Lecture 16
Color

October 20, 2016

Where are we?

- You can intersect rays surfaces
- You can use RGB triples
- You can calculate illumination:
  - Ambient, Lambertian and Specular
- But what about color, is there more to know
  - Yes …

Basics: What is Color?

- Eyes, films and CCD/CMOS cameras all convert light into electrical energy
  - More intensity => higher (brighter) value

- This is sufficient for black-and-white (i.e. intensity) images

- What about color?

The Physics View

- Coherent light has a wavelength
  - Visible range typically described as:
  - 380nm (deep purple) to 780 nm (pure red)
- Natural light mixes many frequencies
  - Roughly equal across the spectrum ‘white’
  - Prisms split light by frequency (rainbows)
- Wavelengths ≠ perceptual colors
  - Metamers: wavelength combinations appearing the same to normal human observers

Eye Can See

- Human Receptors 101
- Rods = grayscale
- Cones = color
  - Generally RGB
- Both ‘count’ photons
- Rods highly sensitive
- Cones need a lot of light

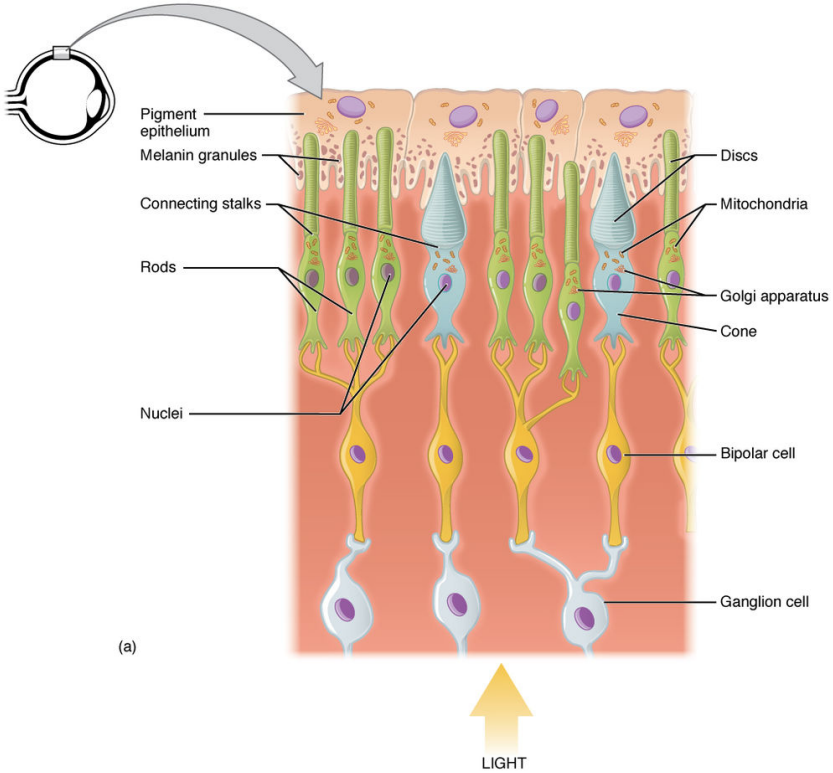


Illustration from Anatomy & Physiology, Connexions via Wikipedia

For Most People – 3 Flavors

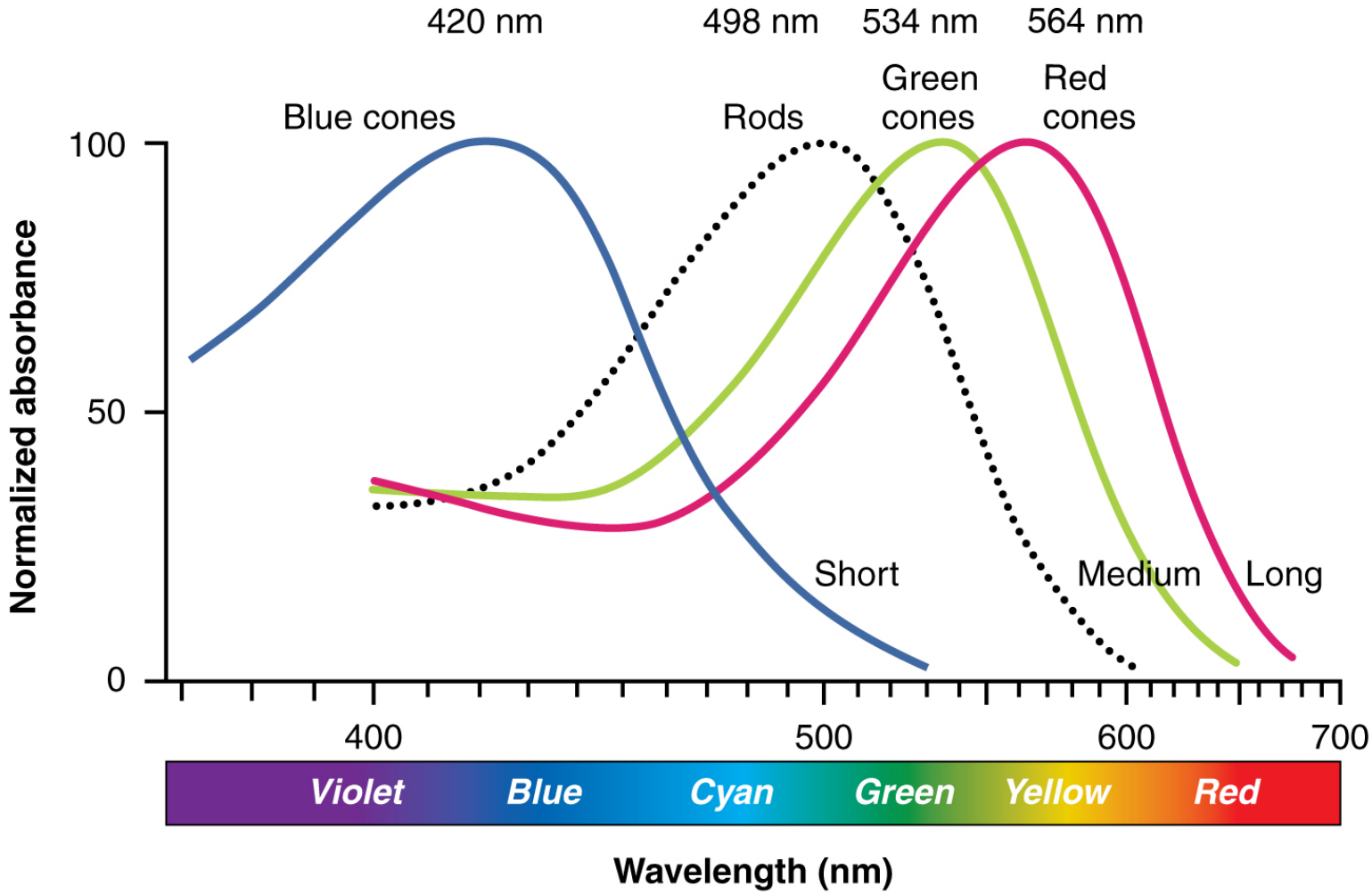


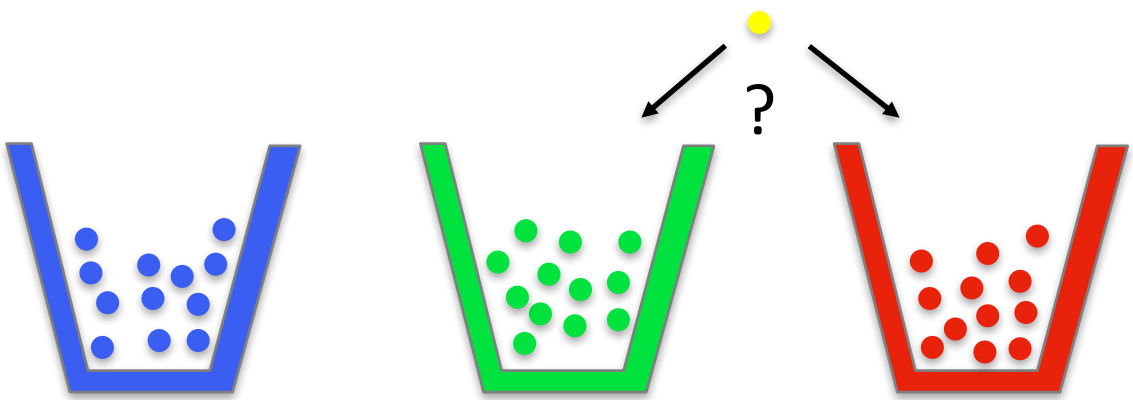
Illustration from OpenStax College - Anatomy & Physiology, Connexions Web site. http://cnx.org/content/col11496/1.6/ via Wikipedia

Integration Over Time

Catch photons in a bucket – a metaphor.

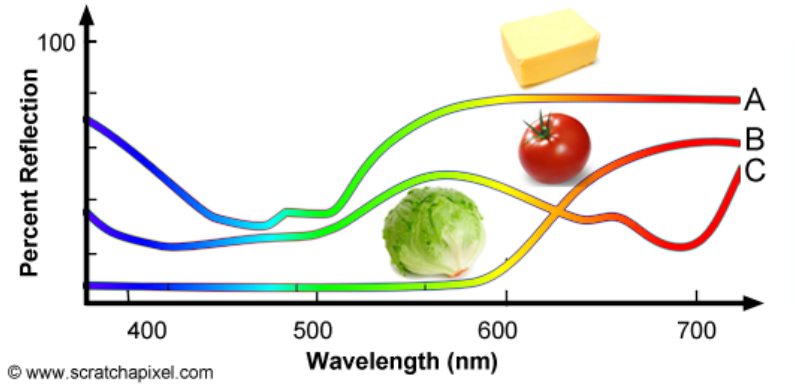
First simple model, photons in 3 flavors

But: what about a 551 nm photon?

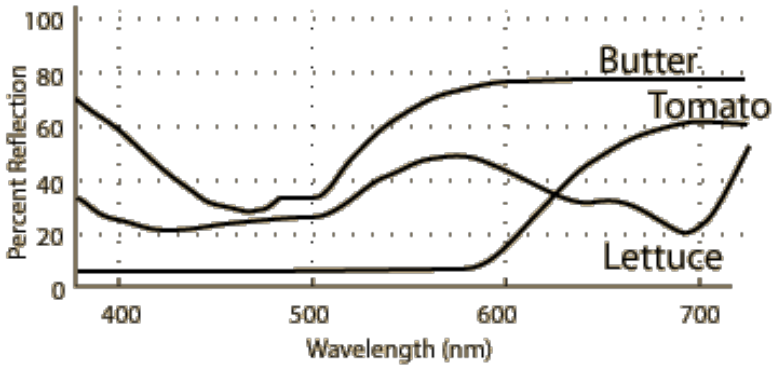


Spectral Power Density

- An illuminated object throws off an entire festival of different wavelength photons.



http://www.scratchapixel.com/old/assets/Uploads/Lesson004/l004-spd.png?

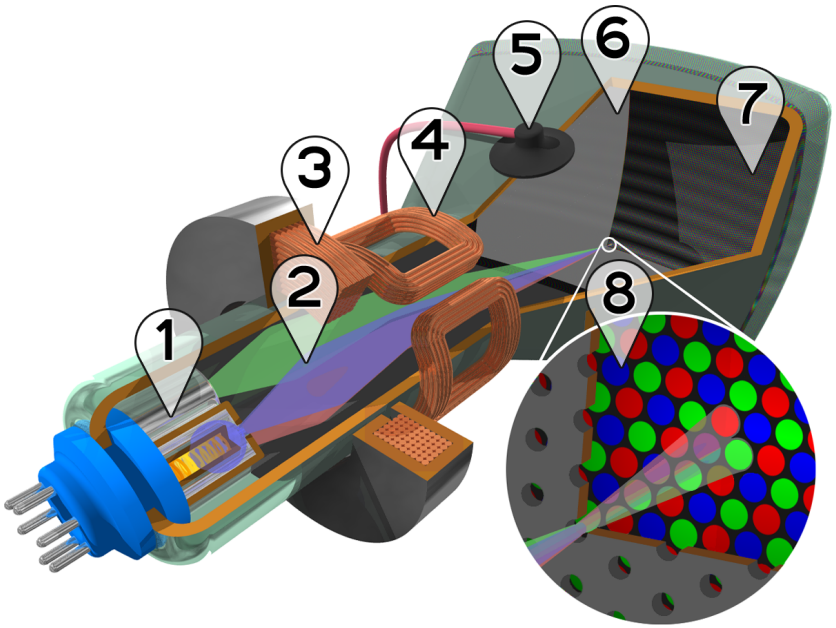


http://hyperphysics.phy-astr.gsu.edu/hbase/vision/spd.html

Your eye takes all this rich information and transduces it through essentially three accumulators, your RGB cones.

Displays: Clever Fakes?

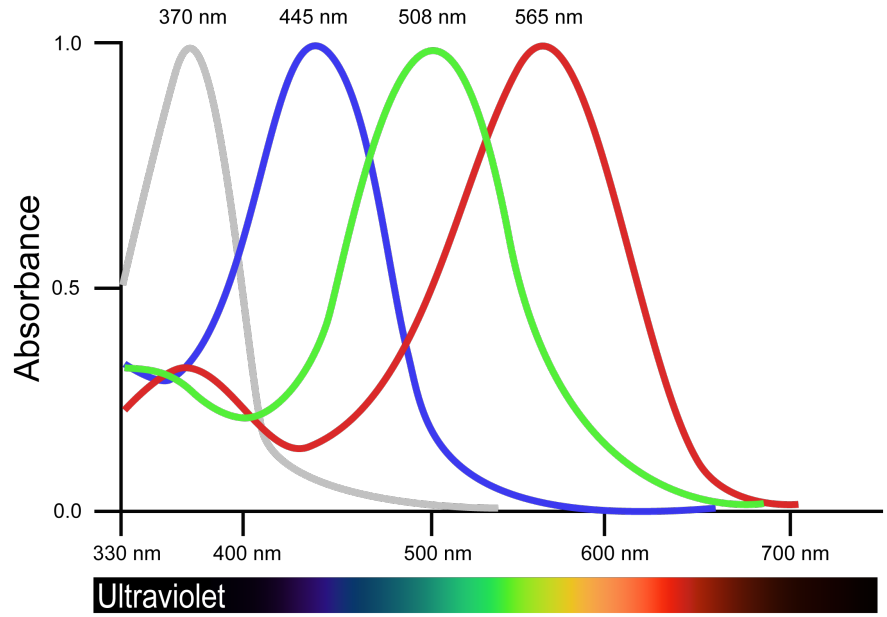
- So how does a display create color images?
  - By stimulating R,G and B cones
- This is(was) easy to explain for TVs



This image and associated numeric key to the right is from wikimedia.
https://commons.wikimedia.org/wiki/File:CRT_color_enhanced.png

1. Electron guns
2. Electron beams
3. Focusing coils
4. Deflection coils
5. Anode connection
6. Mask for separating RGB beams
7. Phosphor layer with red, green, and blue zones
8. Close-up of the phosphor-coated inside

Do Others Do It Differently?



"Uncorrected absorbances of visual pigments of birds based on Pryke, Sarah R. (2007)" from https://commons.wikimedia.org/wiki/File:BirdVisualPigmentSensitivity.svg

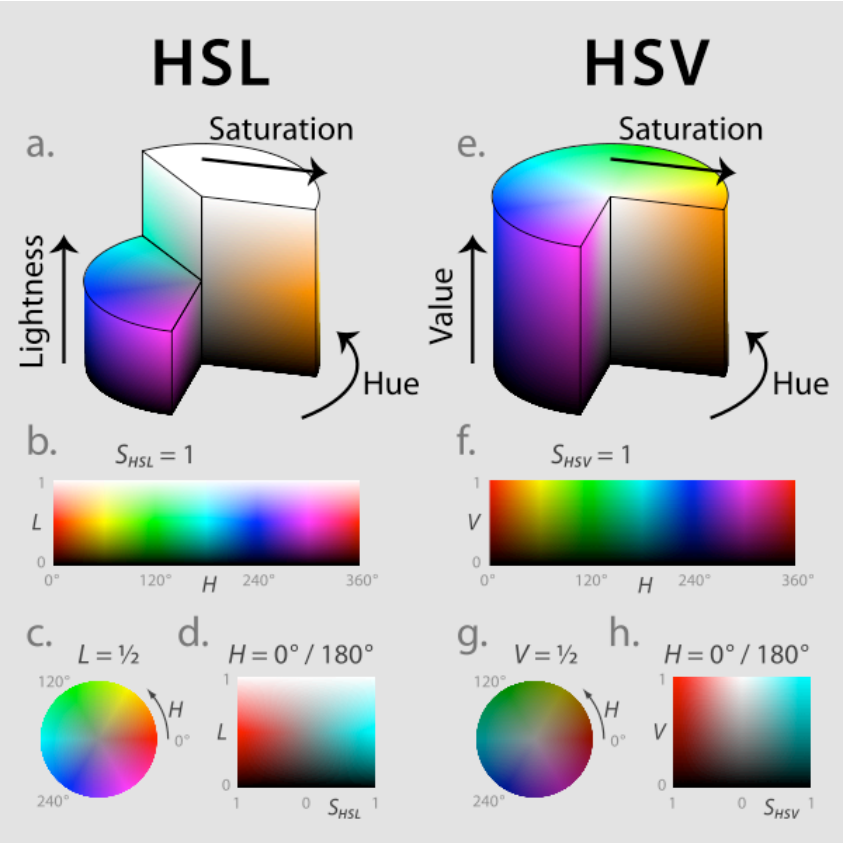
Our displays are specifically tuned to fools standard human color perception.

All color perception of this type subject to confusion: Metamers

Why Dogs Don't Like TV ?

Related Concepts (III)

- Perceptual Color
- Based roughly on opponent colors
  - Red – green
  - Blue – yellow
- Described in terms of Hue, Saturation and Intensity (or value)
  - Blue "wraps around" to red



http://en.wikipedia.org/wiki/File:Hsl-hsv_models.svg

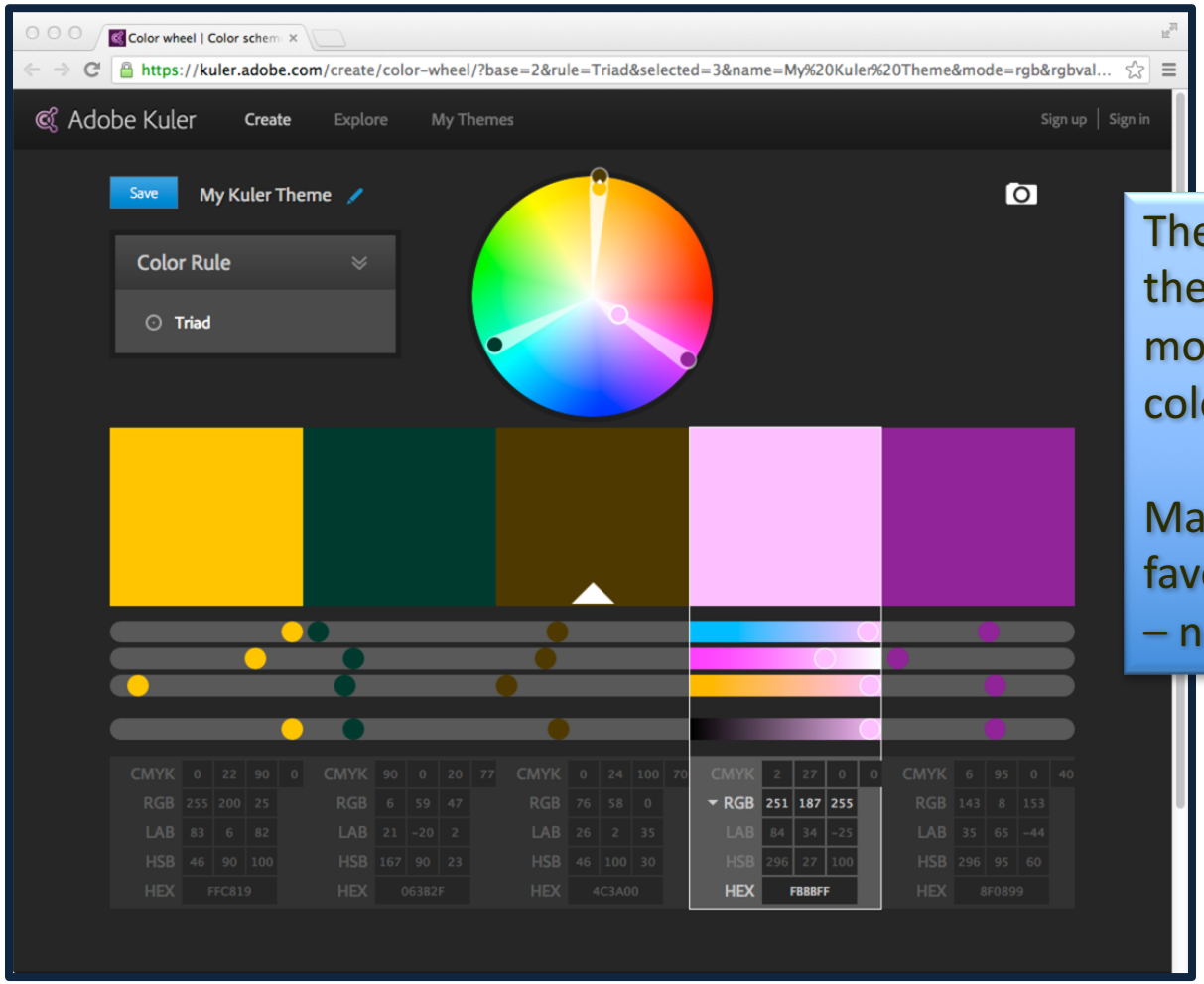
More Human Color Vision

- Reality is complex
- Some women are quadchromatic
- Three different genes code for red pigment
  - … with slightly different wavelengths
- Distribution of color receptors is a function of eccentricity
  - … and then there is macular pigmentation
- White & Black are comparative, not colors
  - In a dark cave, you will see gray, not black

Graphics = Trichromatic Color

- Our displays produce trichromatic colors
  - Simple red, green and blue
- Every pixel has three values (R, G, B)
- 8-bit values : 0 to 255
- We will model light & reflectance in terms of (R,G,B) triples (vectors)

CS 410 Not a Design Course, but



There is a lot to consider and there is value in learning more, not less, about using colors.

Many computer scientists favor high levels of saturation – not such a good thing.

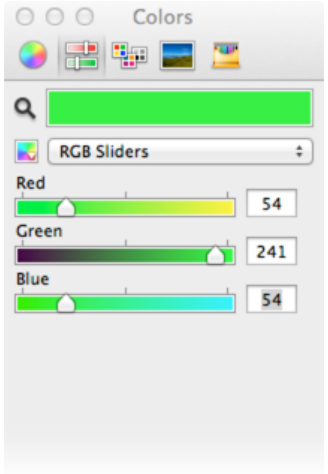
RGB Bits and Hex

- Get used to easily shifting from two views
- 8 bits per color

Red	Green	Blue
0 0 1 1 0 1 1 0	1 1 1 1 0 0 0 1	0 0 1 1 0 1 1 0

54 241 54

Sample



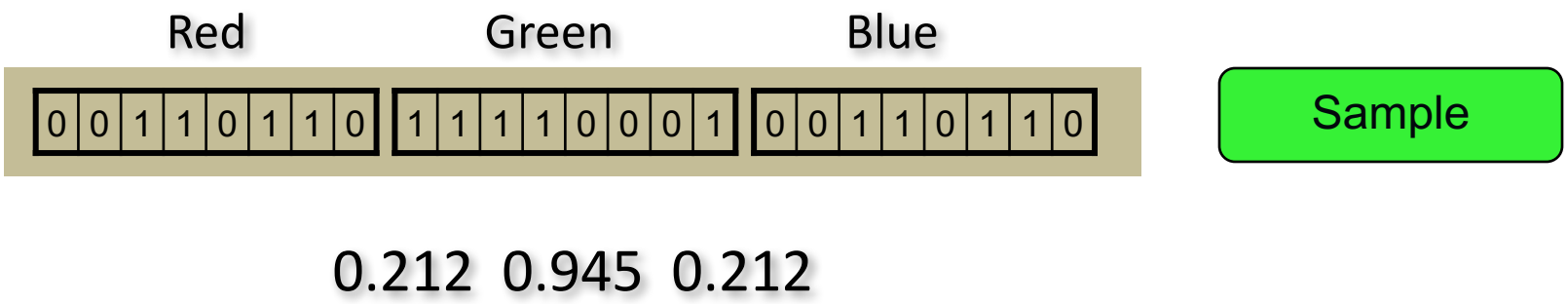
- 2 digit hex number.

Red	Green	Blue
0 0 1 1 0 1 1 0	1 1 1 1 0 0 0 1	0 0 1 1 0 1 1 0

36 F1 36

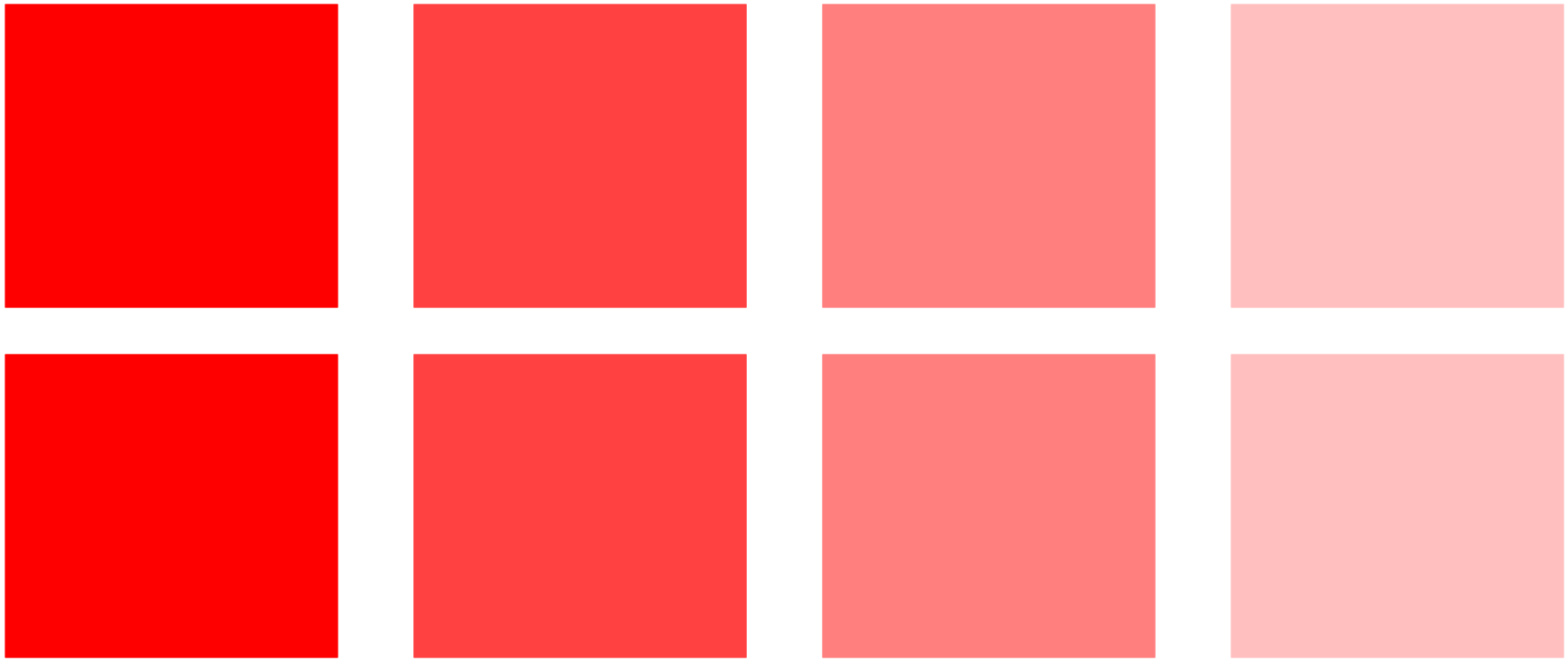
RGB values as floats

- When we move to illumination – bits byte ☺
- Want an easier way to blend and combine.
- Shift to floating point numbers.
- Constrained to the range 0.0 to 1.0



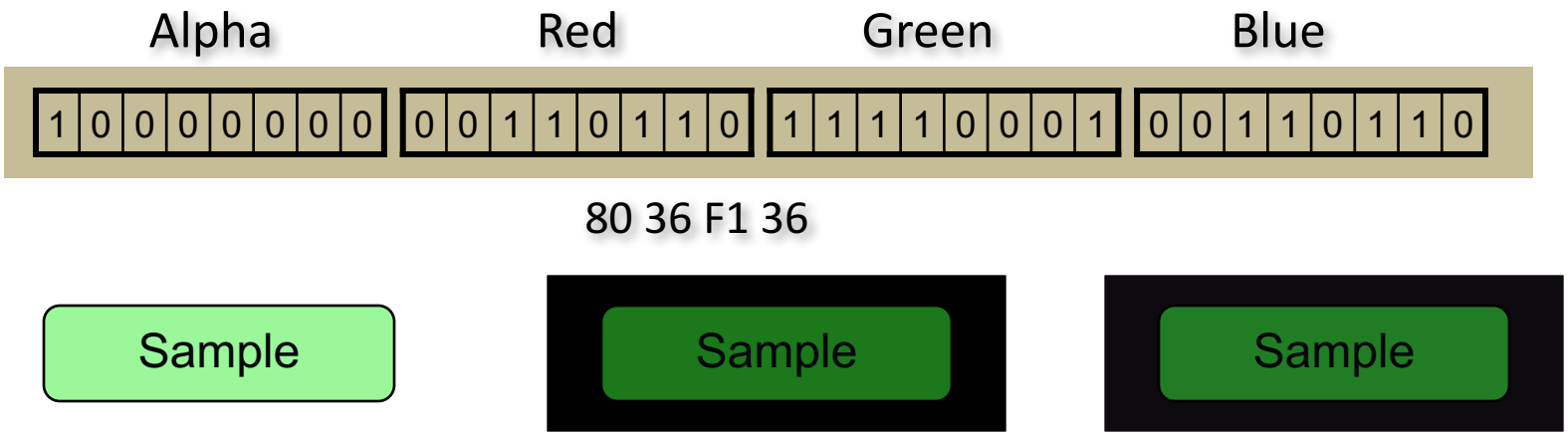
One more thing - Transparency

- Modern systems store a 4th value
- α controls transparency of a color.
- means color below can be seen beneath.



Alpha Channel - Pragmatics

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



- Alpha controls blending
  - Alpha = 0 (000) - transparent.
  - Alpha = 1 (255) - completely covers.
  - Alpha = 0.5 (128) - 50/50 mix with underneath.

Not all RGBs are Equal

- In the capture of color things are getting exciting. Read that as more complicated
  - Start with sRGB, but there is more
  - Adobe RGB,
  - Camera RAW, with complex sensing filters
  - Extended output displays
- I was searching for a personal metaphor
  - Next slide

Sound, Sight and Being Picky

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

Beveridge 2SW loudspeaker system

By J. Gordon Holt • Posted: Dec 8, 2015 • Published: May 1, 1978

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This is an electrostatic column speaker, 6' tall and costing $6000/pair. An integral, fan-cooled amplifier is located in the base (footnote 1). The 2SW is said to cover almost the entire frequency range and is based on a patent, number 3,668,335, issued to manufacturer/designer Harold Beveridge on June 6, 1972. Internal acoustic lenses in front of the electrostatic panels widen the speaker's dispersion: In

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

Better Color …?

iPhone 7 and Apple's next Retina Display frontier: Wide Color

By Daniel Eran Dilger
Friday, July 08, 2016, 04:38 pm PT (07:38 pm ET)

In 2010, Steve Jobs introduced a new leap forward in display resolution for iPhone 4 that passed up the rest of the industry to deliver pixels virtually invisible to the human eye. For iPhone 7, Apple appears to be making a similar leap in the realm of "Retina Color."

http://appleinsider.com/articles/16/07/08/iphone-7-and-apples-next-retina-display-frontier-wide-color-

A similar issue to that faced by audiofiles will emerge, how much does the average person care/notice.

One certainty – what we teach about color generation will be changing now displays seem to be moving forward at a more rapid clip.