Interactive Computer Graphics: Lecture 7

Colour

Ways of looking at colour

1. Physics

2. Biology (how do human visual receptors work?)

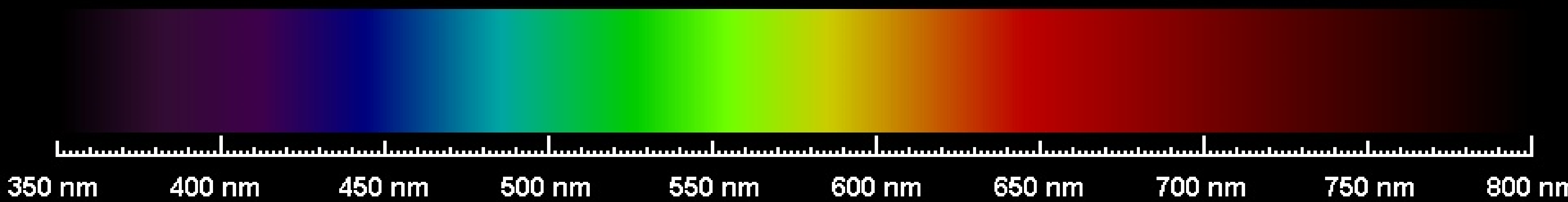
3. Psychology (how do humans subjectively assess colour?)

The physics of colour

- A pure colour is a wave with:

Wavelength (λ)

Amplitude (intensity or energy) (I)

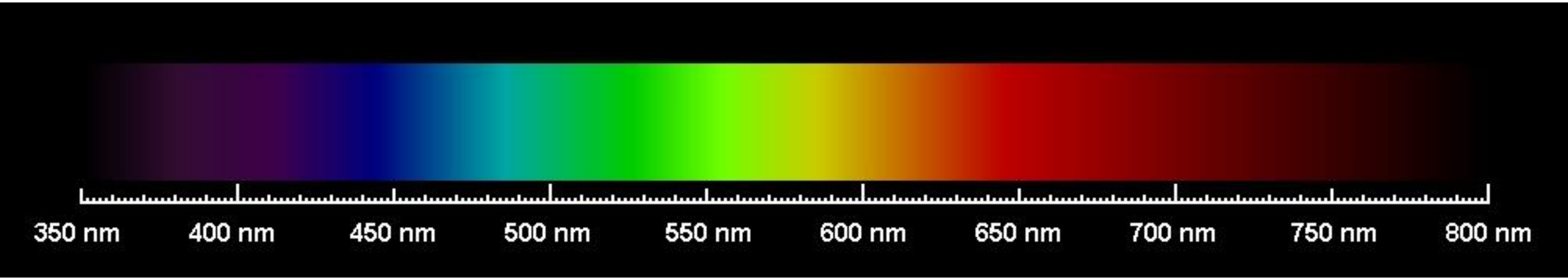


Visible Continuous Spectrum 2

(Perceived Brightness Partially to Scale)

Colours are energy distributions

Color	Frequency	Wavelength
violet	668–789 THz	380–450 nm
blue	631–668 THz	450–475 nm
cyan	606–630 THz	476–495 nm
green	526–606 THz	495–570 nm
yellow	508–526 THz	570–590 nm
orange	484–508 THz	590–620 nm
red	400–484 THz	620–750 nm

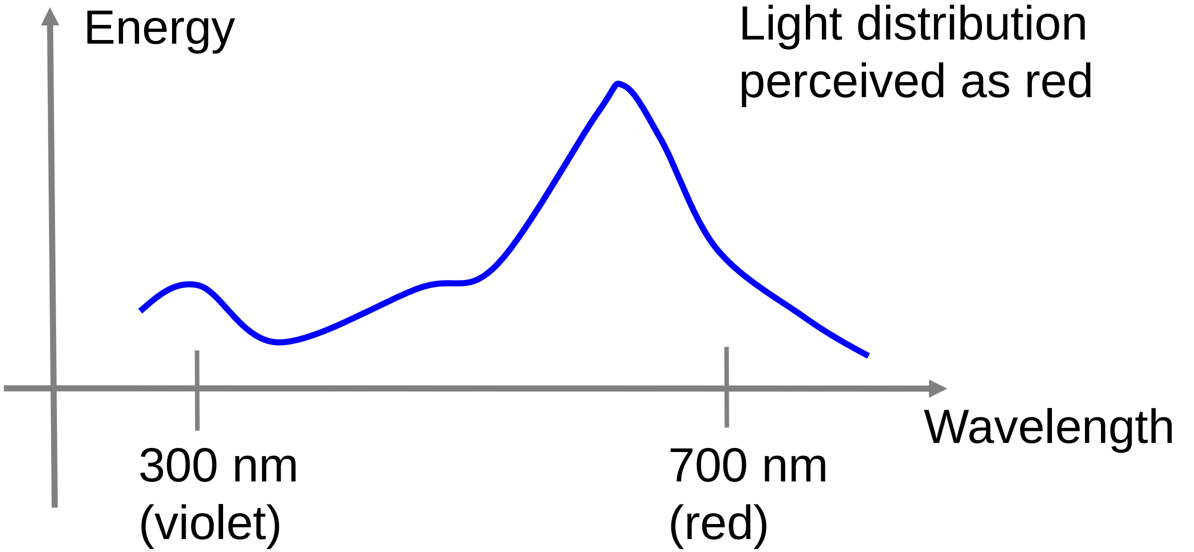


Colours are energy distributions

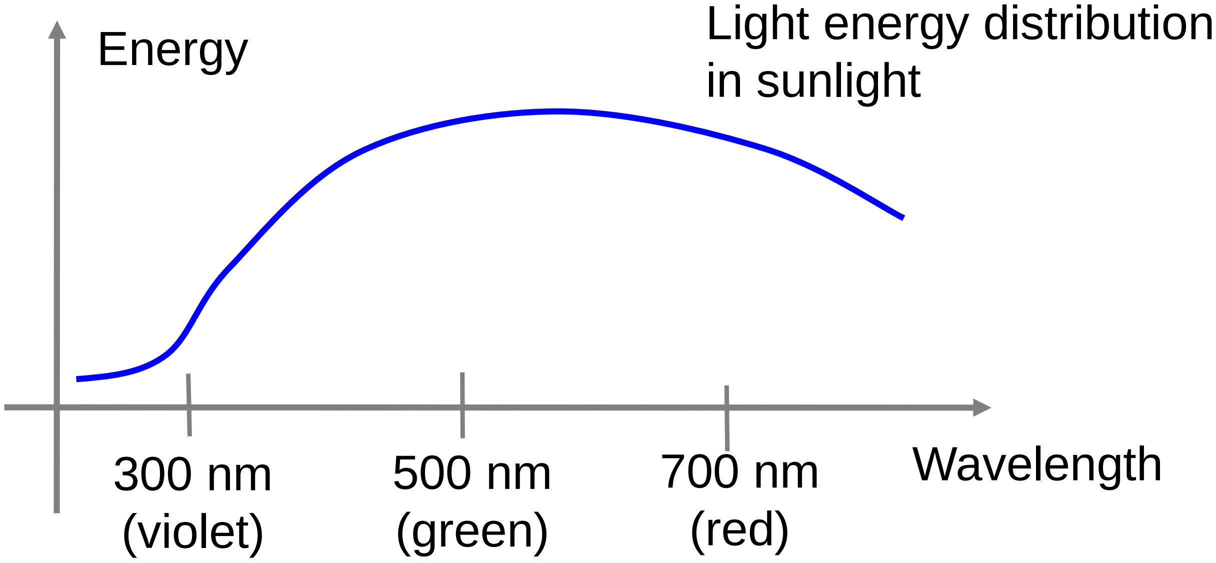
- Lasers are light sources that contain a single wavelength (or a very narrow band of wavelengths)

- In practice light is made up of a mixture of many wavelengths with an energy distribution.

Light distribution for red



Sunlight

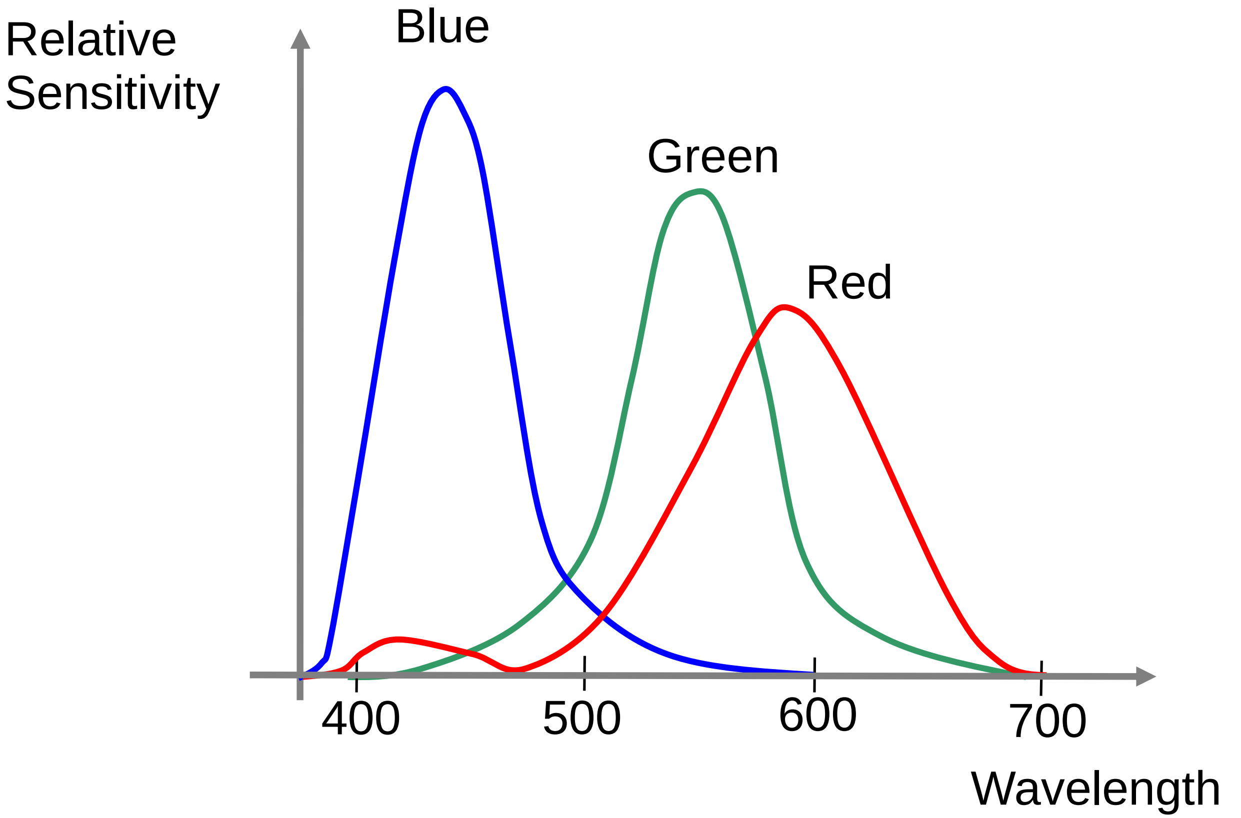

Energy
Light energy distribution
in sunlight
300 nm
(violet)
500 nm
(green)
700 nm
(red)
Wavelength

Human Colour Vision

- Human colour vision is based on three ‘cone’ cell types which respond to light energy in different bands of wavelength.

- The bands overlap in a curious manner.

Human receptor response



Tri-Stimulus Colour theory

The receptor performance implies that colours do not have a unique energy distribution.

<u>And more importantly:</u>

Colours which are a distribution over all wavelengths can be matched by mixing three.

R G B

Colour Matching

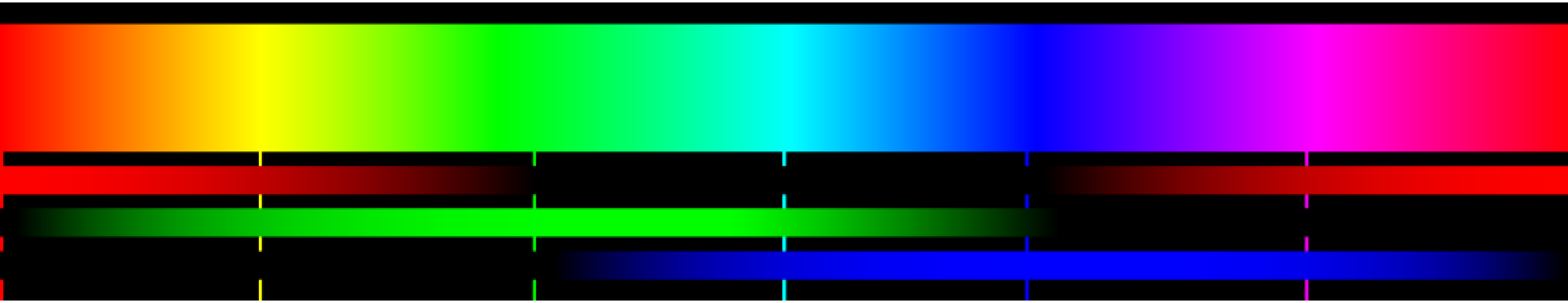
Given any colour light source, regardless of the distribution of wavelengths that it contains, we can try to match it with a mixture of three light sources

$$X = r\,R + g\,G + b\,B$$

where R, G and B are pure light sources and r, g and b their intensities

For simplicity we can drop the R G B.

Colour Matching



Subtractive matching

Not all colours can be matched with a given set of light sources (we shall see why later)

However, we can add light to the colour we are trying to match:

$X + r = g + b$

With this technique all colours can be matched.

The CIE diagram

The CIE diagram was devised as a standard normalised representation of colour.

As we noted, given three light sources we can mix them to match any given colour, providing we allow ourselves subtractive matching.

Suppose we normalise the ranges found to [0..1] to avoid the negative signs.

Normalised colours

Having normalised the range over which the matching is done we can now normalise the colours such that the three components sum to 1.

Thus

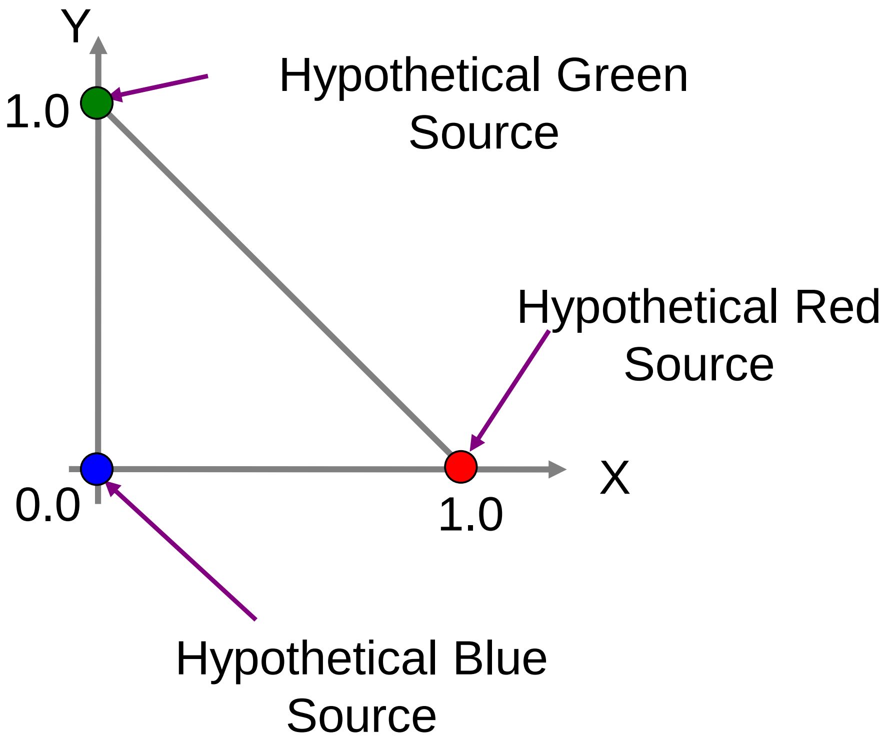
$$x = r/(r+g+b)$$

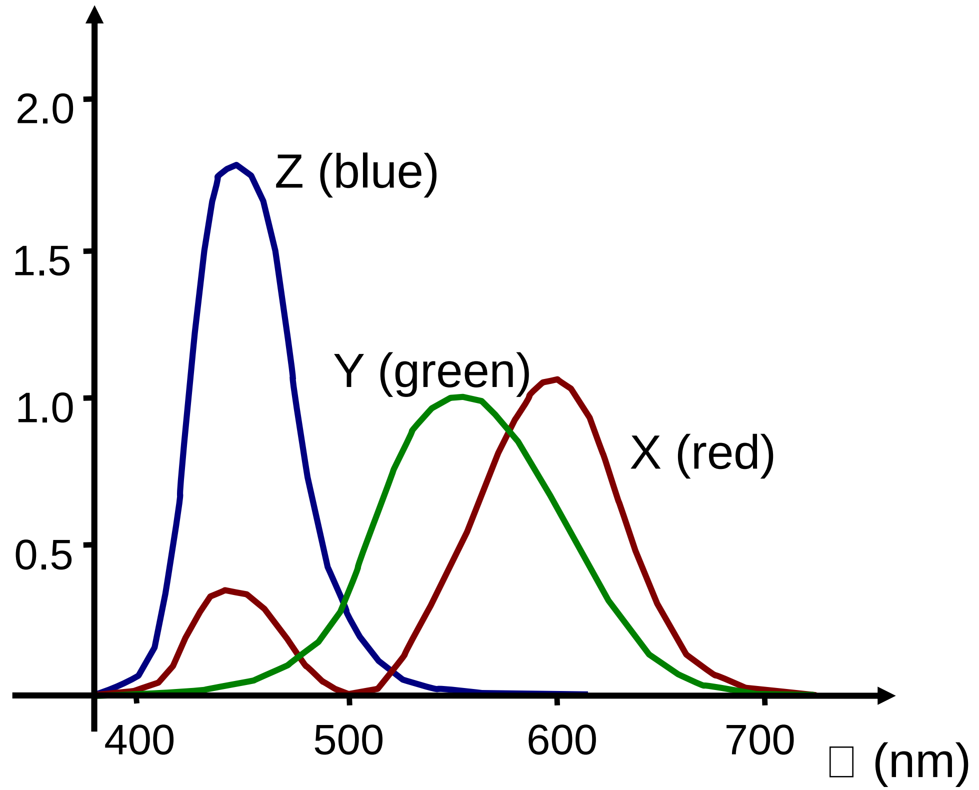
$$y = g/(r+g+b)$$

$$z = b/(r+g+b) = 1 - x - y$$

We can now represent all our colours in a 2D space.

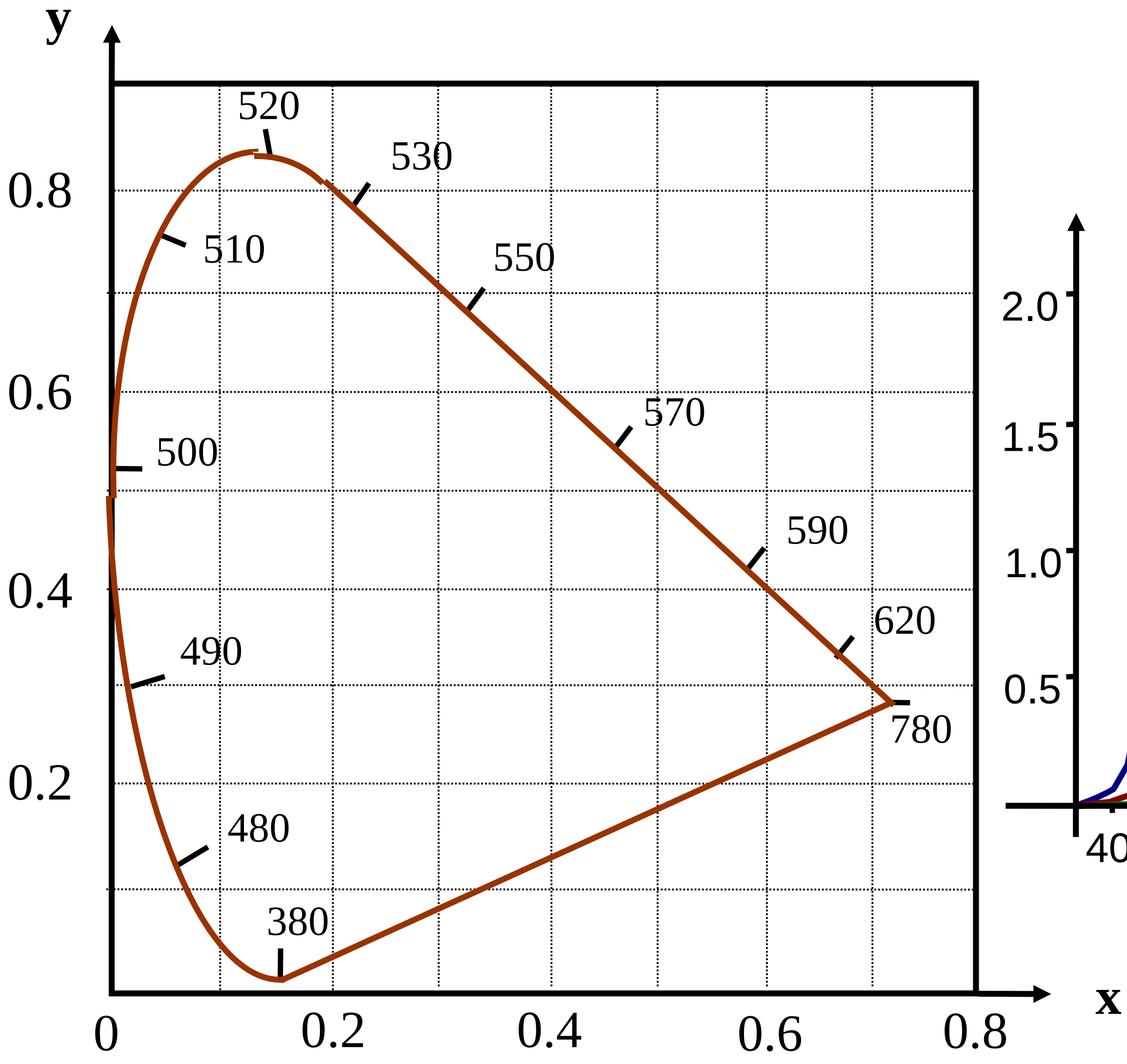
Defining the normalised CIE diagram

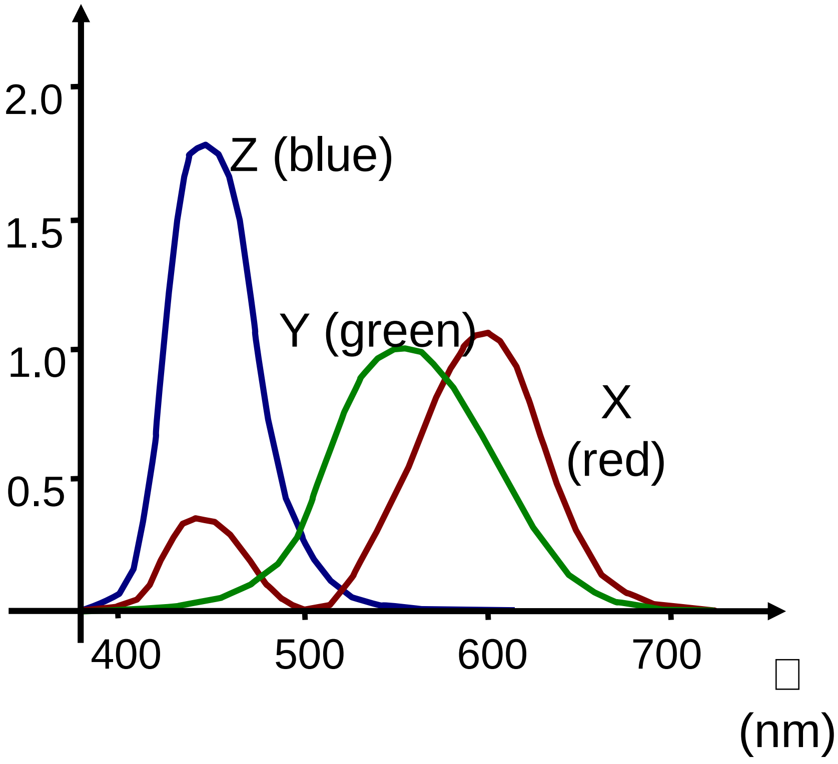




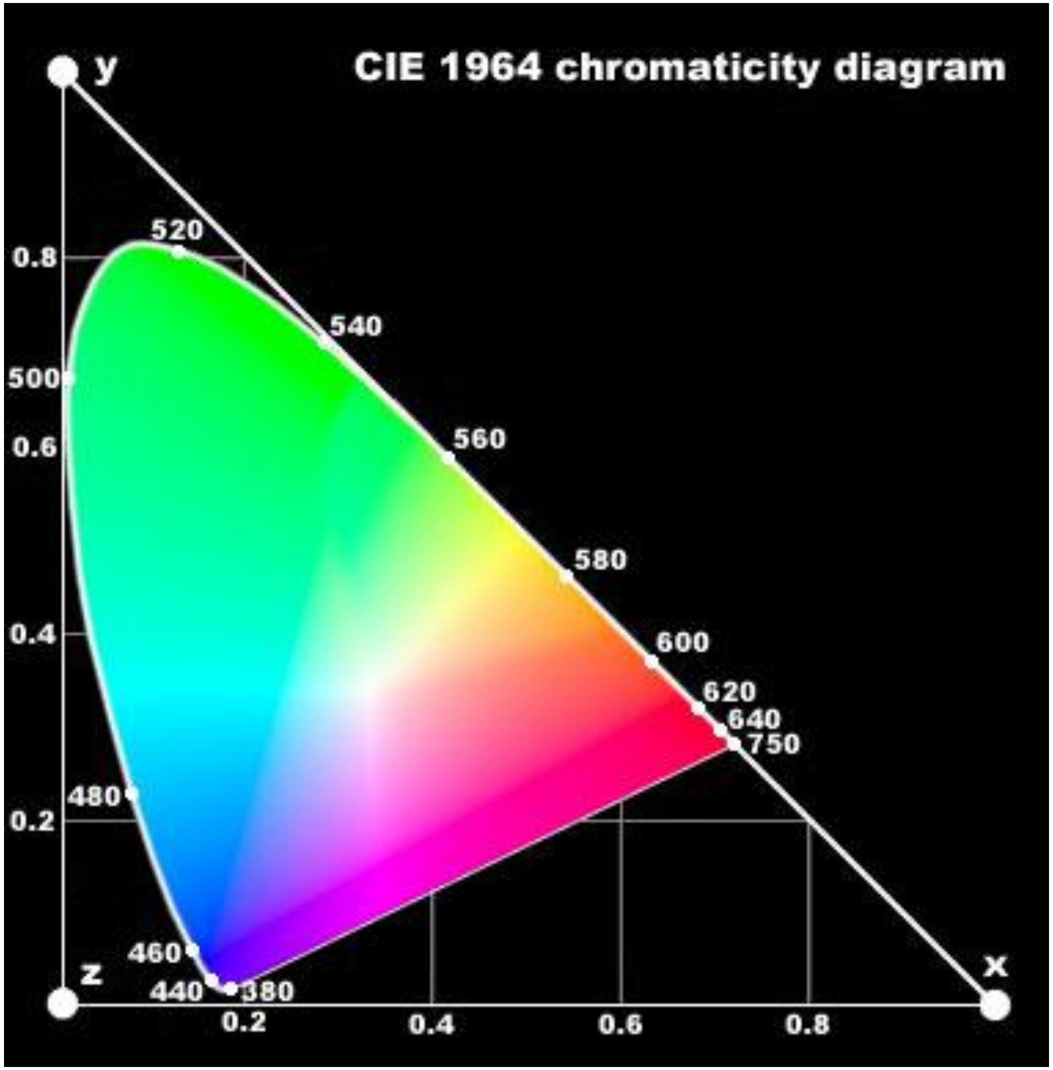
Standard observer response accounting for the cone cell densities in a solid angle

Actual Visible Colours





The CIE Diagram 1964 standard



Convex Shape

Notice that the pure colours (coherent λ) are round the edge of the CIE diagram.

The shape must be convex, since any blend (interpolation) of pure colours should create a colour in the visible region.

The line joining purple and red has no pure equivalent. The colours can only be created by blending.

Intensities

Since the colours are all normalised there is no representation of intensity.

By changing the intensity perceptually different colours can be seen.

White Point

When the three colour components are equal, the colour is white:

$x = 0.33$

$y = 0.33$

This point is clearly visible on the CIE diagram

Saturation

Pure colours are called fully saturated.

These correspond to the colours around the edge of the horseshoe.

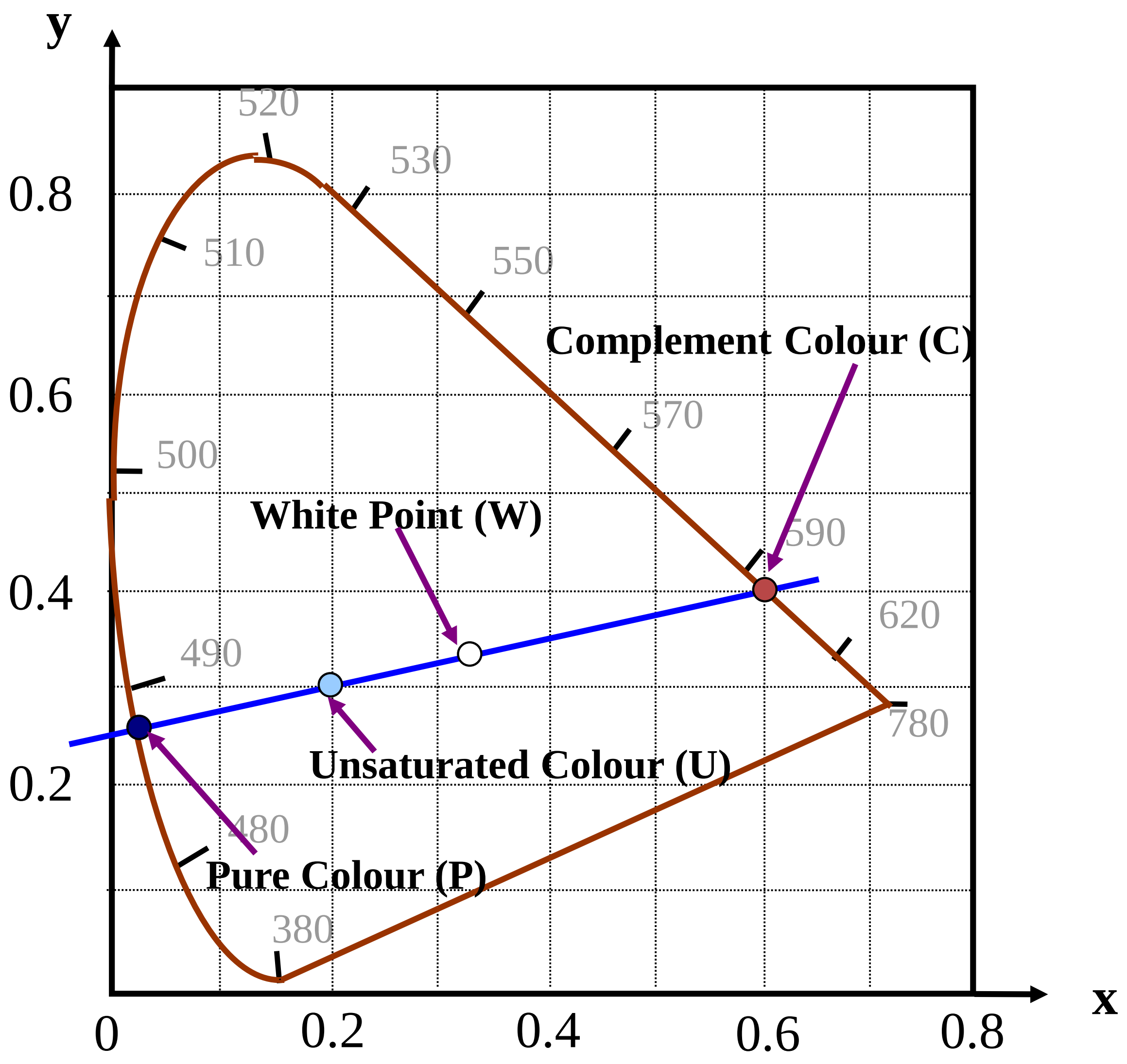
Saturation of a arbitrary point is the ratio of its distance to the white point over the distance of the white point to the edge.

Complement Colour

The complement of a fully saturated colour is the point diametrically opposite through the white point.

A colour added to its complement gives us white.

Actual Visible Colours



Subtractive Primaries

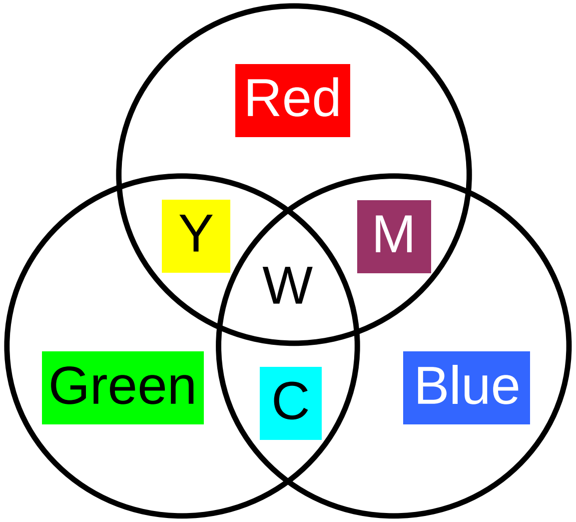
When printing colour we use a subtractive representation.

Inks absorb wavelengths from the incident light, hence they subtract components to create the colour.

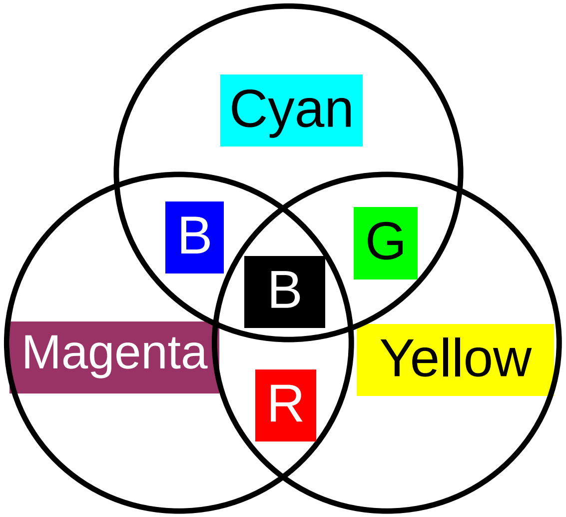
The subtractive primaries are

- Magenta (purple)
- Cyan (light Blue)
- Yellow

Additive and Subtractive Primaries



Additive Primaries



Subtractive Primaries

Colour Perception

Perceptual tests suggest that humans can distinguish:

128 different hues

For each hue around 30 different saturation.

60 and 100 different brightness levels.

If we multiply these three numbers, we get approximately 350,000 different colours.

Colour Perception

These figures must be treated with caution since there seems to be a much greater sensitivity to differentials in colour.

Never the less, a representation with 24 bits (8 bits for red, 8 bits for green and 8 bits for blue does provide satisfactory results.

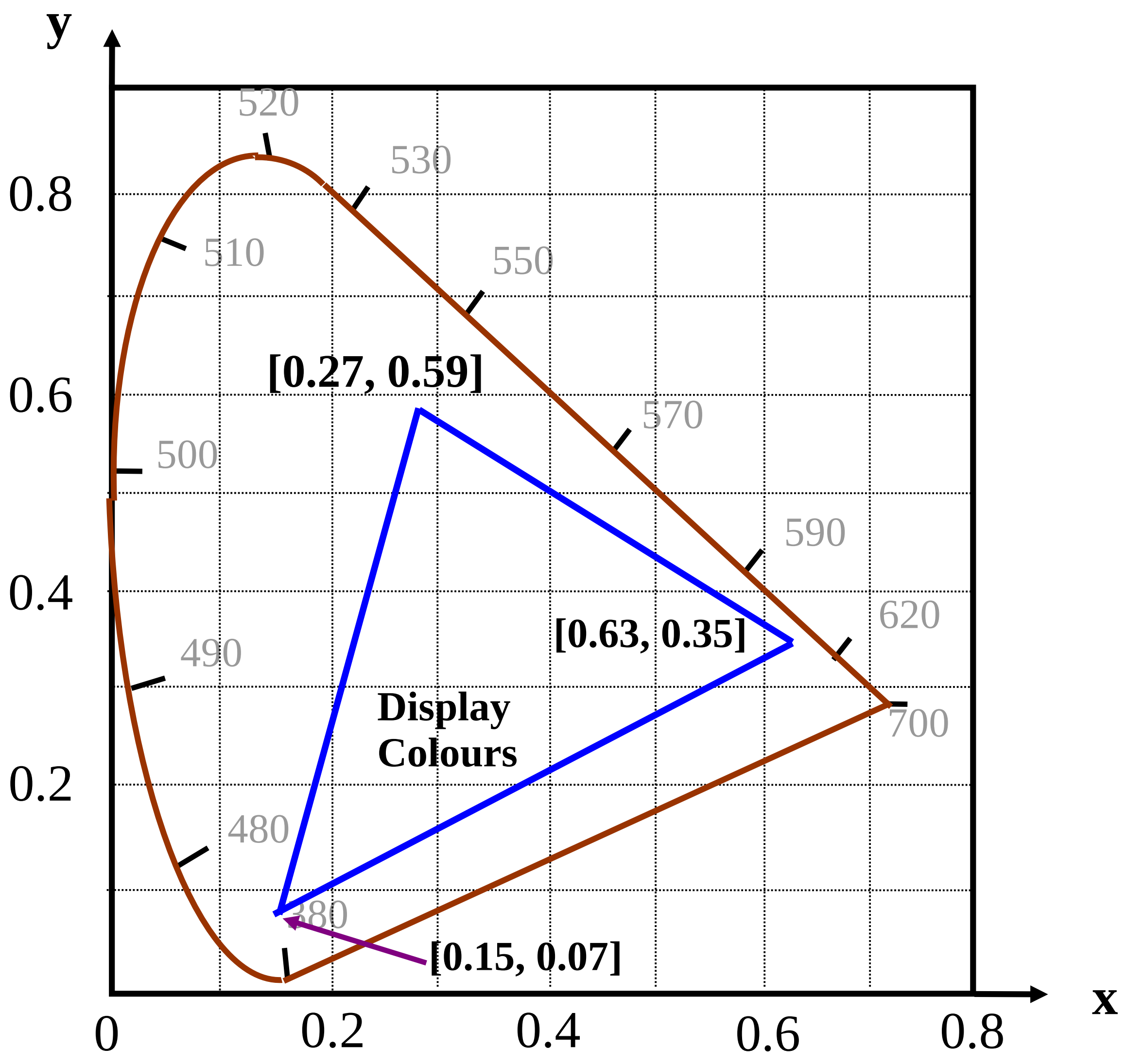
Reproducible colours

Colour monitors are based on adding three the output of three different light emitting phosphors or diodes.

The nominal position of these on the CIE diagram is given by:

	x	y	z
Red	0.628	0.346	0.026
Green	0.268	0.588	0.144
Blue	0.150	0.07	0.780

Actual Visible Colours



RGB to CIE

The monitor RGB representation is related to the CIE colours by the equation:

$$(x, y, z) = \begin{pmatrix} 0.628 & 0.268 & 0.15 \\ 0.346 & 0.588 & 0.07 \\ 0.026 & 0.144 & 0.78 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

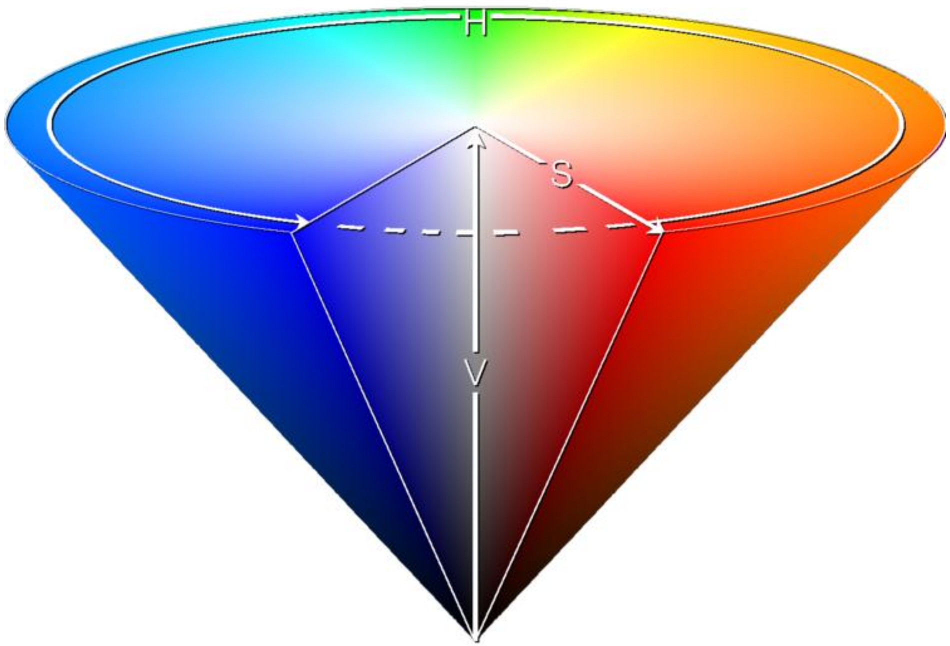
HSV Colour representation

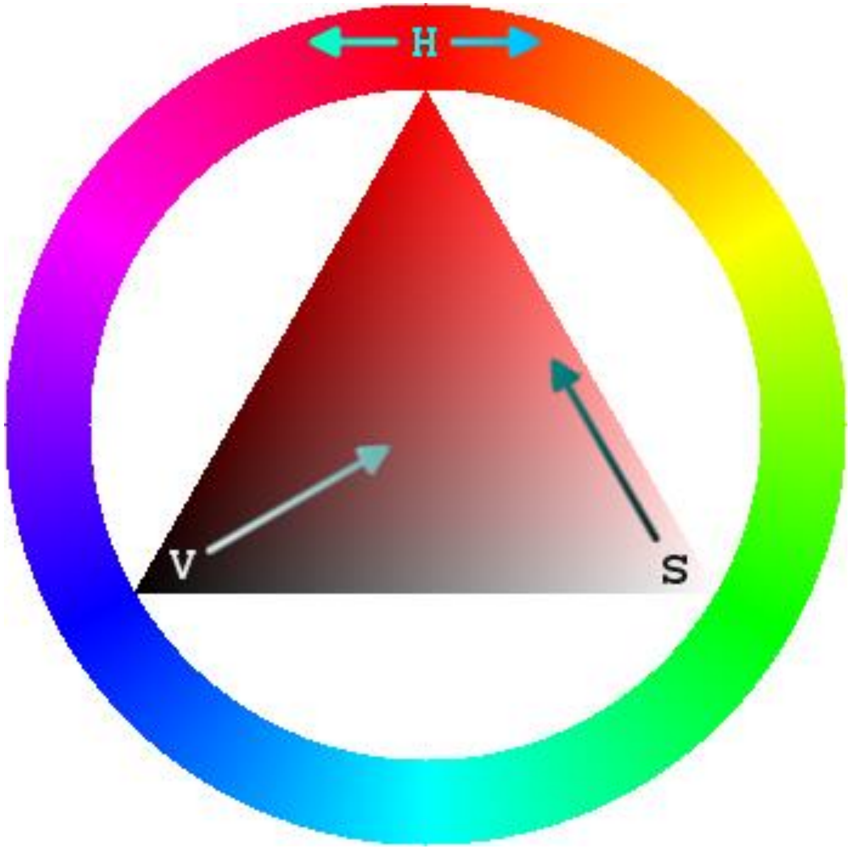
The RGB and CIE systems are practical representations, but do not relate to the way we perceive colours.

For interactive image manipulation it is preferable to use the HSV (or HSI) representation. HSV has three values per colour:

- Hue - corresponds notionally to pure colour.
- Saturation - The proportion of pure colour
- Value - the brightness (Sometimes called Intensity (I))

Visualising the Perceptual Colour Space





Conversion between RGB and HSV

V = max(r,g,b)

S = (max(r,g,b) - min(r,g,b)) / max(r,g,b)

Hue (which is an angle between 0 and 360o) is best described procedurally

Calculating hue

if (r=g=b) Hue is undefined, the colour is black, white or grey.

if (r>b) and (g>b) Hue = 120*(g-b)/((r-b)+(g-b))

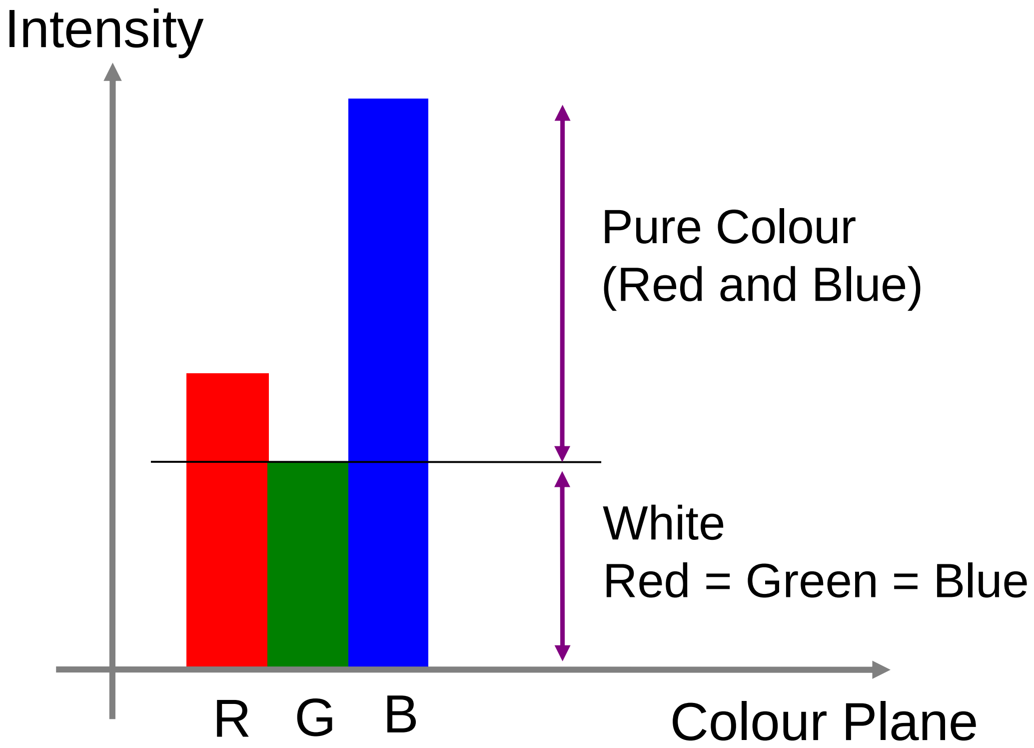
if (g>r) and (b>r) Hue = 120 + 120*(b-r)/((g-r)+(b-r))

if (r>g) and (b>g) Hue = 240 +120*(r-g)/((r-g)+(b-g))

Saturation in the RGB system

- In the RGB system we can treat each point as a mixture of pure colour and white.
- Note however that the so called pure colours are not coherent wavelengths as in the CIE diagram

The composition of a tri-stimulus colour



Alpha Channels

- Colour representations in computer systems sometimes use four components - r g b α.

- The fourth is simply an attenuation of the intensity which:

  – allows greater flexibility in representing colours.
  – avoids truncation errors at low intensity
  – allows convenient masking certain parts of an image.

Alpha Channels

- Images are represented by quadruples:
  - R, G, B indicating color
  - Alpha channel encodes pixel coverage information
    - $\alpha = 0$ transparent
    - $0 < a < 1$ semi-transparent
    - $\alpha = 1$ opaque

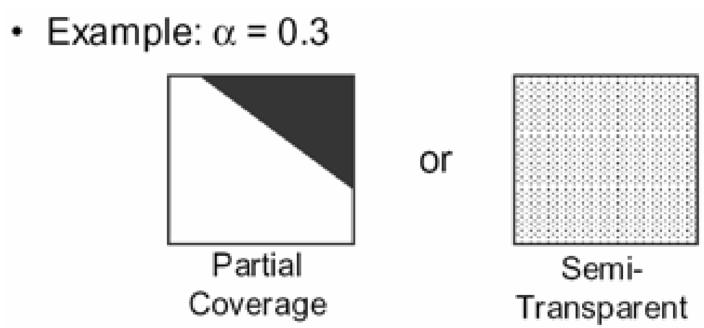
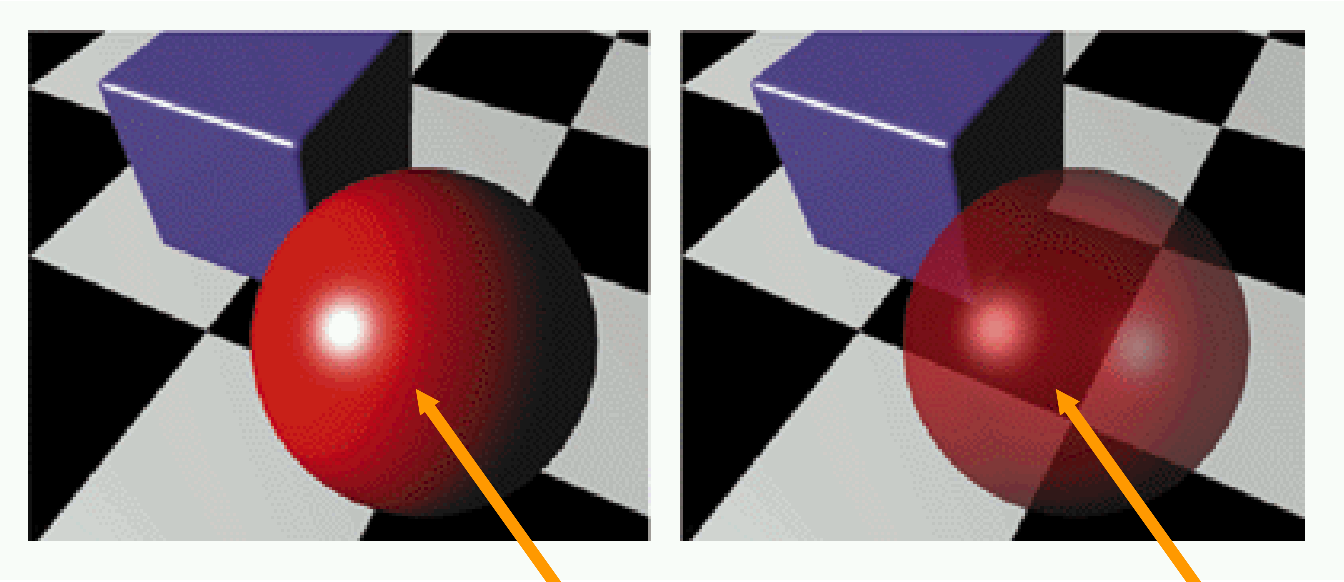


Image Combination: Alpha channel blending

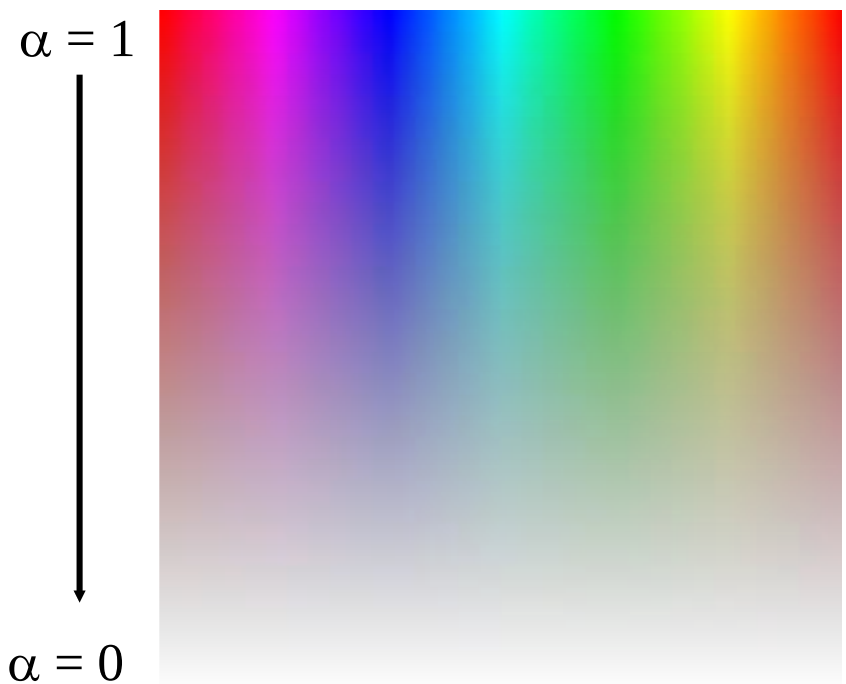


$\alpha = 1$ $\alpha = 0.5$

Image Combination: Alpha channel blending

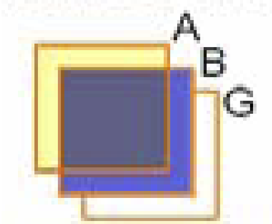
- Convention:
  - RGBA represents a pixel with color $C = (R, G, B)$ as

$$C = (ar, ag, ab, a)$$



Alpha Channels

- Suppose we put A over B over background G



  - How much of B is blocked by A?

$$\alpha A$$

  - How much of B shows through A?

$$(1 - \alpha A)$$

  - How much of G shows through both A and B?

$$(1 - \alpha A)\ (1 - \alpha B)$$