Victor Steinberg

Video Standards

Signals, Formats and Interfaces

Part 2

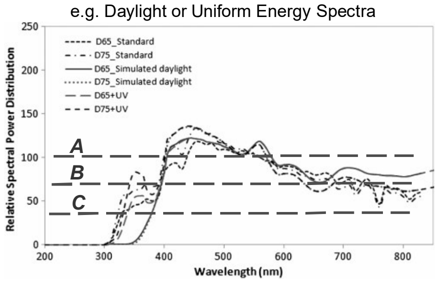
Color Perception & Color Rendition

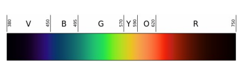
www.videoq.com

CIE 1931 XYZ Color Space

Object Spectrum:

e.g. Daylight or Uniform Energy Spectra

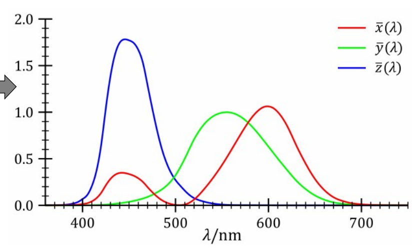


UV  IR

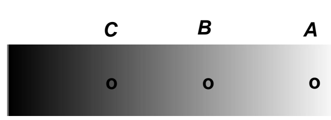
Visible Spectrum: 380…750 nm

Standard Observer:

X Y Z filters



Color Luminous Energy, cd/m² (nit) = Y



Normalization:

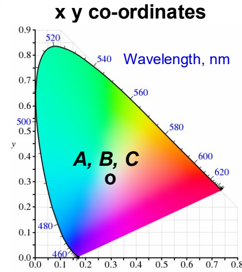
X Y Z ⇒ x y

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

Color Chromaticity:

x y co-ordinates



In **CIE XYZ** system (and in **SI** system) any ***subjectively perceived color*** is defined by:

1. **Y** = Luminance (absolute value in **cd/m²** aka **nits**)
2. **x, y** = Chromaticity (normalized values)

CIE 1931 RGB Color Space

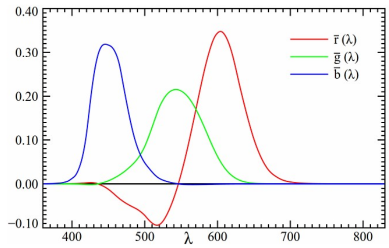
CIE XYZ to CIE RGB:

Vector Conversion Matrix:

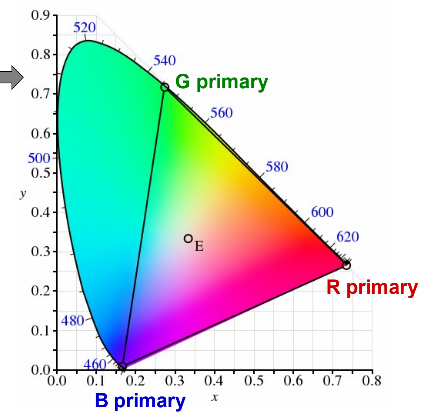
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.418{,}47 & -0.158{,}66 & -0.082{,}835 \\ -0.091{,}169 & 0.252{,}43 & 0.015{,}708 \\ 0.000{,}920{,}90 & -0.002{,}549{,}8 & 0.178{,}60 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

Color Matching Functions:

R G B filters



Gamut of the CIE RGB primaries
and location of these primaries
on the CIE 1931 xy chromaticity diagram



The CIE RGB color space is only **one of many RGB color spaces**, distinguished by a particular set of **3 primary colors.**

*In case of CIE RGB color space these primaries are monochromatic (single-wavelength) colors, but **in some other systems they are not**. Note the negative lobe of R filter. Real optical filters can not produce **negative** output. The RGB functions shown above are just a mathematical model. To produce correct RGB output signals modern cameras use **addition** & **subtraction** of "raw RGB" signals provided by the imager(s).*

Trichromacy & Color Rendition

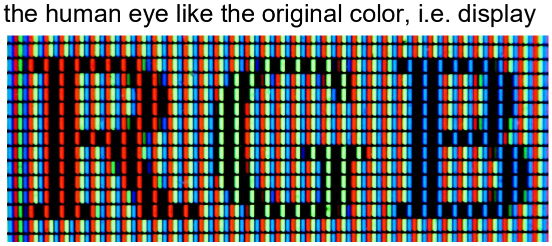
Trichromacy is the possessing of three independent **channels** for conveying color information, derived from the three different types of **cone cells in the eye**.

The XYZ and RGB systems exploit this human eye feature: the enormous amount of information contained in the original **spectral distribution** is reduced to just **3 numbers**.

Very useful side-effect of such transformation is the existence of an **infinite number** of spectral distributions resulting in the same XYZ or RGB values, i.e. sharing the same **perceived color**.

This is known as **metamerism**. Colors that match this way are called **metamers**.

RGB display does not provide for **spectral color match**; instead it produces the spectrum consisting of 3 narrow-band R, G and B light outputs, which **look** for the human eye like the original color, i.e. display always generates metamers.



So, color TV is an illusion (*or "cheat" if you like*).

BTW, "cheating twice" seldom works, that's why pointing your camera at the TV screen will never gives you good colors.

SD, HD and UHD RGB Color Spaces

SD (ITU-R BT.601)

Color space	White point (D_{65})		Primary color					
	x_W	y_W	x_R	y_R	x_G	y_G	x_B	y_B
625 line	0.3127	0.3290	0.640	0.330	0.290	0.600	0.150	0.060
525 line	0.3127	0.3290	0.630	0.340	0.310	0.595	0.155	0.070

HD (ITU-R BT.709)

Color space	White point		Primaries					
	x_W	y_W	x_R	y_R	x_G	y_G	x_B	y_B
ITU-R BT.709	0.3127	0.3290	0.64	0.33	0.30	0.60	0.15	0.06

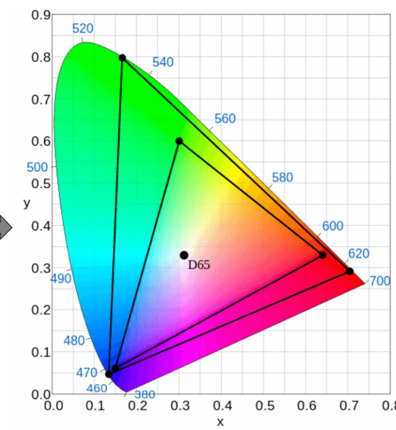
UHD (ITU-R BT.2020)

Color space	White point		Primary colors					
	x_W	y_W	x_R	y_R	x_G	y_G	x_B	y_B
ITU-R BT.2020	0.3127	0.3290	0.708	0.292	0.170	0.797	0.131	0.046

The bigger triangle is new Rec. 2020 (UHD), while the smaller one is Rec. 709 (HD). Clearly, there's a noticeable difference.

But this improvement affects only the rendition of super-saturated "vivid" colors, which very seldom appear in real life.

Note that human face (flesh tone), grass, sky, red flag and other "regular" colors (within the smaller triangle) look ***exactly the same*** on SD, HD and UHD screens.



YUV (YCbCr) & RGB Color Spaces

YCbCr aka **YUV** is a family of color spaces used as a part of the color image pipeline in video systems.
Big advantage of YUV color space is that any errors in UV (color difference) signals, such as significant loss of sharpness, are much less noticeable than the corresponding RGB errors.
The RGB to YUV conversion and inverse YUV to RGB conversion may produce marginal color shifts, especially if 8 bit signals are used. With proper processing these errors are usually not noticeable.

SD RGB to SD YUV Conversion:

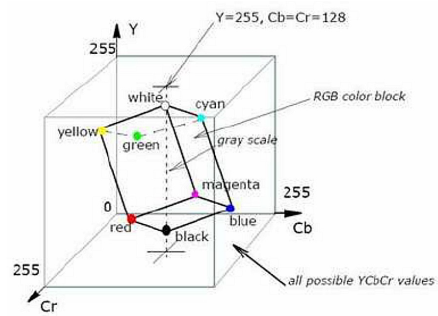
$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

HD RGB to HD YUV & HD YUV to HD RGB Conversion:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.2126 & 0.7152 & 0.0722 \\ -0.09991 & -0.33609 & 0.436 \\ 0.615 & -0.55861 & -0.05639 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

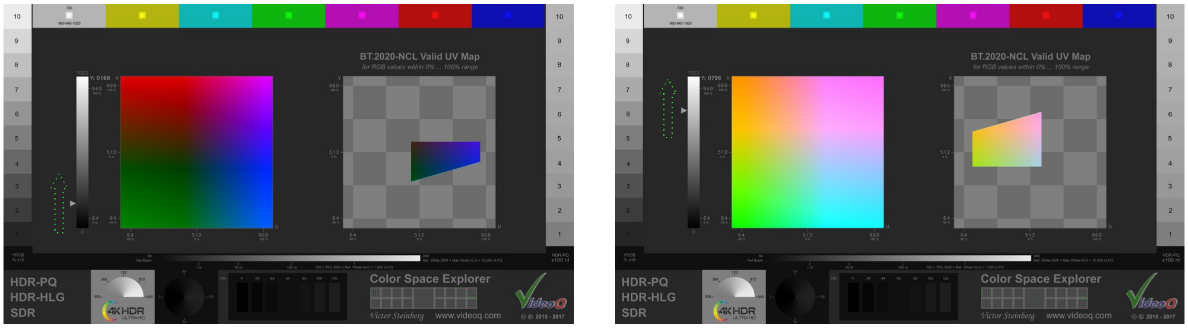
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1.28033 \\ 1 & -0.21482 & -0.38059 \\ 1 & 2.12798 & 0 \end{bmatrix} \begin{bmatrix} Y \\ U \\ V \end{bmatrix}$$

8 bit YUV (YCbCr) Cube vs. RGB Cube



This diagram shows that only ***some*** combinations of YUV values (so called "valid" or "legal" colors) correspond to valid RGB values.

VQCSX – VideoQ Color Space Explorer ™ Dynamic Test



Time

In 50 seconds this sophisticated dynamic source tests more than one billion (**1024^3**) colors of the **10 bit YUV** color space. Thus it covers **all combinations of Y, U and V values** – from 0 to 1023 in each channel, including all "illegal" colors.

VQCSX is equally suitable for **SDR**, **HDR-PQ** and **HDR-HLG** systems, checking processors, codecs and display performance. VQCSX is also suitable for both visual and instrumental tests, the results are visible on regular video monitors, waveform monitors and/or vectorscopes. VQCSX is especially efficient in combination with the VideoQ **VQV** Viewer-Analyzer tool.

About This Presentation

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Based on the book
"Video Standards: Signals, Formats and Interfaces" by Victor Steinberg
Published by Snell & Wilcox

For further reading we recommend wikipedia.org

About VideoQ

Company History

- Founded in 2005
- Formed by an Engineering Awards winning team sharing between them decades of global video technology.
- VideoQ is a renowned player in calibration and benchmarking of video processors, transcoders and displays, providing tools and technologies instantly revealing artifacts, problems and deficiencies, thus raising the bar in productivity and video quality experience.
- VideoQ products and services cover all aspects of video processing and quality assurance - from visual picture quality estimation and quality control to fully automated processing, utilizing advanced VideoQ algorithms and robotic video quality analyzers, including latest UHD and HDR developments.

Operations

- Headquarters in Sunnyvale, CA, USA
- Software developers in Silicon Valley and worldwide
- Distributors and partners in several countries
- Sales & support offices in USA, UK