Colors Space

Stephen J. Guy

Sep 27, 2017

HW 1 Questions?

Common Issues

- Bad Pixel Math
  - (Pixel1 + Pixel2)/2 ---- what's wrong?
  - .1*Pixel1 + .2*Pixel2 + … + .1*Pixel 10 --- wrong?
  - Unwanted Quantization
- Solution
  - Work with floats, then convert to pixels

3

Common Issues

- Editing Image in-place
  - Blur, Sharpen, Edge Detect, etc. all want you to edit the passed in image directly
  - This allows you to chain multiple edits
  - We need to separate source and destination image to get the math right
- Solution
  - Don't edit in place!
  - Write to a new image, then update values of *this* image
  - OR copy this image, to use as the source

4

Common Issues

- Ordered Dither is Confusing
  - Not clear the best way to apply the bayer matrix at arbitrary bit depths
- Solution
  - I don't care about the fine-grain details here
  - Just add some spatial structure to your dithering method based on the Bayer4 matrix

5

Common Issues

- My Edge Detect is not pretty
  - Edges look weird and noisy
- Solution
  - Good edge detect is more than a simple convolution
  - Try to darken the image first to only get bright edges
  - ...or shrink (then scale back up) the image to only get larger edges

6

Common Issues

- Gaussian and Bilinear look too similar
  - When I do reconstruction I can't see differences between the sampling methods
- Solution
  - Try a bigger resize (700x700 -> 200x200)
  - Use a much larger radius in reconstruction

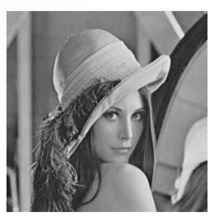
7

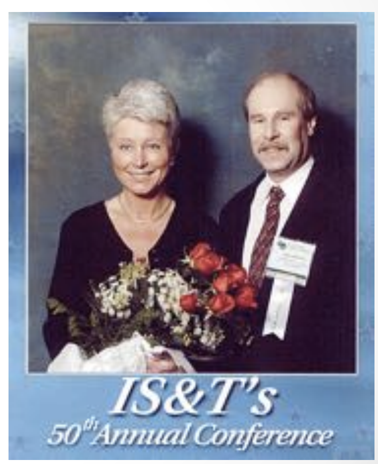
Common Issues

- There is no reference solution for common issues
  - How can I know my implementation is right?
- Solution
  - This was intentional, I want you to:
  - 1) Inspect the results by eye, do they look like what I would hope?
  - 2) Create your own test images!
    - E.g., black and white checkerboard
    - Single line against a solid color background

8

Lena Sjööblom





10

Colors Spaces

Recap

- CRT vs LCD vs LED
  - Electron Beam vs Polarized Light (CRT vs L*D)
  - Backlight technology (LCD vs LED)
- What is Gamma correction
  - Accounting for the power law relationship between intensity and luminance
- Given an sRGB display, what is the gamma law?
  - Lum = input$^{2.2}$
- Why are color spaces 3 dimensional? RGB, HSV, …
  - Humans have tri-chromatic vision.
- Physical spectrum → Perceptual Color?
  - Hue is peak; Saturation is rel peak height; Bright is area

12

Intuitive Color Spaces

HSV is an intuitive color space, corresponding to our perceptual notions of tint, shade, and tone

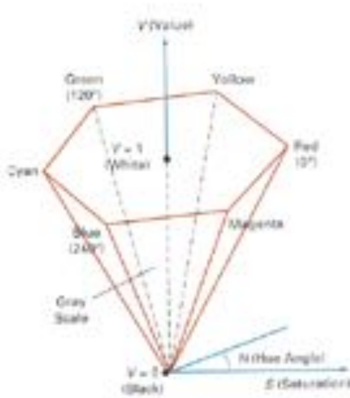
Hue (H) is the angle around the vertical axis

Saturation (S) is a value from 0 to 1 indicating how far from the vertical axis the color lies

Value (V) is the height of the "hexcone"

HSV

- HSV tries to sort RGB values in a perceptually meaningful ways



H	S	V	Color
0	1.0	1.0	Red
120	1.0	1.0	Green
240	1.0	1.0	Blue
*	0.0	1.0	White
*	0.0	0.5	Gray
*	*	0.0	Black
60	1.0	1.0	
270	0.5	1.0	
270	0.0	0.7	

Figure 15.16&15.17 from H&B

14

Quiz

1. My new shirt looked black when I brought it, but green when I wore it outside, what happened?

2. What happens:
   -When you mix blue and yellow light?
   -When you mix blue and yellow paint?

3. Why do printers use CMY, but monitors use RGB?

15

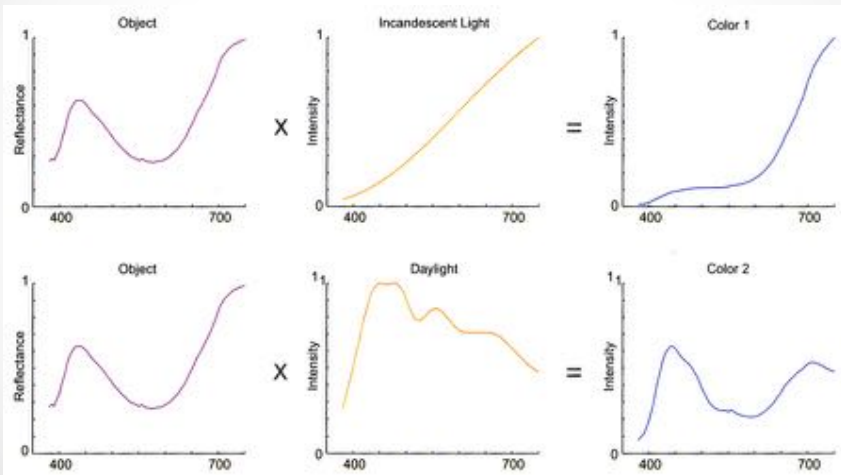
Quiz 1

- My new shirt looked black when I brought it, but green when I wore it outside, what happened?

Metamerism

16

Reflection from colored surface



[Stone 2003]

Color – A Function of Light

Have you ever seen a paint chip or color that you absolutely loved in a store but found it looked completely different when you took it home? You've just experienced "metamerism," a phenomenon whereby colors seem to change when viewed under different light sources. It's always best to view color swatches in the actual space and lighting conditions in which they'll be used. Some colors are particularly prone to metamerism, including tans, taupes, grays, grayed-blues, mauves, lilacs and grayed yellow-greens.

Did You Know

Surrounding colors impact how any one color is perceived. An ivory wall can appear pink when paired with a vibrant red carpet.

Considered the ideal light source, natural sunlight maintains a neutral balance between the warm (yellow cast) and cool (blue cast) ends of the light spectrum. Northern light is the coolest, while light from a southern exposure is most intense. Here, direct sunlight provides the truest rendition of the colors in this room.

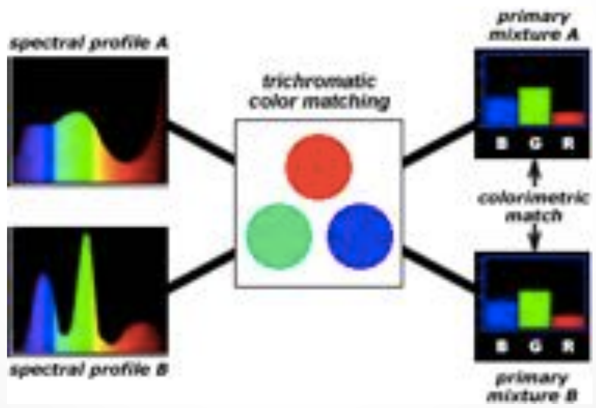
Natural sunlight is not consistent. It changes throughout the day, from sunrise to sunset. The intense golden rays and subsequent distinct shadows of a sunny, late afternoon have a profound effect on the colors in this room.

The color rendition in this room appears warm under incandescent and halogen lights, where reds and yellows are enhanced, and blues and greens are dulled. Under the cool cast of fluorescent lights, blues and greens are enhanced, while reds and yellows are muted.

Benjamin Moore Color Language 2010

Trichromatisism

- Remember, our eyes decompose the complex frequency spectrum down to 3 floats!



www.handprint.com

19

Dealing with Metamerism

- You brain automatically attempts to account for metamerism
  - By looking at the "average" illumination throughout the scene and guessing what the original color was
  - Known as: **Color constancy**

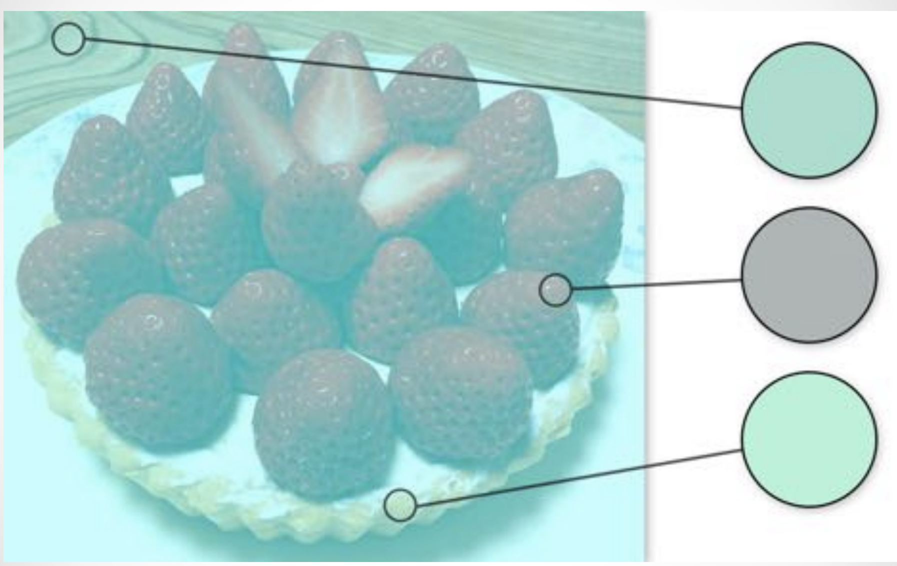
- Recreating this process in photography is know as: *White Balancing* or *Color balancing*
  - Assume darkest region is black, brightest is white, correct other regions

20

Strawberries Illusion

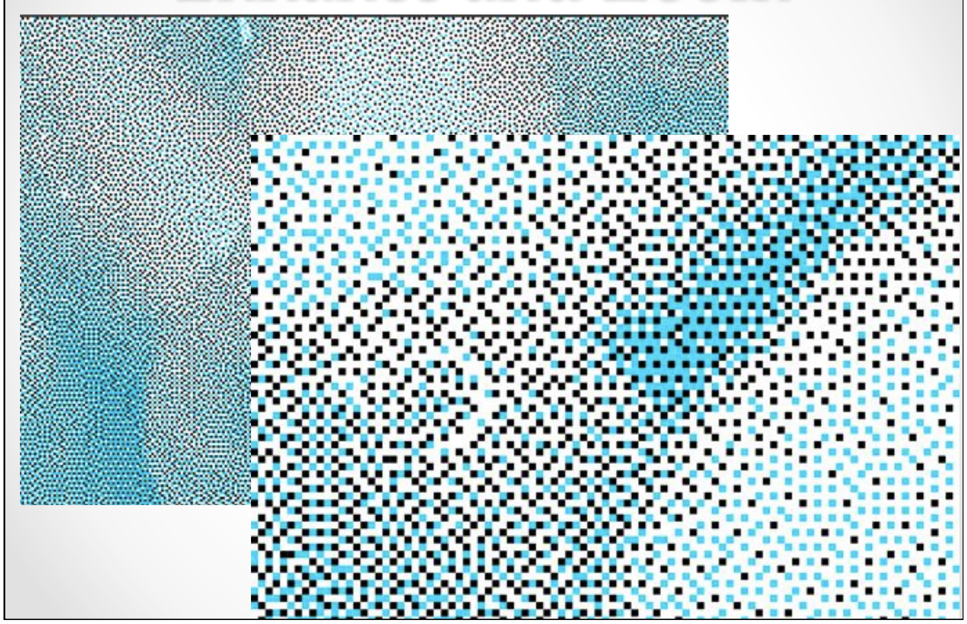
There are no red pixels!

21



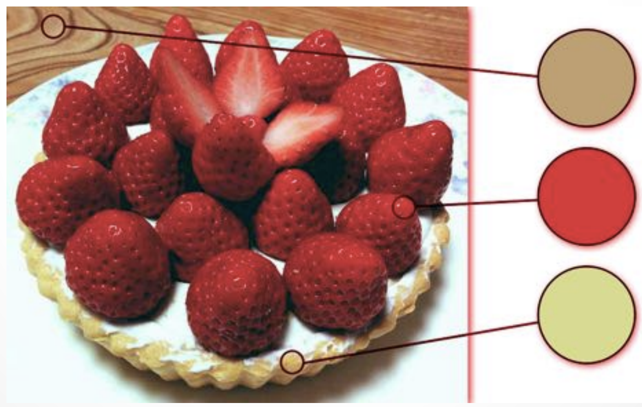
KingDavid73
https://imgur.com/a/y9TGC

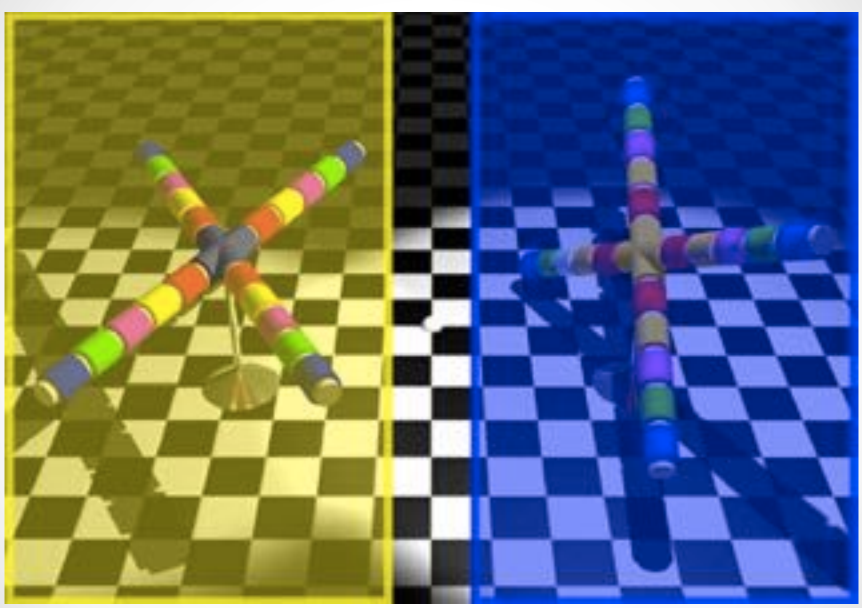
Enhance and Zoom

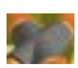


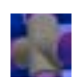
Color Balancing

- We can apply a white balancing transformation to all the pixels to recover the original image



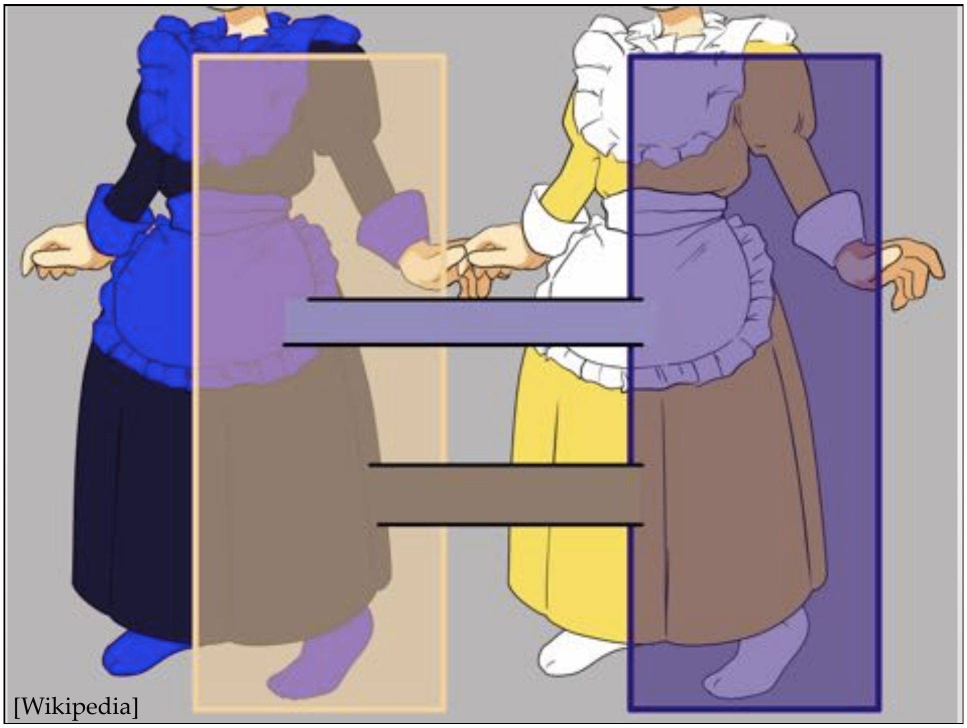






The Dress

29



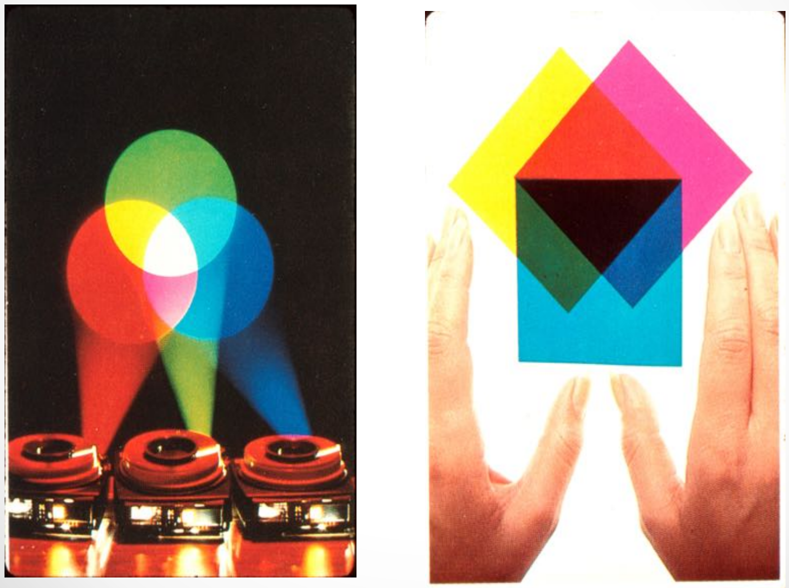
Quiz 2 & 3

- What happens when you "add" yellow & blue
- Why do monitors use RGB and printers CMYK

Reflection vs Emission

32

Additive v. Subtractive Colors



[source unknown]

Non RGB Color Spaces

- Why not just use RGB?
  - Redundancy (similar colors with different RGB values)
  - Non perceptual uniformity (e.g., some very different colors with similar RGB values)
  - Not semantically useful (e.g., difficulty to quickly get brightness)
- Alternatives
  - HSV
  - CIELAB, CIELUV
  - YUV, YCbCr

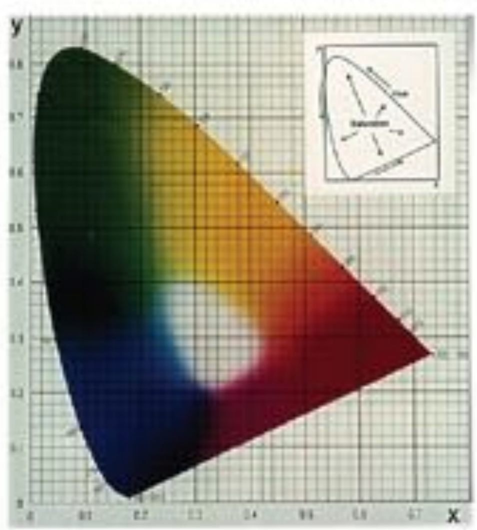
34

Perceptual Color Models

- Can we build perceptual color models?
  - o Models of color the directly account for the human color experience
- Experiments reveal 3 main axis of color vision
  - o Light-Dark
  - o Red-Green
  - o Yellow-Blue
- What's the evidence?
  - o Light green OK; Dark-Green OK; Bluish-Green OK; Reddish-Green?! NO
  - o Also: Afterimages (see next slide…)

35

Chromaticity Design



Converting from RGB to XYZ is a snap:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 2.77 & 1.75 & 1.13 \\ 1.00 & 4.59 & 0.06 \\ 0.00 & 0.57 & 5.59 \end{bmatrix} \begin{bmatrix} R_\lambda \\ G_\lambda \\ B_\lambda \end{bmatrix}$$

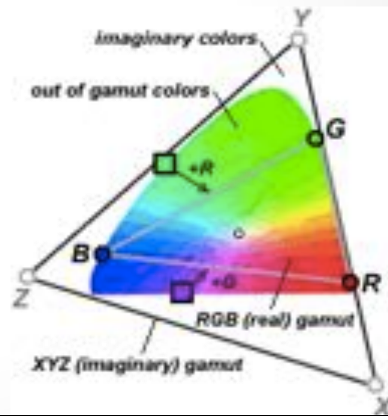
$$x = \frac{X}{X+Y+Z}$$

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

Given x, y, and **Y**, we can recover the **X**,**Y**,**Z** coordinates

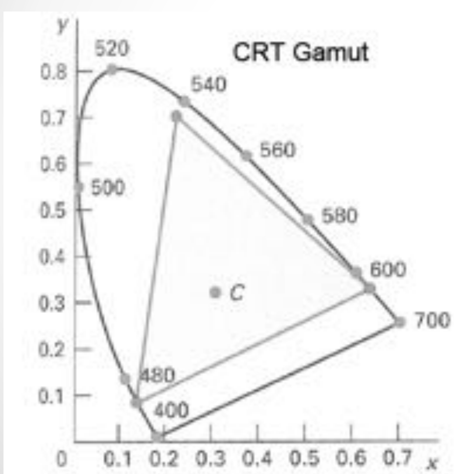
Gamut

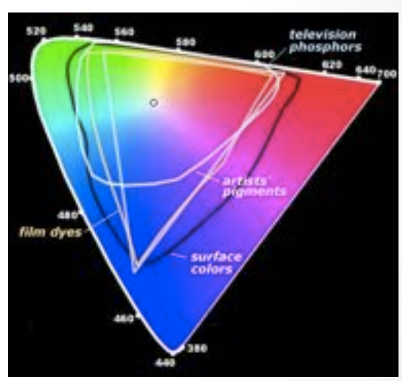
- Gamut is a range of colors
- Colors can only be added not subtracted
- So you can only get colors within the polygon defined by your extrema points
- Colors can can perceive are non-convex so we must use non-perceptible colors as basis

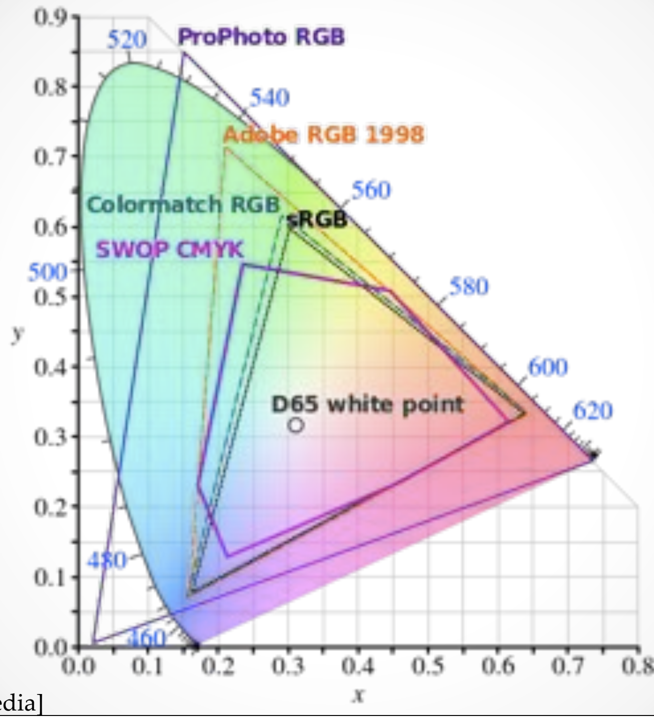


Gamuts

- Not all colors can be reproduced





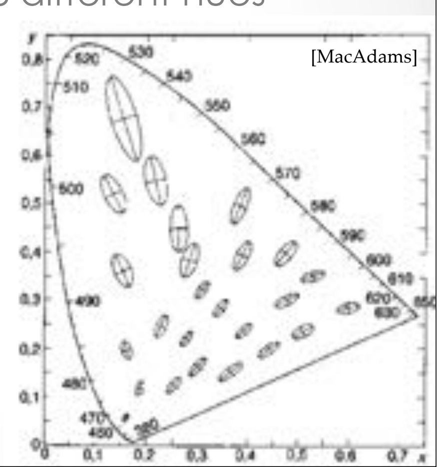


[Wikipedia]

41

Perceptual Non-Uniformity

- The ability to separate two different colors varies of hue, saturation, and brightness
  - o Humans see about 128 different hues
- Distances in RGB (or HSV or XYZ or xyY) do not capture perceptual differences in color!



[MacAdams]

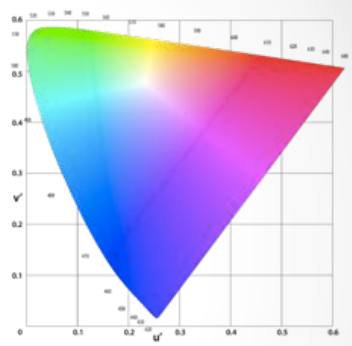
Perceptually uniform spaces

- Two major spaces standardized by CIE
  - designed so that equal differences in coordinates produce equally visible differences in color
  - LUV: earlier, simpler space; *L**, *u**, *v**
  - LAB: more complex but more uniform: *L**, *a**, *b**
  - both separate luminance from chromaticity
  - including a gamma-like nonlinear component is important

 43

Computing LUV

$$u' = \frac{4X}{X + 15Y + 3Z} = \frac{4x}{-2x + 12y + 3}$$
$$v' = \frac{9Y}{X + 15Y + 3Z} = \frac{9y}{-2x + 12y + 3}$$



$$L^* = \begin{cases} \left(\frac{29}{3}\right)^3 Y/Y_n, & Y/Y_n \le \left(\frac{6}{29}\right)^3 \\ 116\,(Y/Y_n)^{1/3} - 16, & Y/Y_n > \left(\frac{6}{29}\right)^3 \end{cases}$$
$$u^* = 13L^* \cdot (u' - u'_n)$$
$$v^* = 13L^* \cdot (v' - v'_n)$$

44

Color Space Zoo

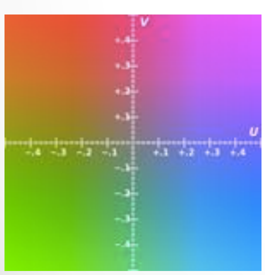
- **RGB**, **CMYK**, **sRGB**
  - o Designed to match display technology
- **HSV**
  - o Semantically meaningful color space
- **XYZ** (CIE 1931)
  - o Can predict which power distributions will be seen the same by a human
- **CIELAB** and **CIELUV**
  - o Perceptually uniform (distances have meaning)
  - o Derived from XYZ
  - o LUV is simpler to compute, LAB is a bit more robust
- **Y'UV**, **YIQ**, **YCC**, **YCbCr**, **YPbPr**
  - o Based on television distribution or image storage needs
  - o Supports perceptual compression

45

Y'UV Color Space

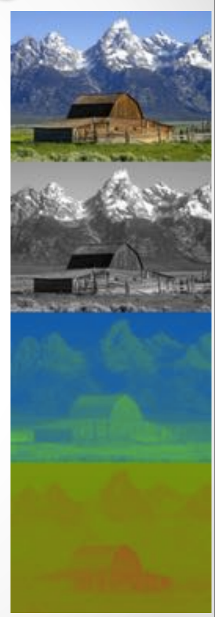
- Store luminance Y in one channel, and 2D color UV in other channels

$$Y' = 0.299 \times R + 0.587 \times G + 0.114 \times B$$
$$U = -0.147 \times R - 0.289 \times G + 0.436 \times B$$
$$V = 0.615 \times R - 0.515 \times G - 0.100 \times B$$



Y' = .5

[Wikipedia]

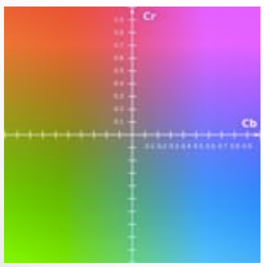


Y'CbCr Color Space

- Store luminance Y in one channel, and 2D color CbCr in other channels

$$
\begin{aligned}
Y' &= & 0.299 \cdot R' &+ & 0.587 \cdot G' &+ & 0.114 \cdot B' \\
P_B &= - & 0.168736 \cdot R' &- & 0.331264 \cdot G' &+ & 0.5 \cdot B' \\
P_R &= & 0.5 \cdot R' &- & 0.418688 \cdot G' &- & 0.081312 \cdot B'
\end{aligned}
$$

$$(Y', C_B, C_R) = (16, 128, 128) + (219 \cdot Y, 224 \cdot P_B, 224 \cdot P_R)$$



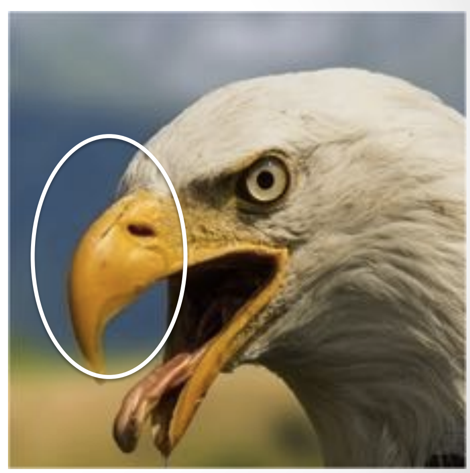
Y' = .5

[Wikipedia]

Example –spacediver@avsforum.com

8x8 block of pixels share same $C_B C_R$ value

Original



Quantized

Example

8x8 block of pixels share same $C_B C_R$ value

Original

Quantized + BiLinear Filtering

Even Better Compression

- Use bigger blocks than 8x8 with more complex representations
  - Dynamically choose block size
- Compress Y signals
- Start with previous pixel block as baseline

References

- MAC ADAM D.L., Specification of small chromaticity differences (p.pp18-26), J. Opt. Soc. Am, 1943--, n° vol. 33, .
- http://www.dailymail.co.uk/news/article-2971409/What-color-dress-White-gold-blue-black.html
- https://www.youtube.com/watch?time_continue=1&v=3wbXA717puU
- https://www.youtube.com/watch?v=iPPYGJjKVco
- http://dew.globalsystemsscience.org/activities/investigations/making-color-with-light/color-basics-in-light-and-paint

51