Human Visual Perception

Color Theory
Additive and Subtractive Color
Color Blindness
Color Theory

• White light is a perception of the human mind
• White light is composed of all the wavelengths of visible light or equal combinations of RGB
• Our eyes have Red, Green and Blue sensitive cells (cones) and light intensity cells that are insensitive to color (rods).
• Mixing Red, Green and Blue light (not true with pigments) will be perceived as white light
• That’s how an RGB monitor works
Color Cube

Hue (color’s name)

More Saturated

Saturation (Chroma)

Less Saturated

Red    Yellow    Green       Cyan    Blue    Magenta
Luminance (Brightness) Range

Brighter (Greater Luminance)

Darker (Lower Luminance)
Color RGB

• **RGB** *(Red, Green, Blue)*

• **Range 0-255** *(0,0,0) tuple*
  - 24 bit color - 8 bits per color - 3 bytes - 1 byte per color
  - Red *(255,0,0)* Green *(0,255,0)* Blue *(0,0,255)*
  - Cyan *(0,255,255)* Magenta *(255,0,255)* Yellow *(255,255,0)*
  - White *(255,255,255)* Black *(0,0,0)* Gray *(128,128,128)*
  - Supports $2^{24} = 256^3 = 16777216$ *(16 x 10^9 individual colors)*
  - 48 bit color *(16 bits each RGB)* $2^{48} = 281 x 10^{12}$ colors *(more variations than the human eye can distinguish)*

• **Color complements** *(adding one - subtracts the other from the overall color balance)*
  - Red and Cyan
  - Green and Magenta
  - Blue and Yellow
  - White and Black
Color RGB

- RGB  Red  Green  Blue
- Range 0-255  (0,0,0) tuple
  - 24 bit color - 3 bytes - 1 per color
  - **Red** (255,0,0)  **Green** (0,255,0)  **Blue** (0,0,255)
  - **Cyan** (0,0,255)  **Magenta** (255,0,255)  **Yellow** (255,255,0)
  - **White** (255,255,255)  **Black** (0,0,0)  **Gray** (128,128,128)
  - Supports $2^{24} = 256^3 = 16777216$ (16 x $10^9$ individual colors)
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- **Color complements** (adding one - subtracts the other from the overall color balance)
  - Red and Cyan
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  - White and Black
(Additive) Color Wheel

- See [http://www.themodelmakersresource.co.uk/facts/facts011.html](http://www.themodelmakersresource.co.uk/facts/facts011.html)
The Color Wheel (Cube) shows various saturations of colors.
**Color HSV / HSL**

- **HSV** - Hue  Saturation  Value
- **HSL** - Hue  Saturation  Lightness

- **Hue** - Relative Color on the color wheel
  (0° - 360°)
- **Saturation (Chroma)** - the amount of color intensity v. gray – 0-100%
- **Value (Luminance)/Lightness** – the amount of white/black added to the color.
Color “salami” in HSV

Value (Lightness)
Hue around the circle, Saturation distance from the center
• "Freehand Color Picker Demo"
Color Demo

- <<pop up the color chooser for the square below. Vary the values in RGB, HSV spaces.>>

![SquareDemo]
Same “color” in different color models

H: 139  
S: 197  
V: 0

R: 0  
G: 0  
B: 0
• Questions
• Comments

• 0.5
(Subtractive) Color CMYK

- CMYK - Cyan Magenta Yellow black
- C+M+Y inks produces a muddy brown NOT black, so they added the black, too.
- Used in the printing industry (Pigments)
- Subtractive Primary Colors – can mix any other color from them
For Paints, Pigments, Dyes and Filtering Light

- They are subtractive (they absorb light)
- Pigments are imperfect absorbers and impure – that makes color mixing paints, dyes or filtering light more art than science.

**Often say ROYGBIV not RYGCBM**

- <notice that artists think RYB not RGB are the primary pigments – you can mix any color from them – not quite true/>

- **Hue** the names of colors (for pigments)
  - (primary) red, yellow, blue
  - (secondary) orange, green, violet
  - (tertiary) red-orange, orange-yellow, yellow-green, green-blue, blue-violet, red-violet
  - tint = add white
  - shade = add black
Subtractive Colors
(filters absorb colors)

- http://home.att.net/~B-P.TRUSCIO/COLOR.htm
Light vs. Pigments
(Illumination vs. Reflectance)

- Light is **additive**
- Pigments are **subtractive**
- Add R G B **lights** together you get **WHITE**
- Add R G B **pigments** together you get **BLACK**
  - (well more like a muddy brown)
- You see what colors are reflected from an object
  - the object absorbs the colors you don’t see
  - it absorbs the **complimentary** colors of the one you see.
- The red apple reflects red light
  (and absorbs all others - green and blue).
- The green apple reflects green light
  (and absorbs all others red and blue)
- Is the color you see really the color of an object or is it just the opposite?
Mixing 3 specific wavelengths vs. continuous wavelength - the eyes see the same color

I see white
Mixing 2 specific wavelengths vs. single wavelength
- the eyes see the same color

I see magenta
Mixing 2 specific wavelengths vs. single wavelength
- the eyes see the same color

I see cyan
Additive Color Combinations
(shining lights together)
Contrast

- “difference” between the foreground and background colors or if shades of gray, difference in luminance

<table>
<thead>
<tr>
<th>Text Color</th>
<th>Background Color</th>
<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>White</td>
<td>High</td>
</tr>
<tr>
<td>White</td>
<td>Black</td>
<td>High</td>
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<td>Gray</td>
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</tbody>
</table>
Contrast

• A color on its complement usually has a very high contrast
  – sometimes too much – often caused by your hardware! Ex: color fringing and “ringing” on TV
• Usually looks a little “circus like”
• Black text on a white background is usually a good place to start for readability

<table>
<thead>
<tr>
<th>Magenta Text on Green Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Text on Magenta Background</td>
</tr>
<tr>
<td>Blue Text on Yellow Background</td>
</tr>
<tr>
<td>Yellow Text on Blue Background</td>
</tr>
<tr>
<td>Cyan Text on Red Background</td>
</tr>
<tr>
<td>Red Text on Cyan Background</td>
</tr>
</tbody>
</table>
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• 1.0
Tools to demo color theory

- Click to see demos
- Hue and saturation
  http://psych.hanover.edu/JavaTest/Media/Chapter6/MedFig.ColorDimensions.html
- Additive Color Mixing
  http://psych.hanover.edu/JavaTest/Media/Chapter6/MedFig.ColorMixer.html
- Color matching experiments
  http://psych.hanover.edu/JavaTest/Media/Chapter6/MedFig.ColorMixer.html
  try yourself!
- Cone Response to Light demo
  http://psych.hanover.edu/JavaTest/Media/Chapter6/MedFig.TrichromatCones.html
- See paper
  http://psych.hanover.edu/classes/sensation/chapters/Chapter%206.doc
Cross section of Human Eye

From http://www.inventoland.net/imaging/uc/understandColor.pdf
Note the strong overlap in the orange-yellow interval.
This means that correct color reproduction cannot be achieved with simple trichromatic methods, because there are always unwanted stimulations.
Hence, the trivial idea of stimulating the cones independently does not work with a simple approach.

From http://www.inventoland.net/imaging/uc/understandColor.pdf
Sensitivities

• Red (S) cones

• Green (M) cones

• Blue (L) cones

  • From http://home.wanadoo.nl/paulschils/05.00.html
• Questions
• Comments

• 1.5
Are these the same color?
Are these the same color?
Optical illusion?

Three flat objects or picture of a white cube illuminated from the top and right?
Optical illusion?

1 color appears as 2
Focus your eyes at the vertical pattern in the center of the image and move our eyes slowly in there. The center appears to move compared to the horizontal pattern in the surround.

From http://home.wanadoo.nl/paulschils/12.00.htm
Count the black dots

- From http://home.wanadoo.nl/paulschils/12.00.htm
Are the red dots same color? Size?

- From [http://home.wanadoo.nl/paulschils/12.00.htm](http://home.wanadoo.nl/paulschils/12.00.htm)
Focus your eyes at the black dot in the middle and move your head backwards and forwards.

• From http://home.wanadoo.nl/paulschils/12.00.htm
Cognitive model for color appearance
Colors are rendered differently on different devices

- Sometimes dramatically different
- Print (magazine) vs. computer monitor very different vs. your printer vs. a photographic print print
What your eye can see versus what an example scanner or monitor or printer can reproduce (different hardware has different limitations)

- From http://home.wanadoo.nl/paulschils/09.02.htm
Color chooser for windows
Color “warmth”

- Warm colors are less purely the base color, they often have a little of other colors in it.
- Warm colors are usually preferred by users and seen as more aesthetically pleasing
- A good primer on graphic design ideas and concepts
  http://www.mkgraphic.com/chap00.html
Do you see a 5 or a 2?

- “5% to 8% (depending on the study you quote) of the men and 0.5% of the women of the world are born colorblind. That’s as high as one out of twelve men and one out of two hundred women. I am going to limit this discussion to protans (red weak) and deutos (green weak) because they make up 99% of this group.”
- See [http://colorvisiontesting.com/](http://colorvisiontesting.com/) for more info
Ishihara colorblindness test
Choosing a color scheme

• **Dichromatic**
  - 2 colors opposite on the color wheel

• **Trichromatic**
  - 3 colors 120 degrees around wheel

• **Quadrachromatic**
  - 4 colors 90 degrees around the wheel
Color Blindness Demo

• How colorblind individuals see color palettes
  http://www.iamcal.com/toys/colors/

• How to a see a website as though being seen by a colorblind person
  http://colorfilter.wickline.org/
Summary

- Color is a “perception”
- Additive RGB model
- Subtractive CMY(K) model
- Eye is a complicated processing subsystem
- HSV is an alternative color space to RGB
- Warm vs. cool
- Color Wheel
- Luminance and Chroma(Color) contrasts
- Color defects occur in a large segment of the population
- Choosing a color scheme
Resources

• A good primer on graphic design ideas and concepts
  http://www.mkgraphic.com/chap00.html

• A paper on ideas for accessibility and people with color defects i.e. color blindness