CSE-170 Computer Graphics

Lecture 8

Color

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Perceived Color

- Perceived color depends on the combination of several factors
  - Properties of the object itself
  - Light source illumination
  - Color of the surrounding area
  - The human visual system

- Ex: if a surface reflects only blue and is illuminated by red light, it appears black

Achromatic Light

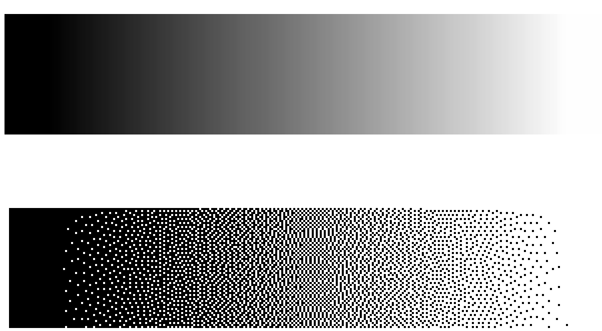
- Achromatic light
  - One intensity/brightness value representation
    - Ex: 0 is black and 255 is white
  - However, we perceive intensities in a nonlinear way: for ex, we equally perceive the differences:

    0.10% to 0.11% of intensity (.1% increase)

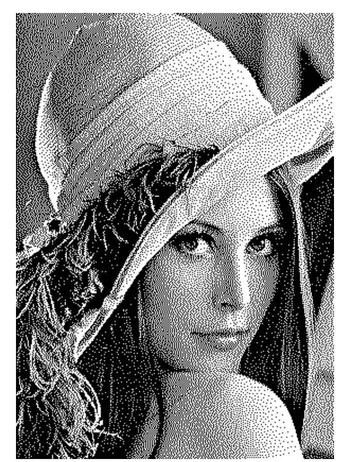
    0.50% to 0.55% of intensity (.5% increase)
  - Intensity levels should be spaced logarithmically to achieve equal steps in brightness
  - CRT monitor behavior is also not linear
    - Gamma correction

Color and achromatic light

- Achromatic light
  - How many intensities are enough?
    - A B&W image can use as many gray levels as needed
  - Halftone approximation
    - Many gray levels perceived from fewer gray levels
      - Dithering techniques in first printers



(can you see how many intensities are used here?)



Color Representation

- How many colors are enough? Depends on:
  - Storage requirements (memory)
  - Processing time requirements (speed)
  - Frame buffer manipulation algorithms
  - Limitations of the monitor and computer

- Working with colors
  - Lookup tables: represent colors as indices to a color table
  - Quantization: reduce the number of colors used while minimizing perception of color changes
  - Dithering: simulate many colors from few ones (see previous slide)

Color Representation

- Today it is common to use 3x8=24-bit descriptions per r,g,b color
  - Called true color representation (256x256x256≈16million)
  - 32-bit descriptions will include “alpha channel” (4x8=32)
    - Alpha channel is most often used to define a transparency level

  - In the support code, we always use 32-bit descriptions
    - vec4 with: (r,g,b,a), each component with 8 bits

Chromatic Color

- Color perception usually involves
  - **Hue**: the color itself (red, green, purple, yellow, etc.)
  - **Saturation**: amount of white mixed in the color, ex:
    - Royal blue: highly saturated
    - Sky blue: unsatured (a pastel color has more white in it)
  - **Lightness**: intensity (colors can be darker or brighter)
  - **Brightness**: perceived intensity of a self-luminous object

Color Representation

- RGB representation
  - We have 3 types of cones in our retinas with different sensitivities to different wavelengths
  - So we can visually match a given color by additively mixing 3 colored lights
  - For example $C = rR + gG + bB$

- Others
  - $\text{RGB}_{\text{monitor}}$, HSV, CIE, etc.

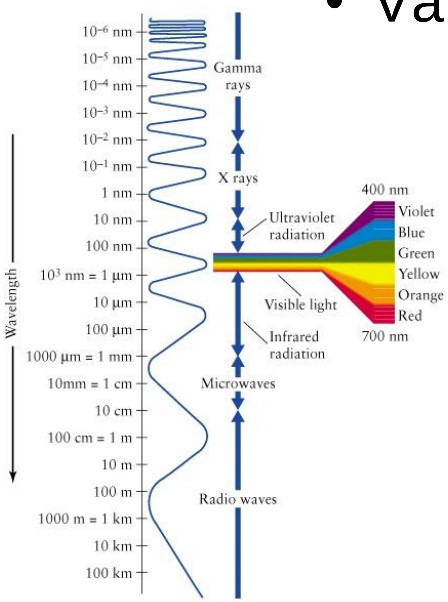
Monitors are built for RGB signals

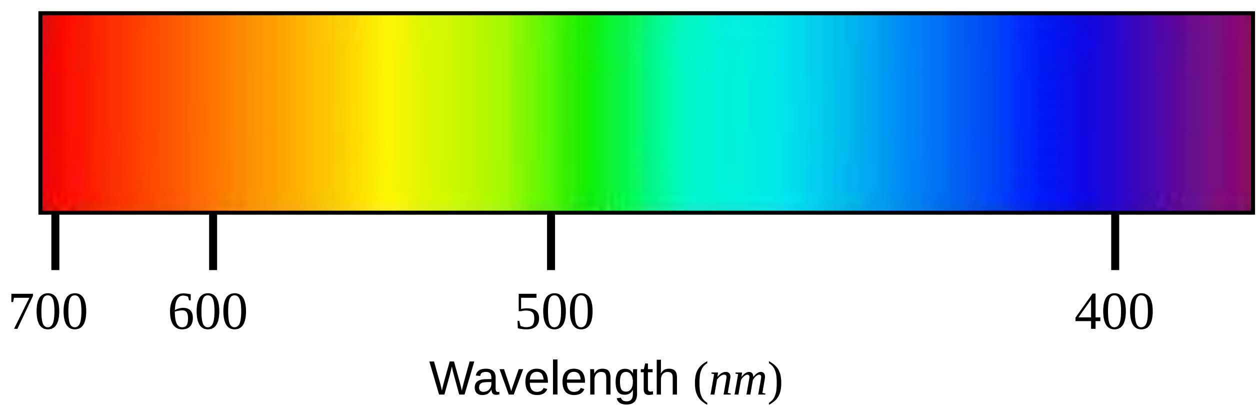
- CRTs
  - produce colors by lighting up triplets of adjacent RGB dots
    - Colors not mixed, remember dithering effect
- LCDs
  - backlight passes through 2 glass substrates with a thin layer of liquid crystal molecules between them that filter the light like Venetian blinds
- How many colors can a monitor display?
  - Chromaticity diagrams can specify

C.I.E. Chromaticity Diagram

CIE: International Commission on Illumination

- CIE XYZ standard
  - CIE triplet is a unique numeric label to any perceivable color
    - Starting with fixed RGB light sources, subjects had to experimentally choose coefficient values *rgb* in order to match given color C
    - Values used: R=700, G=546.1, B=435.8

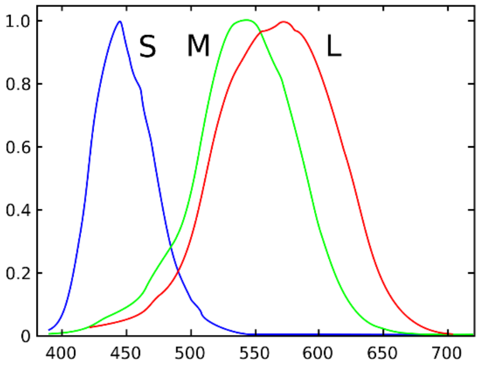




(spectral colors have single wavelength)

C.I.E. Chromaticity Diagram

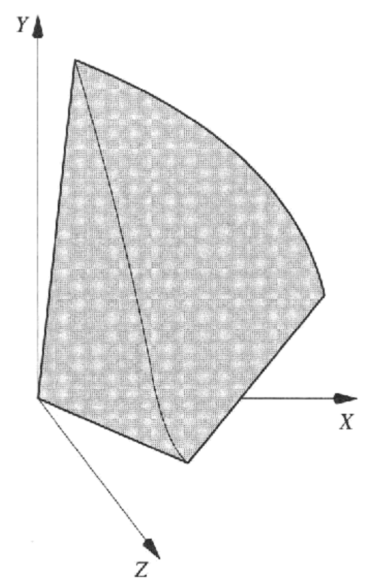
- CIE XYZ standard
  - Problems:
    - When two colors are mixed, a more saturated color is created
    - The 3 primaries form a bounded space and negative values are needed to represent a color outside the space
  - To avoid negative weights CIE devised a standard based on 3 supersaturated artificial primaries XYZ

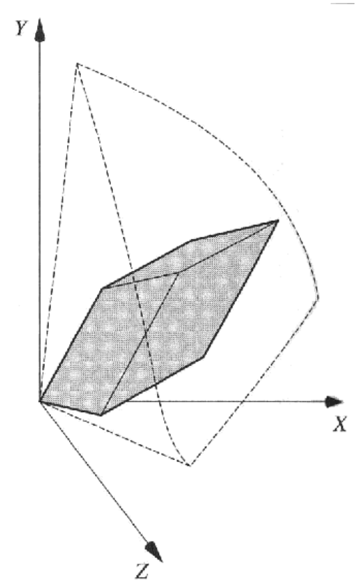


C.I.E. Chromaticity Diagram

- Origin is the black point
- Y is luminance, XZ is chromaticity at that luminance
- Distortion comes from the fact that the space is based on perceptual measurements

CIE XYZ solid





Typical monitor

CIE xyY

- Ignoring luminance Y
  - Colors can be divided into two parts: brightness and chromaticity, so a planar diagram can be built:

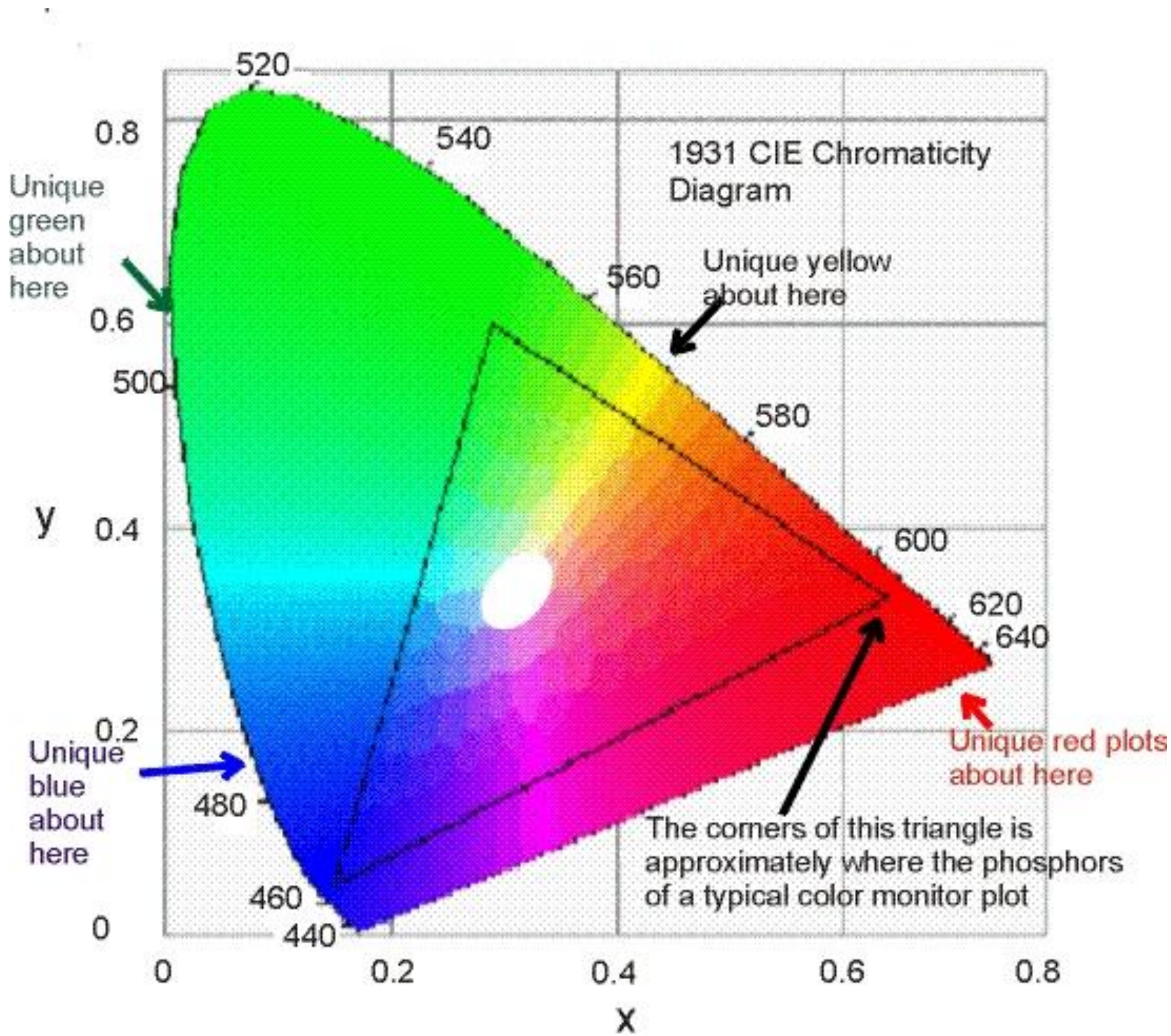
    x = X/(X+Y+Z)

    y = Y/(X+Y+Z)

- Result is the wing-shaped CIE chromaticity diagram
  - All perceivable colors in 2D space, ignoring luminance

C.I.E. Chromaticity Diagram

- All perceivable colors (gamut of human vision)



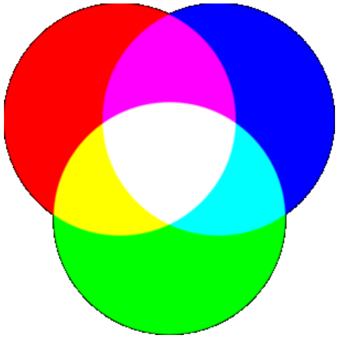
Computer Models

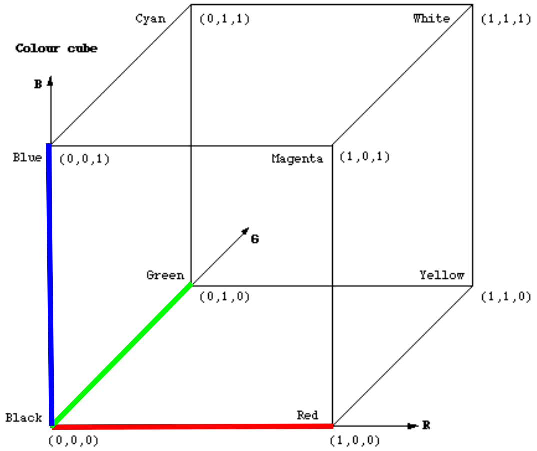
Computer Models

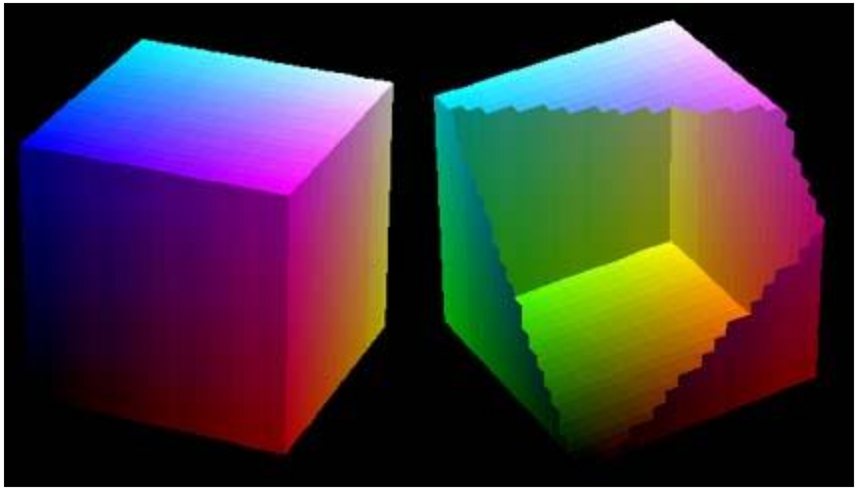
- Monitors are designed to process RGB components
- Other computer representations exist for hardware needs and also for design purposes
  - In the end, the chosen representation is most often converted to RGB

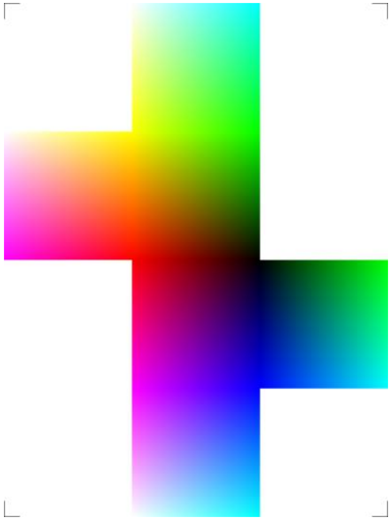
RGB

- (0, 0, 0) is black
- (255, 255, 255) is white
- (255, 0, 0) is red
- (0, 255, 0) is green
- (0, 0, 255) is blue
- (255, 255, 0) is yellow
- (0, 255, 255) is cyan
- (255, 0, 255) is magenta



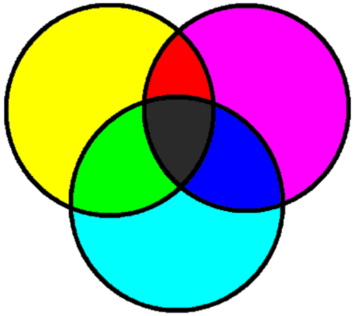






CMYK

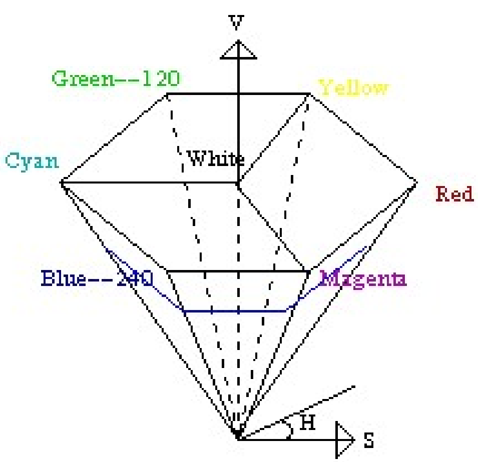
- Cyan, Magenta, Yellow, Key (black)
  - Subtractive model
  - For printers
    - Think how inkjet printers work
  - (0,0,0) is white
    - No ink emission is white (the paper color)
  - Dedicated black component produces better black than mixing other colors, and also saves costs with inks
    - So, ink jet printers have separate black ink
  - A “hardware-oriented” format

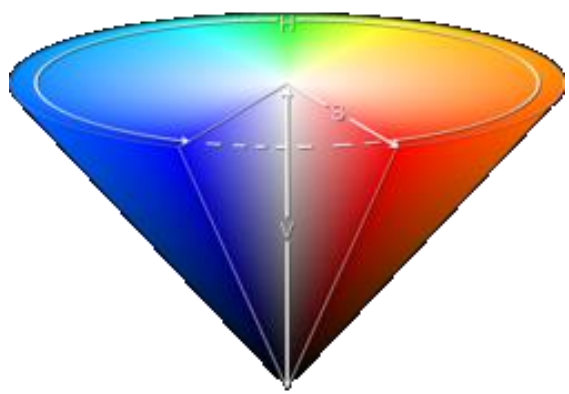


HSV (sometimes called HSL)

- User-oriented format
- Hue, Saturation, Value
  - Hue: red, yellow, green, blue, purple, etc.
  - Saturation: intensity of a specific hue (intense vs. dull)
  - Value: lightness (light vs. dark, or white vs. black)

Another interpretation: saturation gives the amount of white in a hue, and value the amount of black





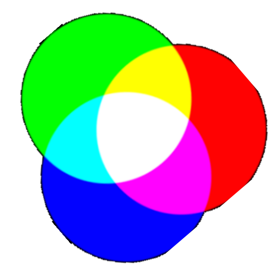
RGB to HSV

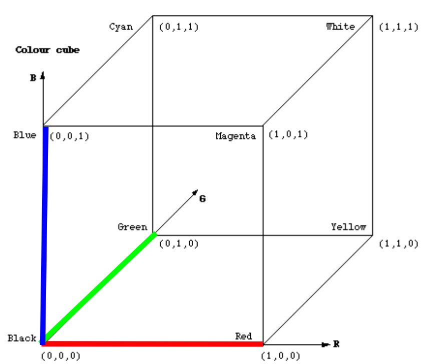
- Convert r,g,b in [0,1], to h,s,v; h in [0,360], s,v in [0,1]

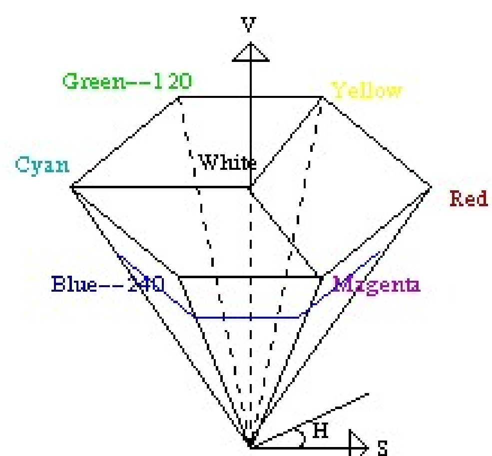
```
max = Max(r,g,b)
min = Min(r,g,b)
v = max;            // max gives the dominant color
if ( max == min ) { s=0; h=0; return; }
s = (max-min)/max; // saturation: how "dominant" v is

delta = max-min;
if ( r == max )       // color is between magenta and yellow
  { h = (g-b)/delta; if(h<0)h+=6; } // h defines 60deg sector
else if ( g == max ) // color is between yellow and cyan
  { h = 2+(b-r)/delta; }
else if ( b == max ) // color is between cyan and magenta
  { h = 4+(r-g)/delta; }

h *= 60; // convert sector to degrees
```

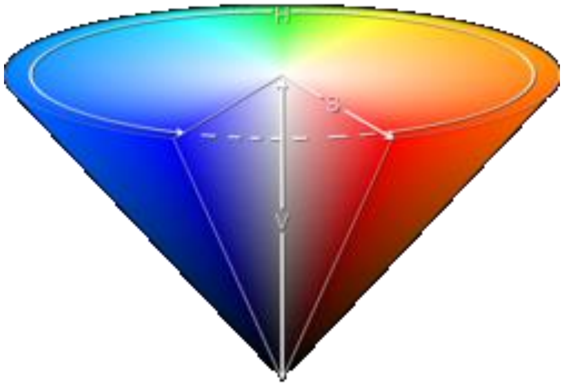






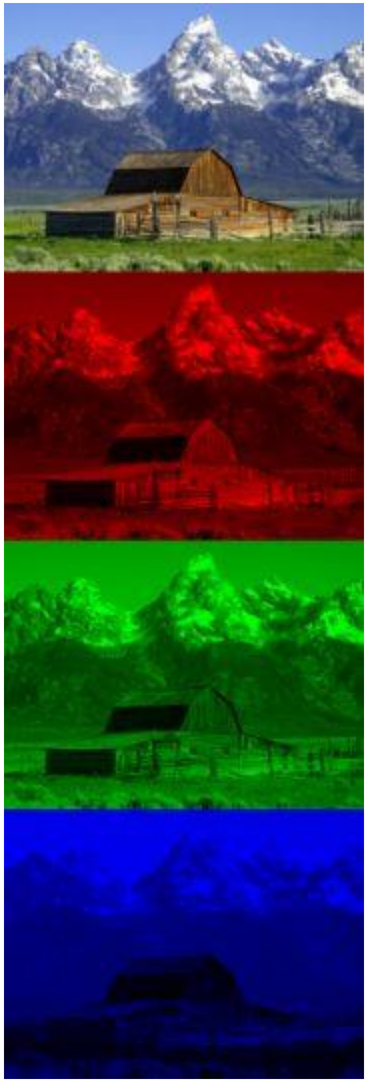
HSV

- Summary
  - HSV is a perceptual user-oriented format
  - Intuitive tint, shade and tone parameters
  - Often chosen in color input dialogs
  - Good for Color Interpolation
    - Hue is interpolated independently from other values

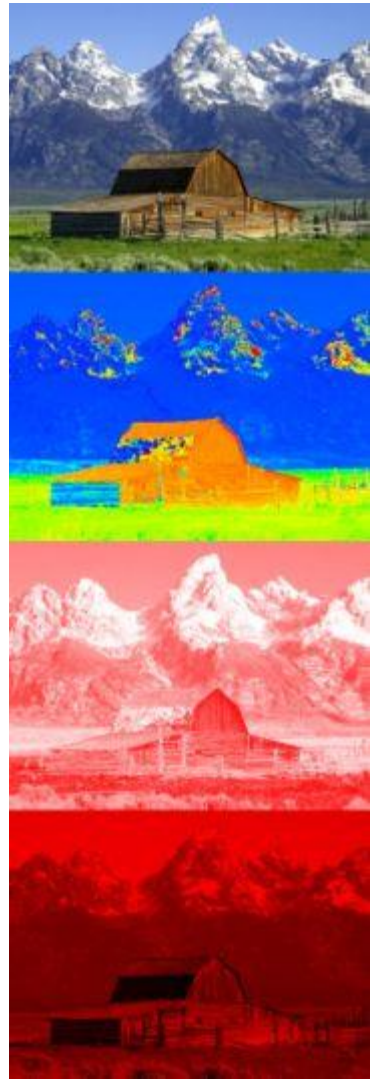


Comparison

RGB



HSV



CMYK

(from Wikipedia)