Faculty of Information Technology
University of Moratuwa

BSc(Hons) in Information Technology and Management

IN 2610 – Computer Graphics and Development

Level 2 Semester 2 Lecture Note 02

1.1 What is the computer color system?

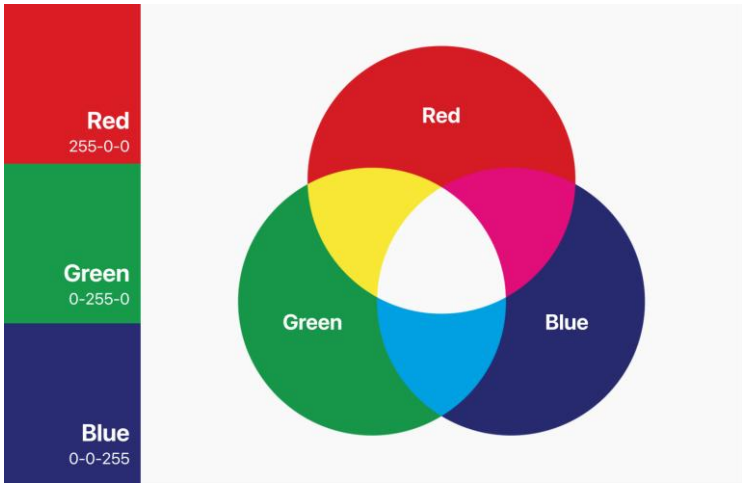
A computer color system is a framework used to represent, process, and display colors in digital devices. These systems define how colors are captured, stored, manipulated, and visualized on screens or in print.

- **Purpose**:
    - Ensure consistency across devices (monitors, printers, cameras).
    - Allow for accurate color representation and manipulation.
- **Components**:
    - **Color Models**: Mathematical representation of colors (e.g., RGB, CMYK, HSL).
    - **Color Spaces**: Specific implementations of color models (e.g., sRGB, Adobe RGB).

1.2 RGB, CMYK, and HSL/HSV color models

RGB (Red, Green, Blue)

- Used in screens and displays.
- Based on **additive color mixing**, where colors are created by combining red, green, and blue light.



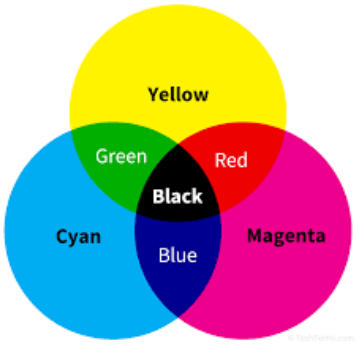
- **Color Representation**:

$$\text{Color} = (R, G, B), \quad 0 \leq R, G, B \leq 255$$

- Example:
  - (255, 0, 0) = Red
  - (0, 255, 0) = Green
  - (0, 0, 255) = Blue
  - (255, 255, 255) = White

CMYK (Cyan, Magenta, Yellow, Black)

- Used in printing.
- Based on **subtractive color mixing**, where colors are created by subtracting light using inks or pigments.



- **Color Representation**:

$$\text{Color} = (C, M, Y, K), \quad 0 \leq C, M, Y, K \leq 1$$

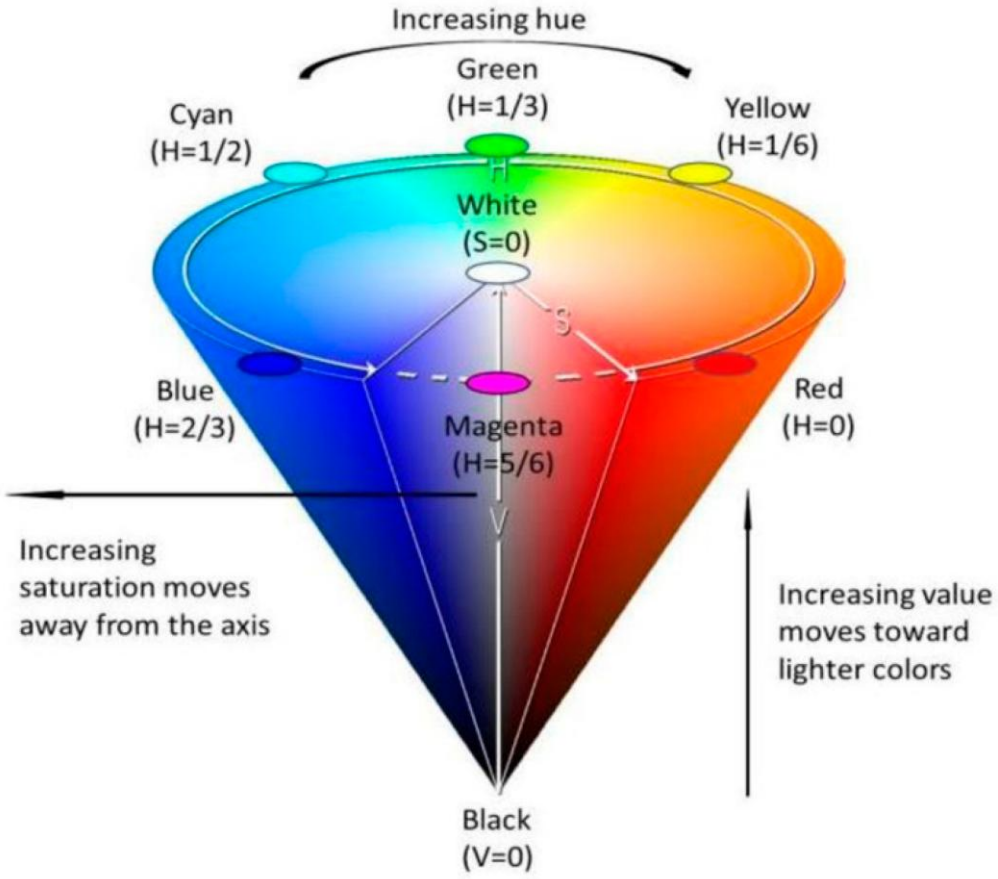
- Conversion from RGB:

$$C = 1 - R, \quad M = 1 - G, \quad Y = 1 - B$$

$$K = \min(C, M, Y)$$

HSL (Hue, Saturation, Lightness) and HSV (Hue, Saturation, Value)

- **Hue (H)**: Represents the type of color (0°–360°).
- **Saturation (S)**: Intensity of the color (0–1).
- **Lightness/Value (L/V)**: Brightness of the color (0–1).



- Conversion from RGB:

1. Normalize R, G, B to [0, 1].
2. Compute max and min values:

$$\text{Max} = \max(R, G, B), \quad \text{Min} = \min(R, G, B)$$

3. Lightness:

$$L = \frac{\text{Max} + \text{Min}}{2}$$

4. Saturation:

$$S = \begin{cases} 0 & \text{if Max} = \text{Min} \\ \frac{\text{Max}-\text{Min}}{\text{Max}+\text{Min}} & \text{if L} \leq 0.5 \\ \frac{\text{Max}-\text{Min}}{2-(\text{Max}+\text{Min})} & \text{if L} > 0.5 \end{cases}$$

5. Hue:

$$H = \begin{cases} 60 \times \frac{G-B}{\text{Max}-\text{Min}} & \text{if Max} = \text{R} \\ 60 \times \left(\frac{B-R}{\text{Max}-\text{Min}} + 2\right) & \text{if Max} = \text{G} \\ 60 \times \left(\frac{R-G}{\text{Max}-\text{Min}} + 4\right) & \text{if Max} = \text{B} \end{cases}$$

1.3 Additive vs. Subtractive color mixing

Additive Color Mixing

- Used in light-based devices (e.g., monitors, projectors).
- Colors are created by adding light.
- Primary Colors: **Red, Green, Blue (RGB)**.
- Formula:

$$\text{Combined Color} = R + G + B$$

- Example: Red + Green = Yellow.

Subtractive Color Mixing

- Used in pigments and printing.
- Colors are created by absorbing (subtracting) light.
- Primary Colors: **Cyan, Magenta, Yellow (CMY)**.
- Example: Cyan + Yellow = Green.

1.4 Importance of color profiles

Color profiles are essential to ensure consistent and accurate color reproduction across different devices, such as monitors, printers, and cameras. A color profile acts as a bridge between devices, helping them interpret and display colors uniformly.

Key Color Profiles

1. **sRGB (Standard Red Green Blue)**:
    - Developed by HP and Microsoft.
    - Ideal for web and standard screen display.
    - Limited color gamut but widely supported.
    - Suitable for environments where consistent color appearance is more critical than wide gamut coverage.
2. **Adobe RGB**:
    - Developed by Adobe Systems.
    - Provides a wider color gamut than sRGB.
    - Used in professional photography and printing workflows.
    - Better for images that will be printed using high-end printers.
3. **ProPhoto RGB**:
    - Extremely wide gamut color space.
    - Used in professional photo editing for high dynamic range images.
    - Not ideal for web or standard displays.
4. **CMYK Profiles (e.g., US Web Coated SWOP)**:
    - Used in printing.
    - Adjusts for specific printer characteristics and ink types.

Mathematical Representation of Profiles

Color profiles define a mapping between a device-dependent color space and a standard device-independent color space, typically CIE XYZ.

- Color Transformation Matrix:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- R, G, B: Input color values in device space.
- X, Y, Z: Transformed values in the standard color space.

- Example
    - sRGB maps RGB values to XYZ using a predefined matrix and gamma correction.

Key Advantages of Using Profiles:

1. **Device Independence: Ensures colors look similar across devices.**
2. **Predictable Output: Crucial for professional workflows, especially printing.**
3. **Accurate Reproduction: Helps retain artistic intent and branding.**

1.5 Color management in design workflows

Color management is a structured approach to maintaining color consistency across devices in a design workflow. It involves calibration, profile selection, and conversion processes.

Steps in Color Management

1. **Calibrate Devices**:
    - Use hardware calibration tools like a spectrophotometer to adjust monitor settings.
    - Match screen brightness, contrast, and gamma to a standard reference.
2. **Assign and Use Standard Color Profiles**:
    - Assign correct profiles (e.g., sRGB for web content, Adobe RGB for print).
    - Ensure all design tools and devices use the same color space.
3. **Soft Proofing**:
    - Preview how colors will appear in the target medium (e.g., paper, fabric) using software tools.
    - Helps adjust designs for printing limitations or screen discrepancies.
4. **Color Conversion**:
    - Transform colors from one profile to another (e.g., RGB to CMYK) using precise mathematical models.

- Formula:

$$\text{Output Color} = \text{Input Color} \cdot \text{Profile Transformation Matrix}$$

- Conversion includes compensation for gamut differences.

Practical Tools for Color Management

1. **Software**:
    - Adobe Photoshop/Lightroom: Handles color profiles and soft proofing.
    - Affinity Photo: For photo editing and color corrections.
    - ColorSync (macOS): Manages profiles at the OS level.
2. **Hardware**:
    - Calibration devices like X-Rite i1 Display Pro.
    - High-end monitors with built-in calibration (e.g., Eizo, BenQ).

Challenges in Color Management

- **Gamut Clipping**: Colors outside the destination profile's gamut may lose detail or shift hues.
- **Device Variability**: Differences in hardware performance lead to discrepancies.
- **User Inexperience**: Mismanagement of profiles can result in color distortion.

1.6 Additional Notes