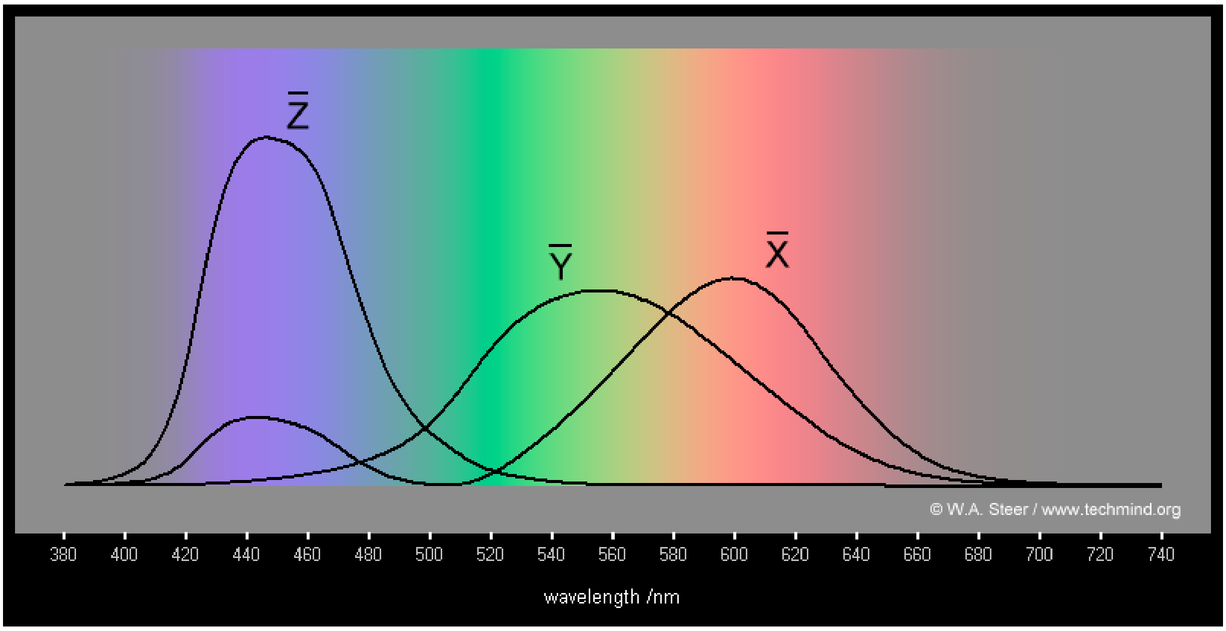
Introduction to the CIE Chromaticity diagram

Source: http://www.techmind.org/color/

Contrary to popular belief, "color" is not really an intrinsic property of the things we see around us. Rather, it is the sensation resulting from a given spectral distribution of light, detected by the three color-sensors in the eye and interpreted by the brain.

Eye sensitivity - color matching functions

Experiments in the 1920's enabled the response of the eye to be characterized. Essentially they involved getting students to match spectral colors (monochromatic light) using a color made by adding varying proportions of red, green and blue "primaries".



CIE 1931 Color matching functions for 2° observer

The three CIE color matching functions (CMFs) are called Xbar, Ybar and Zbar, and for practical color matching and display applications these can be treated as if they were the spectral response curves for the cone-receptors in the human eye. [Actual response curves for the eye are slightly different, but are closely mathematically related.] While it is convenient to think of X, Y and Z as red, green and blue, owing to their wide band and substantial overlap (especially of X and Y), this is a crude approximation. Furthermore, the X (*red*) function has a second lobe in the shortwave end of the visible spectrum!

It is important to note that because of the overlap of the functions, they are not fully independently stimulable, i.e. no physical light source can stimulate one channel while maintaining zero in the other two (although you can get close with the X channel by stimulating it with long wavelength red light).

A "color" is defined by the *relative* stimulus of the eye's XYZ channels (the actual magnitudes will define the brightness or intensity). It makes sense therefore to define a color by an *xyz* triplet which are normalized versions of *XYZ*:

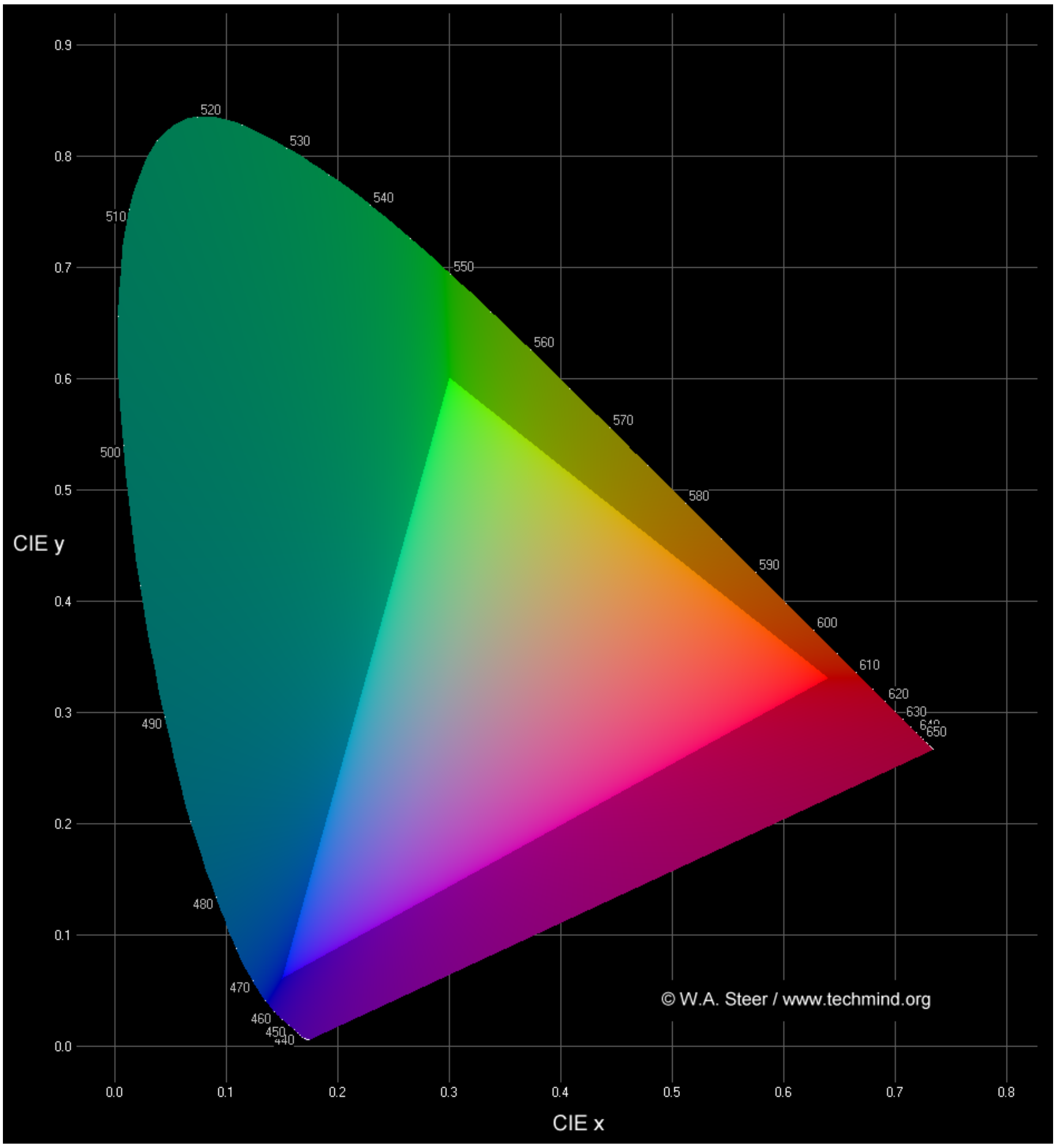
$$x = \frac{X}{X+Y+Z} \qquad y = \frac{Y}{X+Y+Z} \qquad z = \frac{Z}{X+Y+Z}$$

Of course, by definition now, $x + y + z = 1$. As such, only two out of the three *xyz* coordinates are needed to uniquely define a color.

It is conventional to define colors by their *x,y* coordinates. This then gives rise to the CIE chromaticity diagram...

1931 CIE Chromaticity diagram

The chromaticity diagram plots the entire gamut of human-perceivable colors by their *xy* coordinates defined earlier.



1931 CIE Chromaticity diagram

- The inverted-U shaped locus boundary represents monochromatic light, or ***spectral colors*** (loosely *rainbow colors*). [Wavelengths shown in nm]
- The lower-bound of the locus is known as the ***line of purples*** and represents non-spectral colors obtained by mixing light of red and blue wavelengths. In reality this boundary is not hard, as the colors just become dimmer and dimmer owing to the falloff in sensitivity of the receptors of the eye at the extreme ends of the visible spectrum.
- Colors on the periphery of the locus are saturated; colors become progressively desaturated and tend towards white somewhere in the middle of the plot. The point at $x = y = z = 0.333$ represents the ***white*** perceived from an equal-energy flat spectrum of radiation.
- Any color within a triangle defined by three primaries can be created (or recreated) by additive mixing of varying proportions of those primary colors.
- The brighter triangle in the centre of my plot shows the colors which can be reproduced by a standard CRT television or computer screen. The vertices have the color-points of what are known as Rec.709 primaries. The colors accessible to a given display-device are known as its ***gamut***.
- Colors outside my triangle are said to be out-of-gamut for, and ***cannot be reproduced*** on normal display screens (or even recorded in many common image file-formats). They are artificially desaturated in the plot above. Standard monitors are particularly incapable of reproducing saturated greens and turquoises. Mathematically, colors outside each edge of the triangle require a *negative* amount of light from the opposite primary. Clearly this doesn't make physical sense; what it means, essentially, is that the primaries defining the nearest edge themselves "contain" too much of the opposite primary color.
- I have taken great care to render my plot such that colors within the triangle will be displayed accurately on a PC with an *sRGB-compliant* monitor with *white point* set to 6500K whose *brightness* and *contrast controls* are properly set, assuming no (non-standard) *system gamma* control is in force.
- For all its simple derivation from eye-response functions, the 1931 CIE chromaticity diagram is not *perceptually uniform*. That is to say the *area* of any region of the plot does not correlate at all well with the number of perceptually-distinguishable colors in that region. In particular, the vast area of green-turquoise inaccessible to televisions and monitors is not -quite- as serious as it appears.

Other color-space coordinate systems and plots exist; examples include CIE 1976 *u,v*, also CIELUV, CIELAB... in general, by means of fairly abstract transforms these attempt to be more perceptually-uniform (with only limited success). Their use is fairly specialised. The simple and direct relation between CIE *x,y* and the eye-response functions probably accounts for its enduring popularity.