Range of the Intensity

• The visible light emitted/reflect 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)

Quantization of Intensity

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

Color

• Match a color using red, green, & blue
  • Some colors need negative weight for red
• CIE (Commission Internationale de l’Eclairage) 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**
  - \( R = 1 - C \)
  - \( G = 1 - M \)
  - \( B = 1 - Y \)

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**CMYK Model**

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

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

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**HSV (HSL) Model**

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

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

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**Convert RGB to HSV & HSL**

- \( \text{Max} = \max(R, G, B); \)
- \( \text{Min} = \min(R, G, B); \)
- \( V = \text{Max}; \)
- \( \text{if} (\text{Max} = 0) \)
  - \( S = 0; \)
  - \( \text{else} \)
  - \( S = 1 - \frac{\text{Min}}{\text{Max}}; \)
- \( \text{else if} (L \leq 0.5) \)
  - \( S = \frac{\text{Max} - \text{Min}}{2L}; \)
- \( S = \frac{\text{Max} - \text{Min}}{2 - 2L}; \)

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**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 \( U \) & \( V \)

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**YIQ Model**

- Align with human's color perception sensitivities:
  - \( I \) is the orange-blue axis:
    - \( = V \cos 33^\circ - U \sin 33^\circ \)
  - \( Q \) is the purple-green axis:
    - \( = V \sin 33^\circ + U \cos 33^\circ \)

- 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 for \( I \)
  - 0.55 MHz to \( Q \)
Convert RGB to YUV & YIQ

- Y = 0.299*R + 0.587*G + 0.114*B
- U = 0.492*(B - Y)
- V = 0.877*(R - Y)

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