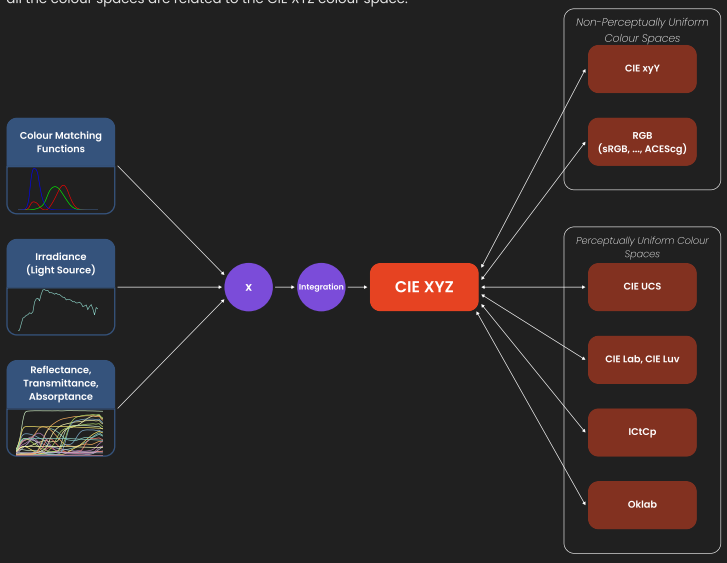
Colour Science Precis

for the CGI Artist

Colour Spaces

A colour space is defined as **the geometric representation of colour in space**. In CIE colorimetry, all the colour spaces are related to the CIE XYZ colour space.



CIE XYZ

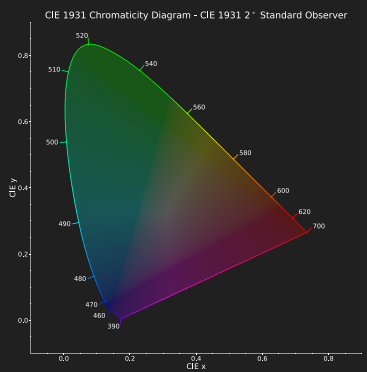
Spectral radiant energy is converted into CIE XYZ tristimulus values, *i.e.*, three dimensional geometric representation, by integrating the result of the product of the reflectance, transmittance or absorptance spectral distribution of a sample and the spectral distribution of a light source (or illuminant) with the colour matching functions, *i.e.*, linear combination of the cone cells sensitivities.

CIE xyY

The CIE xyY colour space is a projective transformation along the luminance axis (Y) of the CIE XYZ colour space that separates the luminance axis (Y) from chrominance plane (x and y axes).

The CIE 1931 Chromaticity Diagram is a visualisation all the colours seen by the CIE 1931 2° Standard Observer, *i.e.*, **standardised average human observer sensitivity for a 2° field of view**, on the CIE xyY colour space chrominance plane.

The curved edge forming the horseshoe shape is known as the Spectral Locus and is composed of physically realisable monochromatic, i.e., one wavelength, colours. The line that closes the horseshoe shape is known as the line of purples.



Perceptually Uniform Colour Spaces

The CIE xyY colour space's representation of colour distances does not correlate with perceptual differences. This discrepancy has led to the development of alternative colour spaces aimed at achieving perceptual uniformity, where ideally, a one-unit change would have a consistent perceptual impact in any direction.

However, no colour space has yet achieved complete uniformity across all perceptual attributes such as lightness, chroma, and hue. Different perceptually uniform colour spaces prioritise certain attributes at the expense of others, therefore, making them more suitable for specific applications despite the overarching goal of perceptual uniformity.

- **CIE UCS** : Used to represent the correlated colour temperature of light sources (or illuminants)
- **CIE Lab** : Current CIE recommendation
- **CIE Luv**: Adopted simultaneously with CIE Lab, used by the CIE 1976 UCS chromaticity diagram
- **IPT** : Excellent hue uniformity, used in gamut mapping applications
- **ICtCp** : Used for HDR imaging
- **Oklab** : Good perceptual uniformity, used by Cascading Style Sheets (CSS)
- **CAM-UCS** : Research state of the art

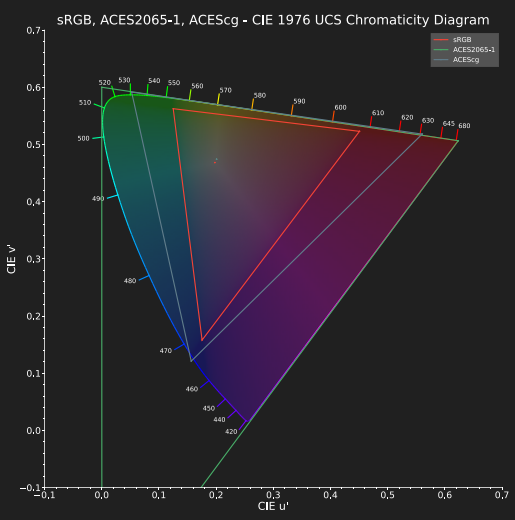
One objective for a perceptual uniform colourspace is the measure of colour differences, i.e., ΔE. The CIE recommends using the CIE 2000 colour difference formula which improves on measuring euclidean distances in CIE Lab.

RGB Colour Space

An additive RGB colour space, related to the CIE XYZ colour space by a matrix transformation, is fully specified by three components:

Primaries

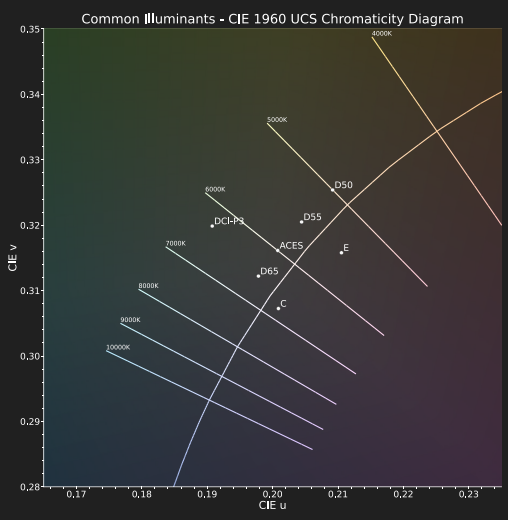
Colour primaries, typically specified as chromaticity coordinates, along with the device's dynamic range, define an RGB colour space's colour gamut, or the range of colours it can reproduce. Although RGB gamuts span a three-dimensional volume, they are frequently depicted as two-dimensional triangles on chromaticity diagrams for visual simplicity. Despite a preference for using uniform colour space representations, *e.g.*, CIE 1976 UCS Chromaticity Diagram, the non-uniform CIE 1931 Chromaticity Diagram remains a common choice for these illustrations.



Whitepoint

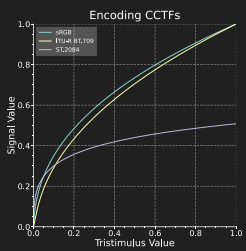
The whitepoint of a RGB colour space is the reference point that represents the colour perceived as pure white. It is obtained with full emission of the red, green and blue components.

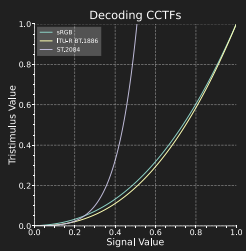
Colours lying on the neutral axis line passing through the whitepoint and the origin of the RGB colour space gamut, irrespective of their luminance, are achromatic.



Colour Component Transfer Functions

Colour Component Transfer Functions (CCTFs) are mathematical functions applied to the individual, *e.g.*, R, G, and B, colour channels of a colour space.





Encoding CCTFs, *e.g.*, Opto-Electronic Transfer Function (OETFs) used by digital cameras, convert RGB scene relative luminance to non-linear R'G'B' code values. Non-linear encoding is used for storage and bandwidth optimisation and to improve perceptual uniformity by leveraging the non-linearity of the HVS.

The primes in R'G'B' denotes the non-linearity of the encoded values.

Decoding CCTFs, *e.g.*, Electro-Optical Transfer Function (EOTFs) used by displays, TVs or projectors, on the other hand, convert non-linear R'G'B' code values back to RGB scene relative luminance.

It describes how, for example, a display, such as a TV or a projector, responds to an incoming electrical signal and converts it back into light.