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Chapter 2
Fundamentals of Digital Imaging

Part 4
Color Representation
In this lecture, you will find answers to these questions

• What is RGB color model and how does it represent colors?

• What is CMY color model and how does it represent colors?

• What is HSB color model and how does it represent colors?

• What is color gamut? What does out-of-gamut mean?

• Why can't the colors on a printout match exactly what you see on screen?
Color Models

• Used to describe colors numerically, usually in terms of varying amounts of primary colors.

• Common color models:
  – RGB
  – CMYK
  – HSB
  – CIE and their variants.
RGB Color Model

• Primary colors:
  – red
  – green
  – blue

• Additive Color System
Additive Color System
Additive Color System of RGB

- Full intensities of red + green + blue = white
- Full intensities of red + green = yellow
- Full intensities of green + blue = cyan
- Full intensities of red + blue = magenta
- Zero intensities of red, green, and blue = black
- Same intensities of red, green, and blue = some kind of gray
Color Monitors

From a standard CRT monitor screen
Color Monitors

From a SONY Trinitron monitor screen
Color Monitors

From a LCD screen
RGB Color Model

- depicted graphically as a cube defined by three axes in 3-D space
- The maximum value on each axis is normalized to 1.
RGB Color Model

- **x-axis**: red values
- **y-axis**: green values
- **z-axis**: blue values
RGB Color Model

• The coordinates within the color cube represent the relative intensities of red, green, and blue colors.
RGB Color Model

- origin (0,0,0): black
RGB Color Model

- $(1,0,0)$: full intensity of red
RGB Color Model

- $(0, 1, 0)$: full intensity of green
RGB Color Model

- (0,0,1): full intensity of blue
RGB Color Model

• $(1,1,1)$: white
RGB Color Model

• $(1,1,0)$: full red + full green = full yellow
RGB Color Model

• $(1,0,1)$: full red + full blue = full magenta
RGB Color Model

- \((0,1,1)\): full green + full blue = full cyan
Color Picker

So where is the color whose RGB values are (150, 200, 100) in the RGB cube?
Correlating RGB Color Cube with Color Picker

This is a 2-D slice containing all the colors with red = 150.
Correlating RGB Color Cube with Color Picker

This is a 2-D slice containing all the colors with green = 200.
Correlating RGB Color Cube with Color Picker

This is a 2-D slice containing all the colors with blue = 100.
The color (150, 200, 100) is located in the 3-D space of the RGB color cube. It is at the intersection of the three 2-D slices.
CMYK Color Model

• Primary colors:
  – cyan
  – magenta
  – yellow
  – black

• Subtractive Color System
Subtractive Color System of CMY
Subtractive Color System of CMY

- Full intensities of cyan + magenta + yellow = black (theoretically, but in practice with inks, it is not full black)
- Full intensities of cyan + magenta = blue
- Full intensities of cyan + yellow = green
- Full intensities of magenta + yellow = red
- Zero intensities of cyan, magenta, and yellow = white
HSB Color Model

• Hue:
  – basic color
  – 0° to 360°: the location on a color wheel
  – in the order of colors in a rainbow

• Saturation:
  – purity of the color
  – how far away from the neutral gray of the same brightness

• Brightness
HSB Color Model
HSB Color Model
HSB Color Model

A slice of the color wheel from the HSB model
HSB Color Model

• Matches well with the way humans intuitively think about colors

• For example, how would you describe this color?

  • Would you think of it in terms of how much red, green, and blue?
  • Would you first think of it as a yellowish color and then figure out the lightness and how washed out the color is?
Problems with RGB and CMYK Color Space

• Do not encompass all the colors human can see
CIE XYZ Color Model

• Primaries:
  – X
  – Y
  – Z

• Primaries are not physical colors

• Its color space encompasses all the colors human can see.

• Normally not used in digital image editing because monitors and printers cannot reproduce all the colors in the CIE XYZ color space anyway.
Color Gamuts

• Refers to the range of colors of a specific system or device can produce or capture
Color Gamuts

a) Colors that human can see
b) RGB color gamut of typical CRT monitors
c) CMYK color gamut of typical inkjet printers
Color Gamuts

- Monitors and inkjet printers cannot reproduce all the colors that human can see.
- Some of the colors that monitors can reproduce cannot be reproduced by inkjet printers. Most of these colors lie at the corners of the color gamut of the monitor, which means these are highly saturated colors.
Identifying Out-of-Gamut Colors in Images

• Out-of-gamut colors will not be printed correctly.

• In digital image editing programs such as Adobe Photoshop, you can tell whether a color is out of gamut based on your CMYK setting.

• Click on the icon to use the closest color in gamut for printing.
Identifying Out-of-Gamut Colors in Images

• Out-of-gamut colors will not be printed correctly.

• In digital image editing programs such as Adobe Photoshop, you can tell whether a color is out of gamut based on your CMYK setting.
Identifying Out-of-Gamut Colors in Images
Identifying Out-of-Gamut Colors in Images

Click on the icon to replace the out-of-gamut color with the closest color in gamut for printing.
Identifying Out-of-Gamut Colors in Images

The out-of-gamut color is replaced with the closest color in gamut for printing.
Difficulties in Reproducing Colors in Digital Images

• Digital devices cannot produce all of the colors visible to human

• Difficulties exist in reproducing color across devices
  – different devices have different color gamuts
  – additive color system for screen display vs. subtractive color system for printing
Indexed Color
Indexed Color
Review Questions

Note to instructor:
Depending on your preference, you may want to go over the review questions at the end of this lecture as an instant review or at the beginning of next lecture to refresh students' memory of this lecture.
Review Question

What are the primary colors in the RGB color model?
Review Question

What are the primary colors in the CMY color model?
Review Question

What are the primaries in the HSB color model?
Review Question

Which of the following color models take(s) the form of a color cube?

A. RGB
B. CMY
C. HSB
D. CIE XYZ
Review Question

Which of the following color models take(s) the form of a hexacone?

A. RGB
B. CMY
C. HSB
D. CIE XYZ
Review Question

Which of the primaries in the HSB color model takes the form of a color wheel?

A. Hue
B. Saturation
C. Brightness
Review Question

What is the color mixing method for the RGB color model?

A. additive
B. subtractive
Review Question

What is the color mixing method for the CMY color model?

A. additive
B. subtractive
Review Question

What are the RGB values for white?
What are the CMY values for white?
Review Question

What are the RGB values for black?
What are the CMY values for black?
Review Question

What are the RGB values for red?
What are the CMY values for red?
Review Question

What are the RGB values for green?
What are the CMY values for green?
Review Question

What are the RGB values for blue?
What are the CMY values for blue?
Review Question

What are the RGB values for yellow?
What are the CMY values for yellow?
Review Question

Why don't the colors in the printed image look exactly the same as you see on screen?