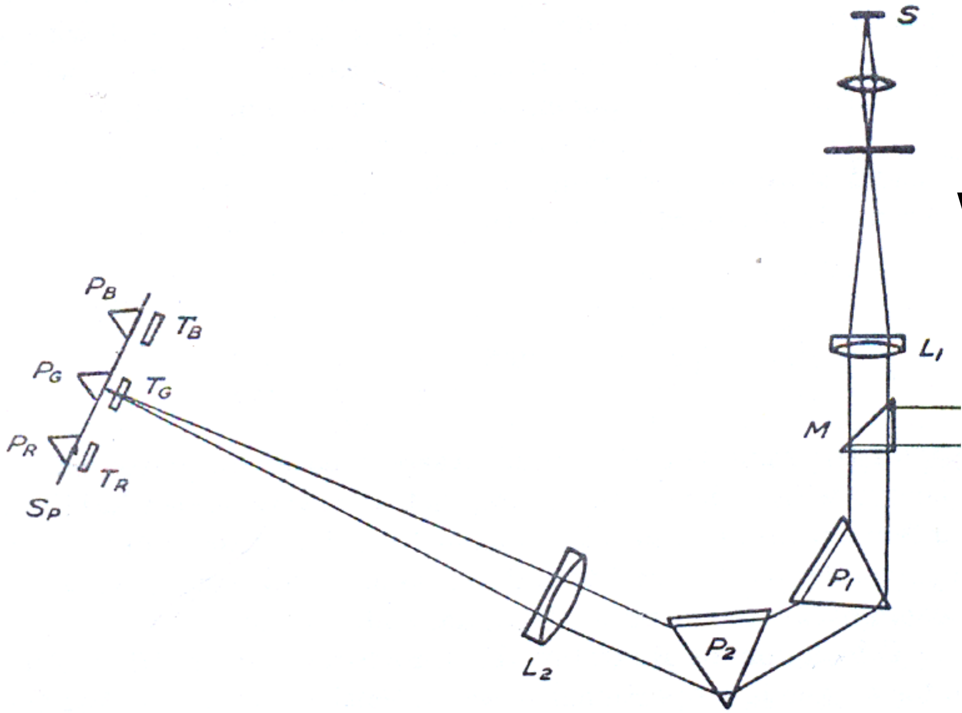
- ➔ Person placed in room with well-defined lighting
- ➔ Upper half disk illuminated by monochromatic light of wavelength λ and intensity U_λ
- ➔ Lower half disk illuminated by 3 monochromatic lights
  - Adjust intensity of lights until perfect match
  - Record intensities I_R, I_G, I_B
  - Repeat until entire visible spectrum is measured



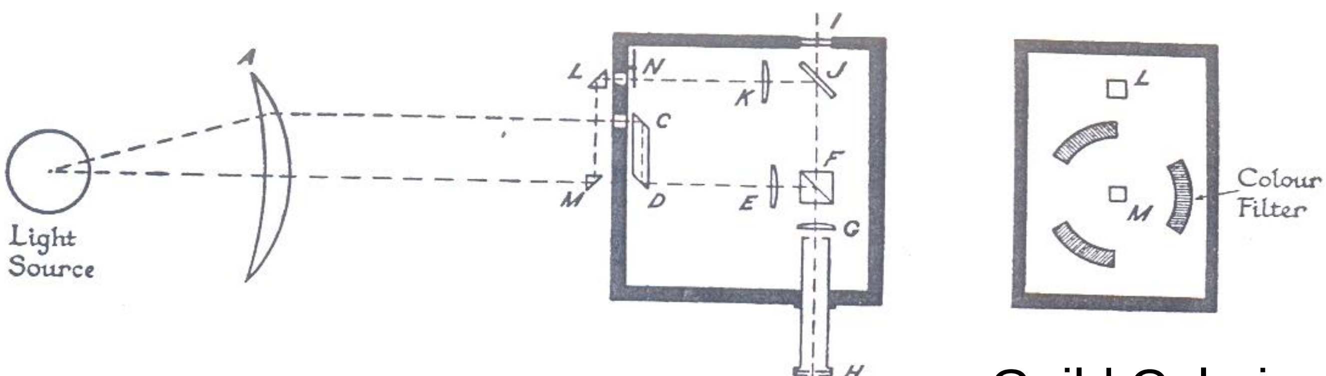
Color Matching Experiment



Trichromatic Colorimeters

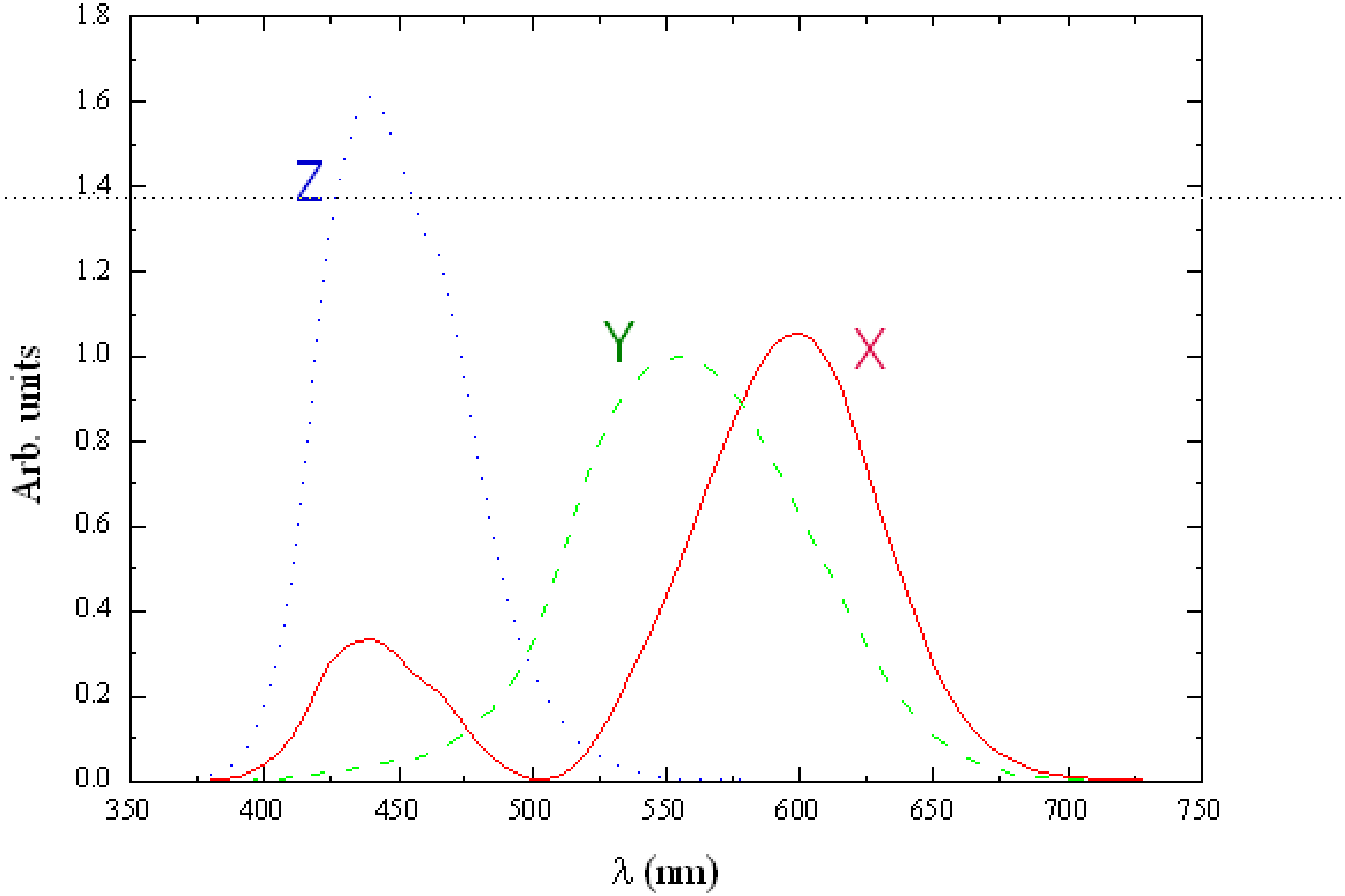


Wright Colorimeter



Guild Colorimeter

CIE Color Matching Functions: (X, Y, Z)



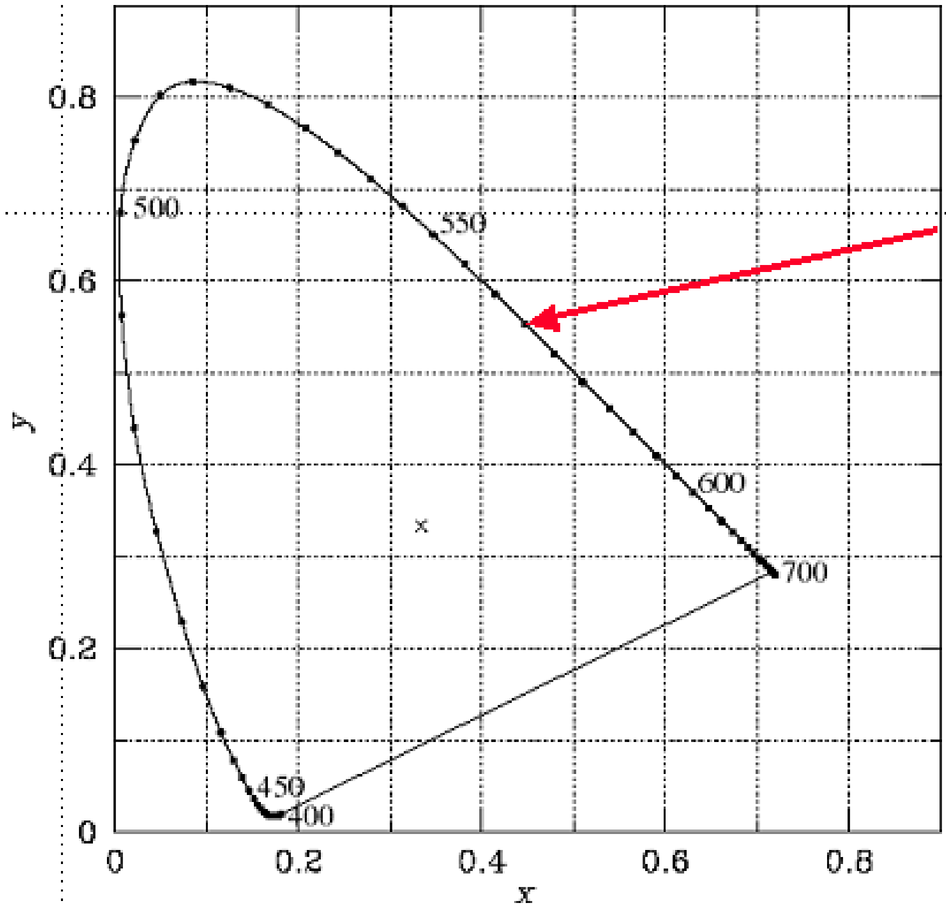
CIE "Chromaticity" Diagram

- For every wavelength
  - Find (X,Y,Z) from CIE color matching functions
  - From (X,Y,Z), calculate (*x*, *y*, *z*)

$$x = \frac{X}{X+Y+Z} \quad y = \frac{Y}{X+Y+Z} \quad z = \frac{Z}{X+Y+Z}$$

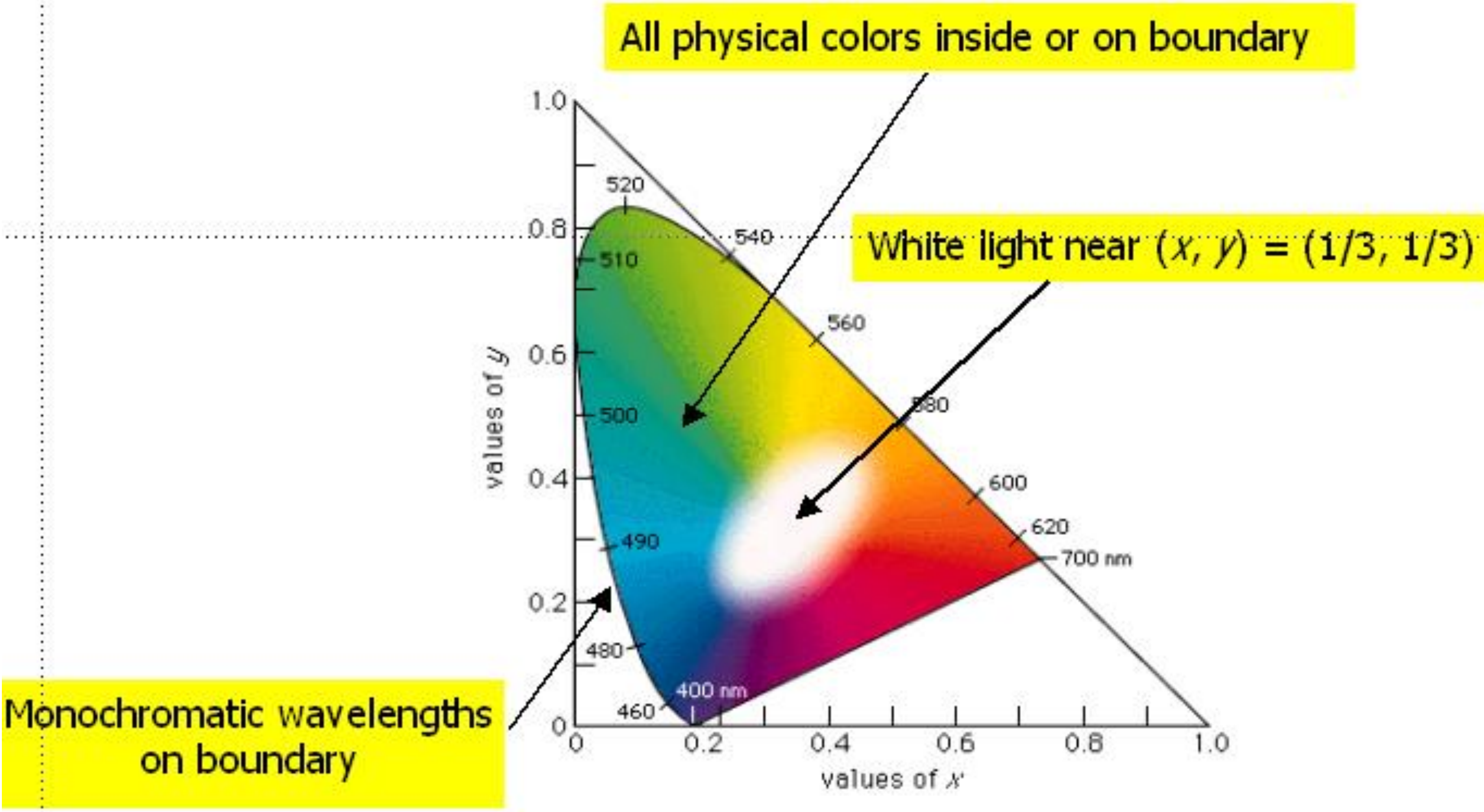
- Plot (*x*,*y*) for each wavelengths in spectrum
  - Generates a horseshoe shaped diagram
  - All physical colors lie *inside* the horseshoe

Chromaticity Diagram



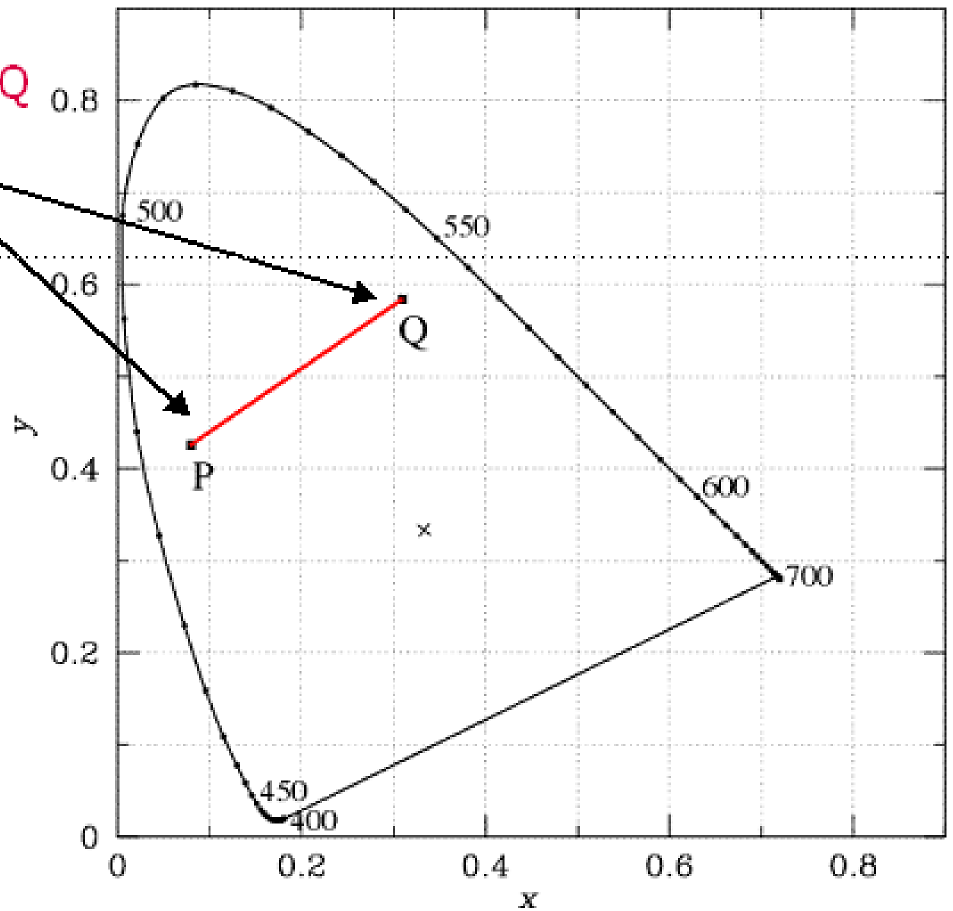
All colors inside horseshoe

Artist's Rendition of Chromaticity Diagram



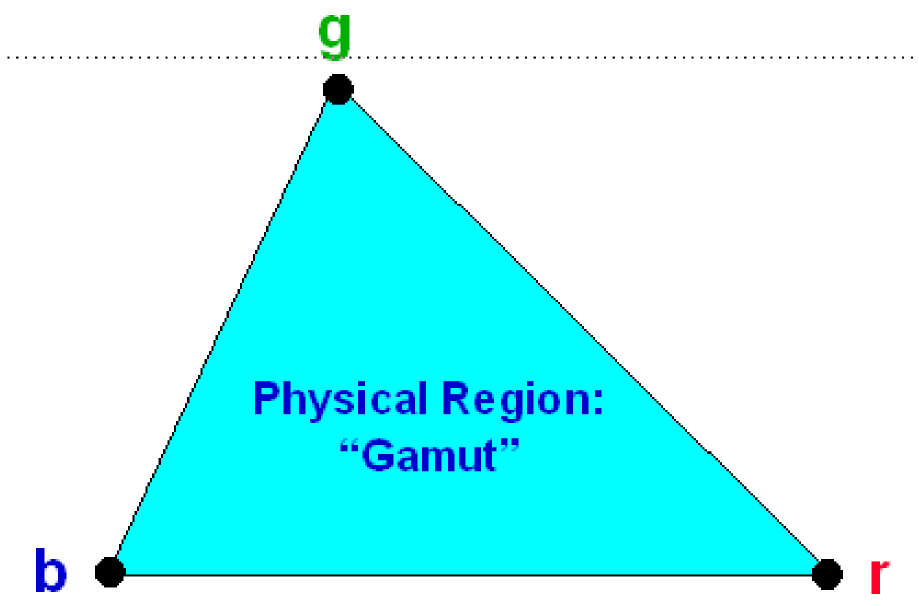
Combining Colors in CIE System

- ➔2 colors: P and Q
- ➔Add different amounts of P, Q
  - ◆Generates all colors on line connecting P and Q



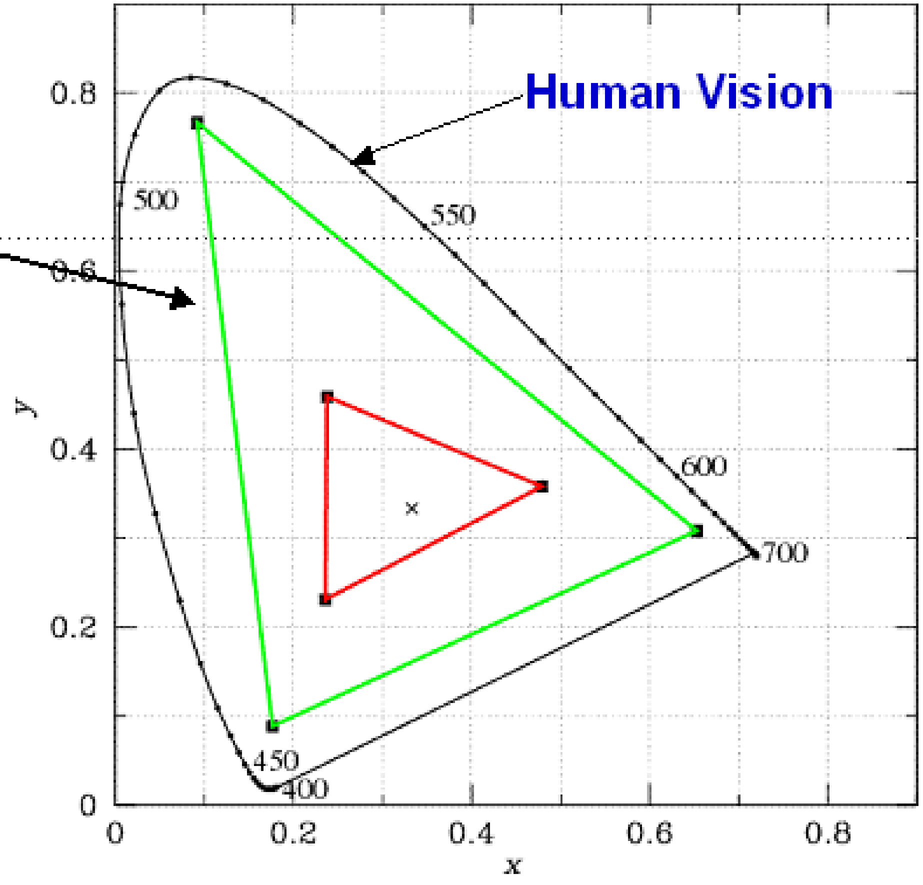
Color Gamuts

- Any three colors form a triangle
- Combinations of 3 colors must lie inside triangle.



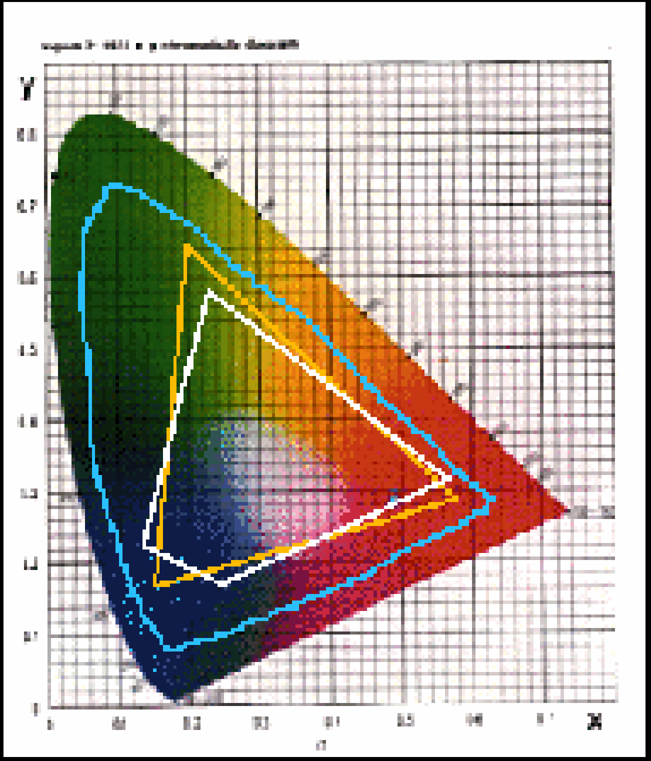
Color Gamuts and Color Reproduction

- ➔ Best color reproduction
  - ◆ Use biggest color gamut
  - ◆ True for all media, print, monitor, film, slides
- ➔ 3 primary sources cannot fully reproduce all colors
  - ◆ Need more primaries!



CIE 1931 xy chromaticity diagram

Commission Internationale de l'Eclairage



Film

Monitor

Printing Press

Production of color depends on

• Light source:	Provides light
• Object:	Thing to be studied
• Eye+brain:	Reception and interpretation of light

Light sources standardized by C.I.E.

• Illuminant A:	Tungsten filament bulb @ $T = 2854K$
• Illuminant B:	Noon sun (obsolete)
• Illuminant C:	"Average" overcast day
• Illuminant D65:	Similar to C, color $T \approx 6500K$
• Illuminant F:	Series of fluorescent bulbs

Human Vision - Illusions

Illusions occur when what we perceive does not match with the true state of the world. When our thoughts do not accurately reflect objective reality.

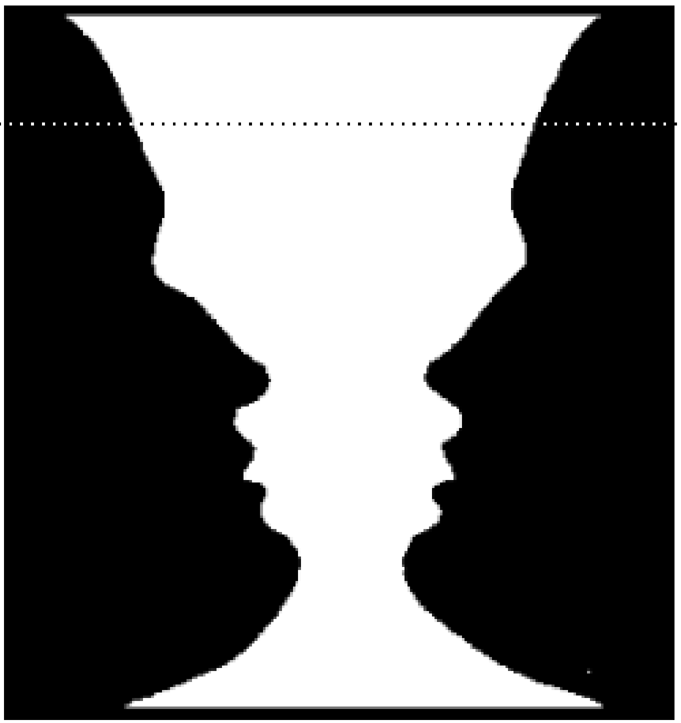
Visual illusions make this obvious, & we usually enjoy them.

Human Vision - Illusions

➔ We see constructed image, not "the world as it really is"

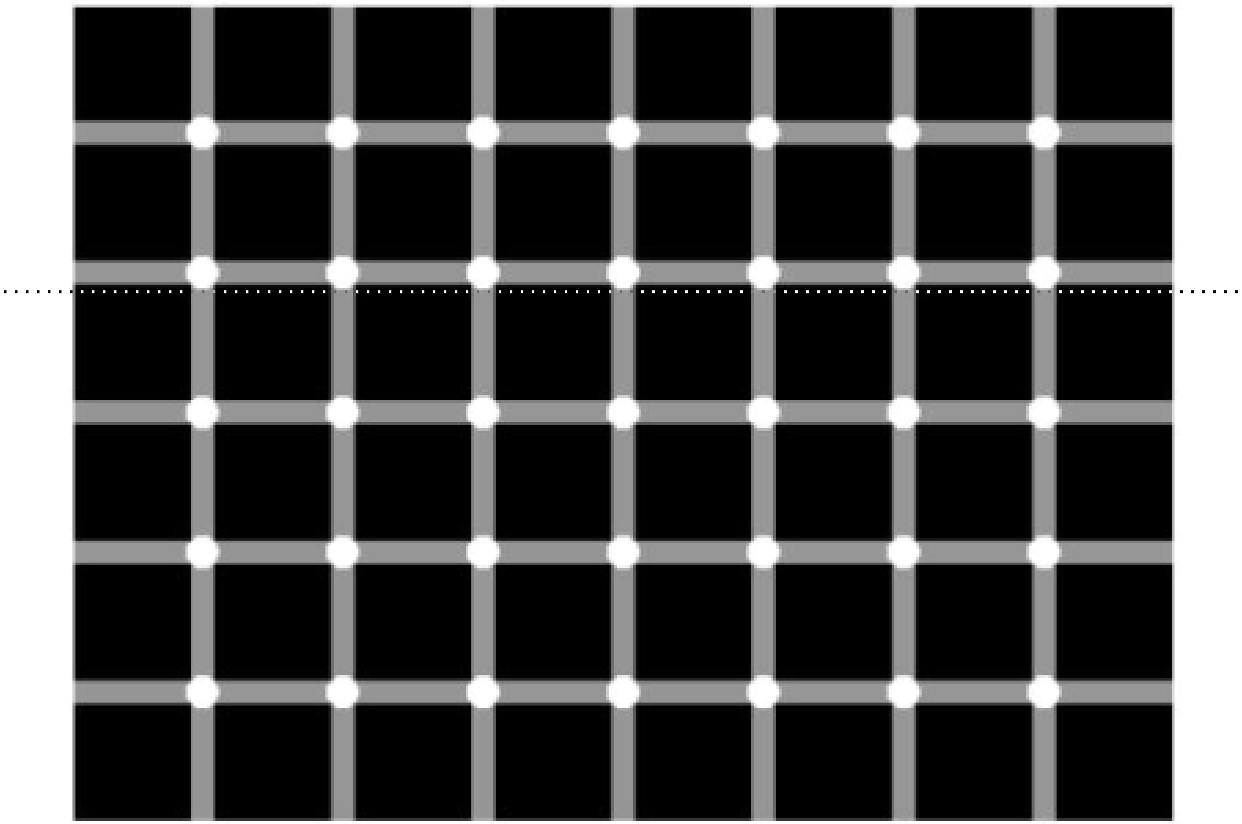
- Full spectrum ⇒ 400 – 700 nm visible
- 400-700 nm spectrum ⇒ 3 independent colors (XYZ)
- Optimized for edges ⇒ discern shapes from background
- Contrast enhancement
- Afterimages ⇒ positive, negative, motion
- Blind spot adaptation
- Visual illusions

Illusions I



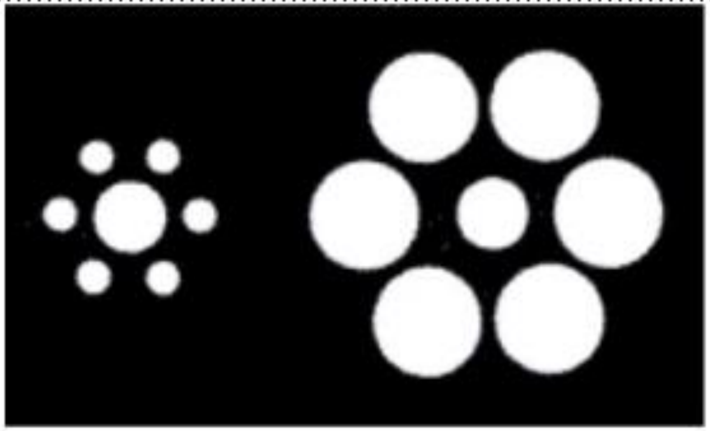
A vase or two faces?

Old or young woman?

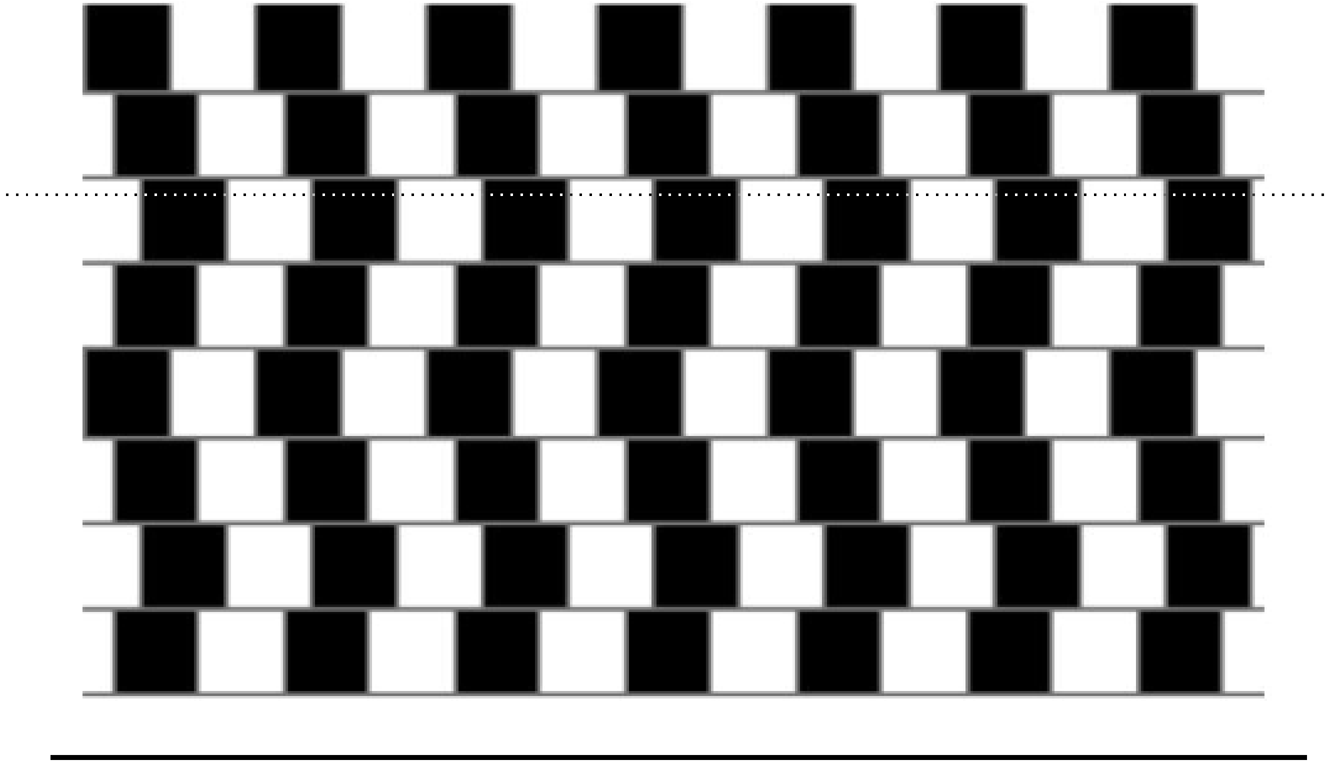


Count the black dots

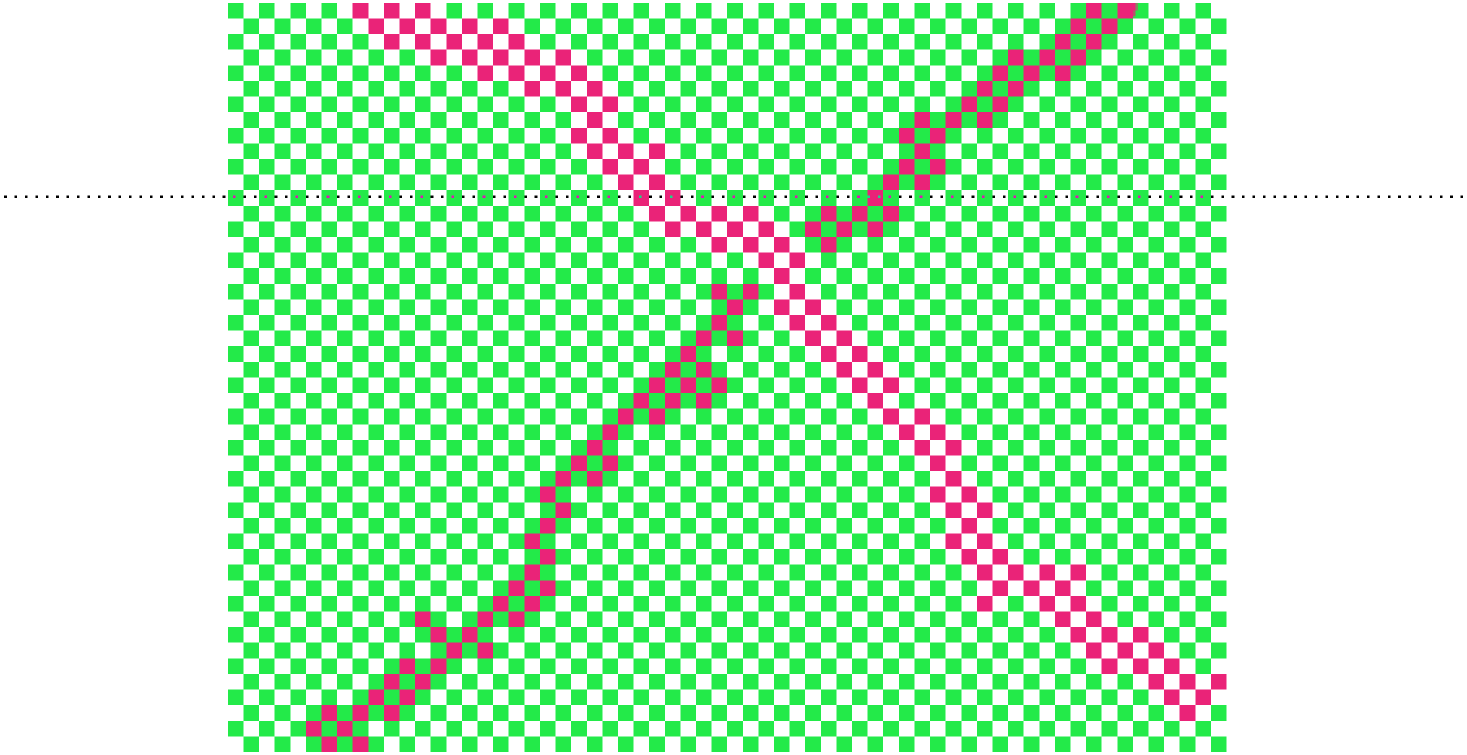
Which Inner Circle is Bigger?



Are the Horizontal Lines Straight?



How Many Colors Are in the Picture?



Red Spirals

There appear to be spirals of two different types of red. Actually, they are identical.

THE TIMES OF INDIA 17-10-2017

Are optical illusions one of the best ways to trick your mind?

Got this puzzle on your phone before? You're asked to stare into a screen full of dots only to suddenly discover another hidden image staring back at you. It's not magic, but an optical illusion trick that shows how the mind can be easily fooled by drawings. Vision scientist Michael Bach is quoted as defining an illusion as a 'match between the immediate visual impression and the actual properties of the object.'

DIFFERENT KINDS

Illusions hark back to the time of the Greeks when Aristotle noticed that if you keep your eyes steady on a waterfall and then move them to nearby rocks, the rocks seem to move in the direction opposite to the water's flow. In the 19th century, the Ponzo illustration (by Italian psychologist Mario Ponzo), demonstrated how the human mind judges an object's size based on the background it is in. This illusion showed how identically-sized lines can appear to be different lengths when placed between converging parallel lines, where the slant lines create confusion about line lengths. Since then, there have been several illusions, all of which are on the same premise — that the brain interprets what is seen by the eye. There are three main kinds of illusions — literal, where objects are drawn or created in images, physiological — for instance counting grey dots in a grid and cognitive illusions, which may be about 'distorting' images.