Intensity & Color

Outline
- Intensity
  - Range
  - Quantization
- Color
  - Color space
  - Color models

Range of the Intensity
- The visible light emitted/reflected from an object varies from very dark to very bright
  - The luminous intensity of a candle is 1 candela
  - The sunlight is about 100,000 candela per m²
- Impossible to capture/represent intensity variations in the whole intensity range
  - The ratio between the maximum and minimum intensities considered is called “dynamic range”
  - Intensity variation smaller than the min is ignored (lack of details in shadow)
  - Intensity value larger than the max is truncated (blow out highlights)

Example of Dynamic Range

Quantization of Intensity
- How to sample the intensity range using a set of discrete numbers?
  - Arithmetic sequence:
    - \( I_0 = a, I_1 = a + k, I_2 = a + 2k, I_3 = a + 3k \ldots \)
  - Geometric sequence:
    - \( I_0 = a, I_1 = a \cdot k, I_2 = a \cdot k^2, I_3 = a \cdot k^3 \ldots \)

Color
- Match a color using red, green, & blue
  - Some colors need negative weight for red
- CIE (Commission Internationale de l’Éclairage) defined 3 standard primaries:
  - \( X, Y, \& Z \)
  - Can match all visible colors using only positive weights
CIE Chromaticity Diagram

- Chromaticity diagram is the X+Y+Z=1 plane in the CIE space
- Can be considered as the colors of lights that have the same total amount of energy

Monitor Gamut

- The range of colors that can be shown is called gamut
- The gamut of a typical monitor does not cover the entire space
  - The corners of the triangle depend on the emittance of the phosphors of the monitor
  - Certain colors cannot be shown

Color Models

- RGB:
  - Red, green, & blue
- CMY (CMYK):
  - Cyan, magenta, yellow (& black)
- HSV (HSL):
  - Hue, saturation, & value (lightness)
- YUV (YIQ)

RGB Model

- Additive color model:
  - Red + Blue = Magenta
  - Blue + Green = Cyan
  - Green + Red = Yellow
  - Red + Blue + Green = White
- Used by most of the monitors

sRGB vs. Adobe RGB

- sRGB (standard RGB) is an RGB color space created by HP & Microsoft
  - Matches what CRT monitors can display
  - Adobe RGB is an RGB color space developed by Adobe in 1998
  - Has a larger gamut than sRGB

CMY Model

- Subtractive color model:
  - Cyan (C) absorbs red
  - Magenta (M) absorbs green
  - Yellow (Y) absorbs blue
- Used by many printers
Convert between RGB & CMY

- RGB -> CMY
  - C = 1 – R
  - M = 1 – G
  - Y = 1 – B

- CMY -> RGB
  - R = 1 – C
  - G = 1 – M
  - B = 1 – Y

CMYK Model

- Add the 4th color:
  - Black (K)
  - Use black ink directly instead of mixing color inks

- Convert from CMY to CMYK
  - K = min(C, M, Y)
  - C' = C – K
  - M' = M – K
  - Y' = Y – K

HSV (HSL) Model

- User-oriented color model:
  - Hue – Dominant wavelength
  - Saturation – Excitation purity
  - Value – Luminance

- HSL model is similar:
  - Use Lightness instead of Value

Convert RGB to HSV & HSL

- Max = max(R, G, B);
- Min = min(R, G, B);
- V = Max;
- if (Max == 0) 
  - S = 0;
- else if (L ≤ ½)
  - S = (Max – Min) / (2 – 2L);
- else
  - S = (Max – Min) / (2L);

YUV Model

- Human perception color model
  - One luminance channel
  - Two chrominance channels
  - Chrominance is defined as the difference between a color and a reference white at the same luminance
  - Used in PAL analog video & digital video
  - Human eyes are more sensitive to luminance than to chrominance
  - 5.5 MHz for Y
  - 1.8 MHz each for U & V

YIQ Model

- Align with human perceptual color sensitivities:
  - I is the orange-blue axis:
    - $I = V \cdot \cos 33° - U \cdot \sin 33°$
  - Q is the purple-green axis:
    - $Q = V \cdot \sin 33° + U \cdot \cos 33°$
  - Used in NTSC color TV broadcasting
  - Eyes are most sensitive to Y, next to I, next to Q
  - 4.2 MHz for Y
  - 1.5 MHz to I
  - 0.55 MHz to Q
Convert RGB to YUV & YIQ

- \[ Y = 0.299R + 0.587G + 0.114B \]
- \[ U = 0.492 \times (B - Y) \]
- \[ V = 0.877 \times (R - Y) \]

- \[ Y = 0.299R + 0.587G + 0.114B \]
- \[ I = 0.596R - 0.275G - 0.321B \]
- \[ Q = 0.212R - 0.523G + 0.311B \]