Lecture 11: A Bit More Color

October 8, 2019
Back to the 1930s

• When are 2 colors perceived the same?

“In the 1920s two color scientists, W. D. Wright and J. Guild, each performed similar color vision experiments. Wright performed his experiment on 10 subjects, Guild used 7. Their results agreed with each other so well that they were combined by CIE to create the RGB color matching functions ...” *


And Our Goal - Understand

C.I.E. 1931 Chromaticity Diagram

Edit 2017: This was the first thing I ever wrote about color. I’m older
Credit Where Credit is Due

The next couple of slides are going to draw upon images and flow from ....
Combine Three Light Sources

Variable power, fixed wavelength lamps

Lamp power controls

Test subject

Fixed power, variable wavelength lamp

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Visible light

Gamma rays | X rays | Ultraviolet | Infrared | Microwaves | Radio

380nm 400nm 450nm 500nm 550nm 600nm 650nm 700nm 750nm

10pm 10nm 1mm 10cm

10/8/19
RGB Matching Spectrum Curves

CIE 1931 RGB color matching functions

Negative Red ??
A Clever Idea – Add to Other Side

Adding on in this side is subtraction on the other.
The numbers in the conversion matrix below are exact, with the number of digits specified in CIE standards.[14]

\[
\begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix}
b_{11} & b_{12} & b_{13} \\
b_{21} & b_{22} & b_{23} \\
b_{31} & b_{32} & b_{33}
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix}
0.49000 & 0.31000 & 0.20000 \\
0.17697 & 0.81240 & 0.01063 \\
0.00000 & 0.01000 & 0.99000
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}
\]

While the above matrix is exactly specified in standards, going the other direction uses an inverse matrix that is not exactly specified, but is approximately:

\[
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix} = \begin{bmatrix}
0.41847 & -0.15866 & -0.082835 \\
-0.091169 & 0.25243 & 0.015708 \\
0.00092090 & -0.0025498 & 0.17860
\end{bmatrix} \cdot \begin{bmatrix}
X \\
Y \\
Z
\end{bmatrix}
\]

https://en.wikipedia.org/wiki/CIE_1931_color_space
Another Great Reference

Excerpted on the following two slides.

https://www.youtube.com/watch?v=82lpxqPP4I
The XYZ Color Plane

Color Space
X-Y-Z

Unit Plane:
at 1 unit
on each
color axis

© CBlackwell 2012
The CIE XYZ color space was deliberately designed so that the $Y$ parameter is a measure of the luminance of a color. The chromaticity is then specified by the two derived parameters $x$ and $y$, two of the three normalized values being functions of all three tristimulus values $X$, $Y$, and $Z$: \[ x = \frac{X}{X + Y + Z} \]
\[ y = \frac{Y}{X + Y + Z} \]
\[ z = \frac{Z}{X + Y + Z} = 1 - x - y \]
Now, Chromaticity Again

Around the outside, pure monochromatic light.

Inside blended XYZ colors.

Center is ‘white’

Triangle is expressible with standard red, green blue emitters.
Expanded Gamut

https://medium.com/hipster-color-science/a-beginners-guide-to-colorimetry-401f1830b65a
Back to Good Old RBG

• Recall basic RGB triple and Hex

Red | Green | Blue
---|---|---
00110110 | 11110001 | 00110110

54 241 54  Sample

Red | Green | Blue
---|---|---
00110110 | 11110001 | 00110110

36 F1 36
Something to See Through

- A good way to use the last byte :-) 
- Consider a 32 bit word ...

Alpha controls blending
- Alpha equals zero means transparent
- Alpha equals one (255) completely covers
- Alpha equal one half (127) is 50/50 mix
Color Temperature

The color temperature of a light source is the temperature of an ideal black-body radiator that radiates light of a color comparable to that of the light source. Color temperature is a characteristic of visible light that has important applications in lighting, photography, videography, publishing, manufacturing, astrophysics, horticulture, and other fields. In practice, color temperature is meaningful only for light sources that do in fact correspond somewhat closely to the radiation of some black body, i.e., light in a range going from red to orange to yellow to white to blueish white; it does not make sense to speak of the color temperature of, e.g., a green or a purple light. Color temperature is conventionally expressed in kelvins, using the symbol K, a unit of measure for absolute temperature.

Color temperatures over 5000 K are called "cool colors" (bluish), while lower color temperatures (2700–3000 K) are called "warm colors" (yellowish). "Warm" in this context is an analogy to radiated heat flux of traditional incandescent lighting rather than temperature. The spectral peak of warm-colored light is closer to infrared, and most natural warm-coloured light sources emit significant infrared radiation.
Examples of Blending
What About HDR

HDR ... High Dynamic Range (when applied to color)

• Think first about the sensor
  – Limiting case - Hyperspectral
• Next about the image representation
  – 16 bits per pixel per channel?
• Finally about the display
  – 10 bits per channel?
Hyperspectral Satellite

HyperSat reveals hyperspectral plans
by Debra Werner — October 5, 2018

Start up HySpecIQ awarded a contract in 2014 to Boeing to build its hyperspectral imaging satellites. HySpecIQ then halted work on its constellation due to a decline in energy prices. This image depicts the output of a hyperspectral sensor, which gathers information on light reflected in every pixel. Credit: Boeing

https://spacenews.com/hypersat-funds/
RGB Reference Images

In the interest of digital imaging research, I am providing a set of four images that represent "perfect" images, that is, they represent a natural scene (as opposed to say, a test pattern or a gradient) which is completely void of any noise, aliasing or other image artifacts. They were taken with a virtual, six mega-pixel camera using a ray tracing program I wrote myself. The intensity of each pixel was computed in double precision floating point and then compacted and quantized to 8- or 16-bits per channel at the last possible moment before writing the image file. The four variations represent all combinations of 8- or 16-bits per channel and gamma of 1.0 or 2.2. I believe these images will be useful for research purposes in answering such questions as "How many bits are needed to avoid visual defects?" and "How does one determine the number of bits of real image information, as opposed to digitized noise?" In this sense, they may provide ideal image references against which actual digitized images may be compared by various visual or statistical analysis techniques.

The scene is titled Delta E and represents an imaginary view of my imaginary desktop (I am a color scientist).

I offer these images for research and other non-commercial purposes. In consideration of the time and effort put forth in their preparation, I request that my copyright notice accompany them wherever they are used.
Display Color HDR

El Capitan quietly added 10-bit color support for new 5K iMac

BY LUKE DORMEHL • 4:02 AM, OCTOBER 30, 2015
Closing Thought: About Sound, Sight, Perception and Being Picky

- Are there ‘audiofiles’ of color?
- I grew up steeped in ‘golden ears’
- What is a ‘golden eye’?

http://www.stereophile.com/content/beveridge-2sw-loudspeaker-system#kVx50V6YADZ6ve7x.97