ECE5554 – Computer Vision
Lecture 8c – Color Quantization and Colorimetry

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Today's Objectives

Color quantization

- Color histogram visualization
- Scalar quantization
- Vector quantization

Colorimetry

- CIE XYZ
- Chromaticity
- Conversions to/from RGB
- Other color representations

Color Quantization is the reduction of the number of different colors present in an image

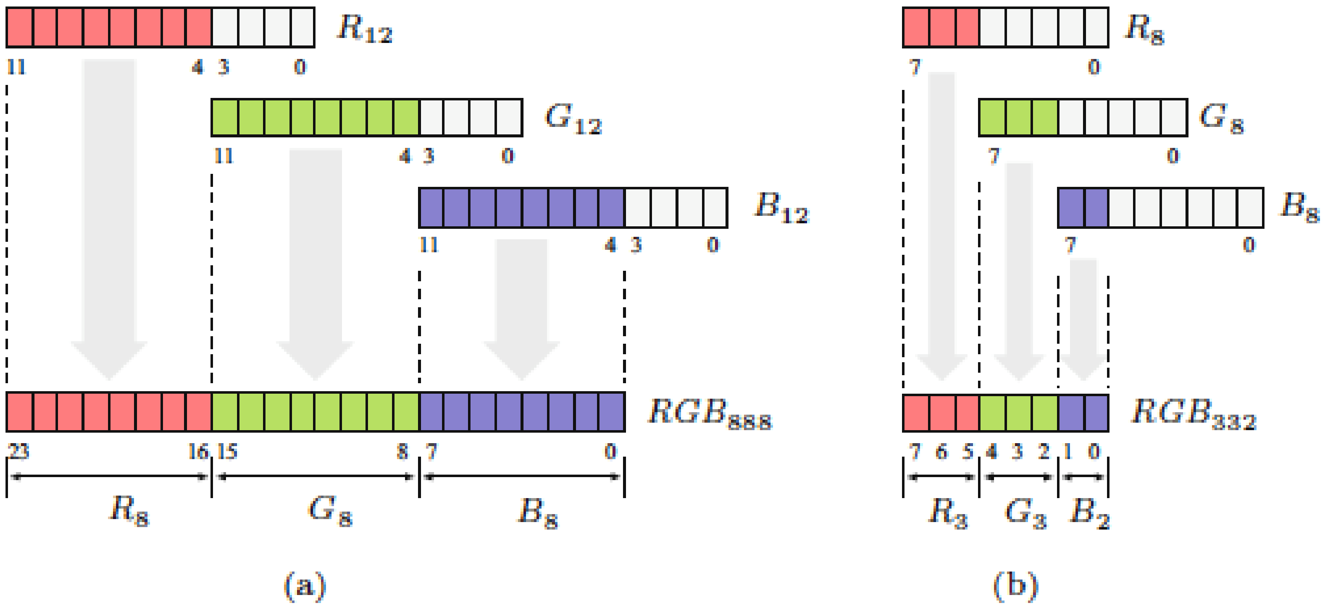
- The motivation may be:
  - transmission or storage limitations
  - visual enhancement
  - segmentation
  - modification of pixel similarities

- It's common for an image storage format to allow 256 (for example) unique colors, but each color can be any of the 256^3 or more possible colors

Scalar quantization is the straightforward reduction of bit-depth in each color plane to fit the new model; the number of bits need not be the same for all colors (it's common for Blue to use less bits)

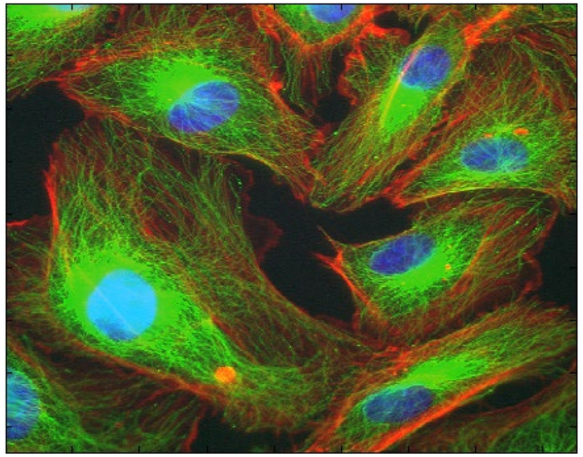
13 Color Quantization

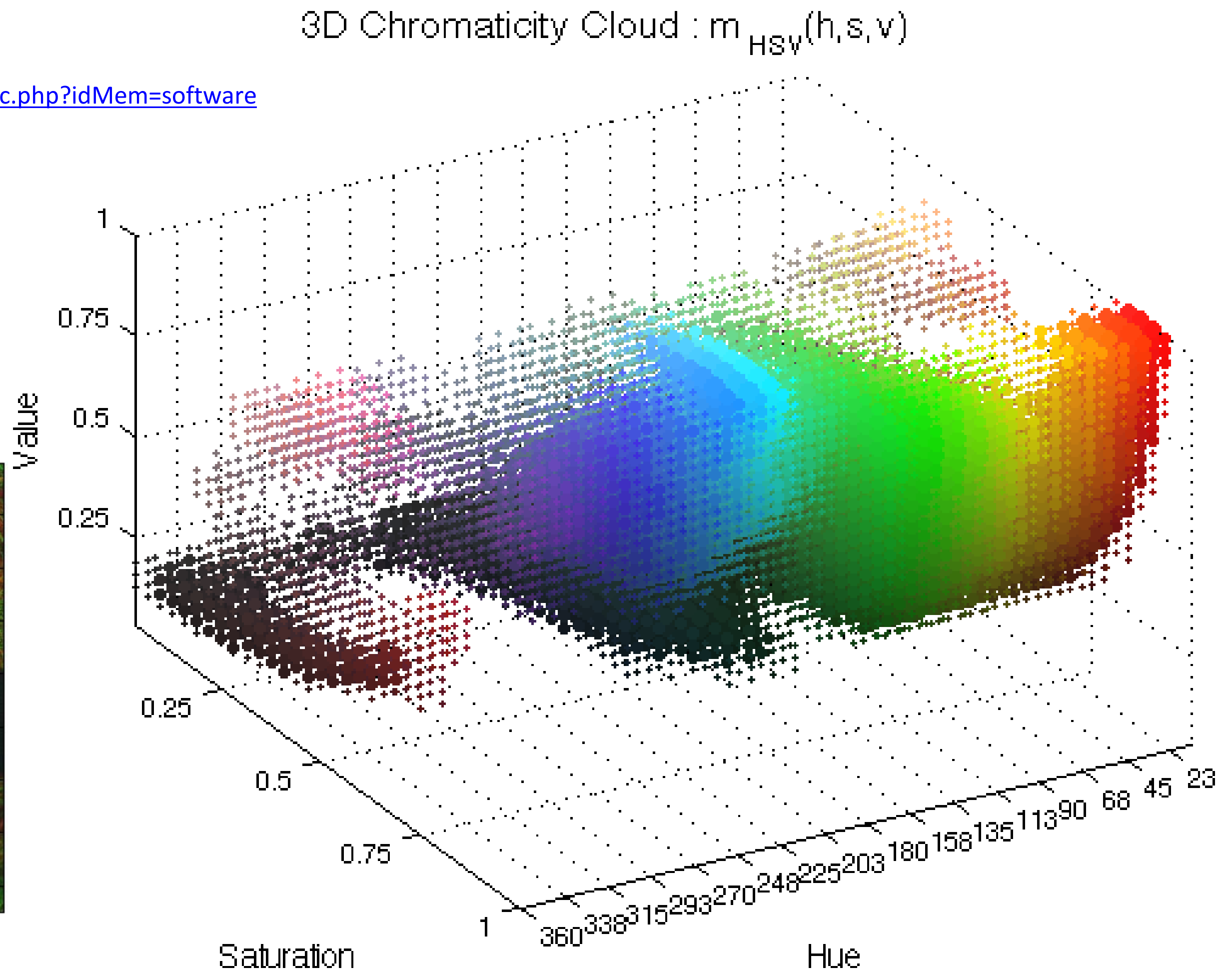
Fig. 13.1 Scalar quantization of color components by truncating lower bits. Quantization of 3 × 12-bit to 3 × 8-bit colors (a). Quantization of 3 × 8-bit to 3:3:2-packed 8-bit colors (b). The Java code segment in Prog. 13.1 shows the corresponding sequence of bit operations.



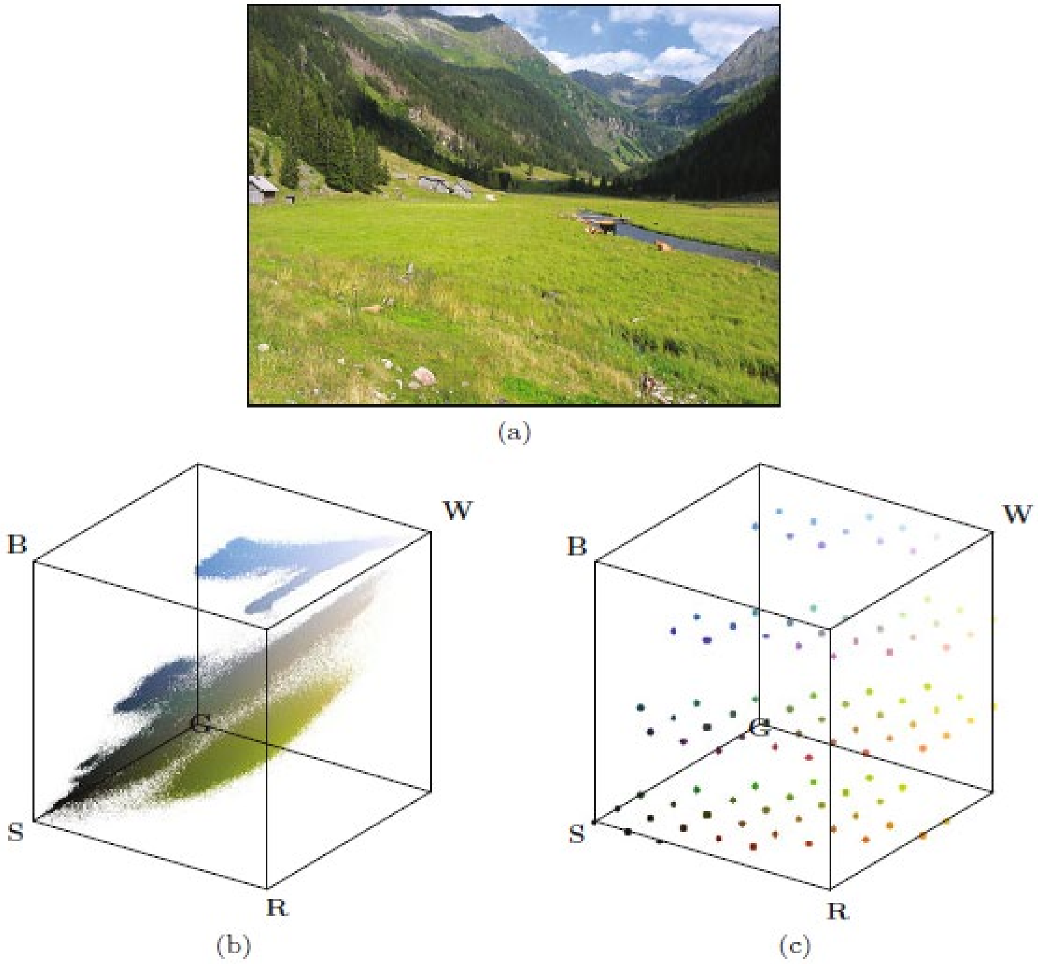
Histograms of color images can be difficult to visualize; this technique plots spheres at each occurring HSI point, where the size of the sphere indicates the frequency of occurrence

http://www.staff.city.ac.uk/~sbbk034/chromatic.php?idMem=software





Vector quantization considers the color image as a vector-valued 2D matrix and reduces the number of distinct color vectors, generally in a manner informed by image contents



13.2 Vector Quantization

Fig. 13.2
Color distribution after a scalar 3:3:2 quantization. Original color image (a). Distribution of the original 226,321 colors (b) and the remaining $8 \times 8 \times 4 = 256$ colors after 3:3:2 quantization (c) in the RGB color cube.

Color quantization by *populosity* keeps the *n* most common color vectors; other colors are replaced by the nearest valid color

Example (24 bit color)

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Populosity Algorithm

- 8 bit image, so the most popular 256 colors
- Note that blue wasn't very popular, so the crystal ball is now the same color as the floor
- Populosity ignores rare but important colors!

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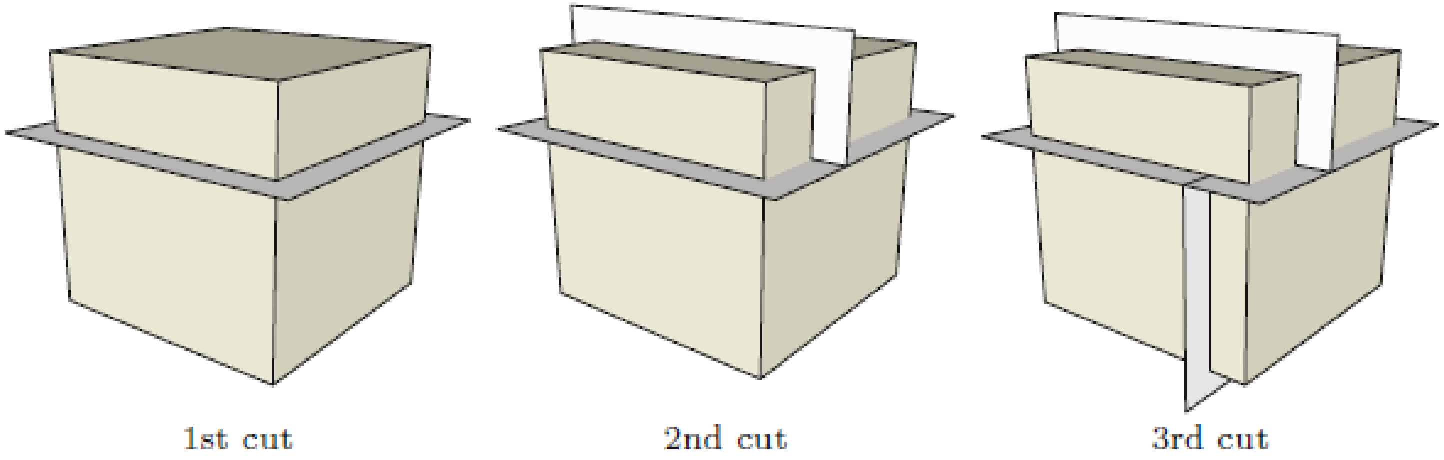
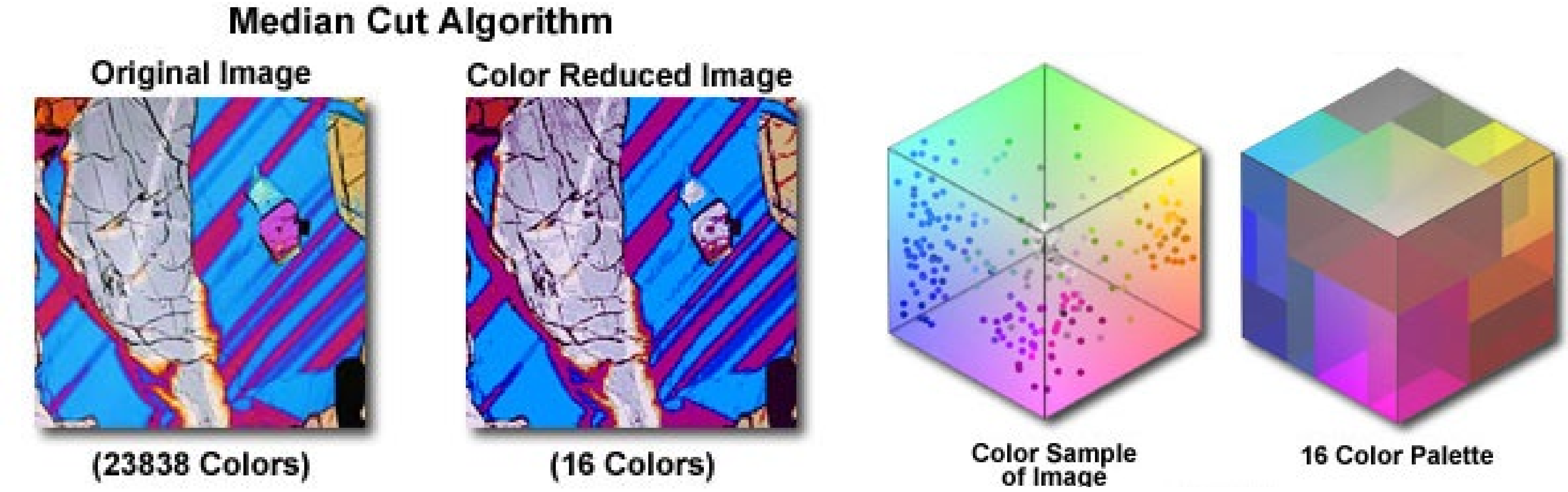
The Median Cut algorithm for color quantization recursively divides the color space by splitting at the median along the (currently) longest of the three axes

Fig. 13.3
Median-cut algorithm. The RGB color space is recursively split into smaller cubes along one of the color axes.



- Do
  - Determine the box containing the largest number of pixels
  - Determine the current longest axis of that box
  - Find the median along that axis
  - Divide the box at that point
- Until we have the desired number of color regions
- Each region is represented by the mean of the color values within it

Median cut can produce results that are efficient in number of colors and natural looking



https://micro.magnet.fsu.edu/primer/java/digitalimaging/processing/colorreduction/index.html

COLORIMETRY

RGB, HSI and the other color spaces that we have discussed are dependent on the properties of the device used to capture, display or print the image

- When we capture a color image and display it on a screen, there is an underlying assumption that the blue filters in the camera exactly match the pure blue displayed on the screen
  - Same for red and green

- In order to precisely and repeatably duplicate colors, we need more
- A system that can describe colors in a way that is precise and not dependent on device properties is called a *colorimetric* or *calibrated* system

- This is the basis of colorimetry – the science of color

The CIE XYZ color system was developed after much experimentation on how humans perceived different colors

- There are three theoretical primary colors: X, Y and Z
  - Y is approximately intensity
- All visible colors are linear combinations of these (no negative weights)
- The space of visible colors is a cone

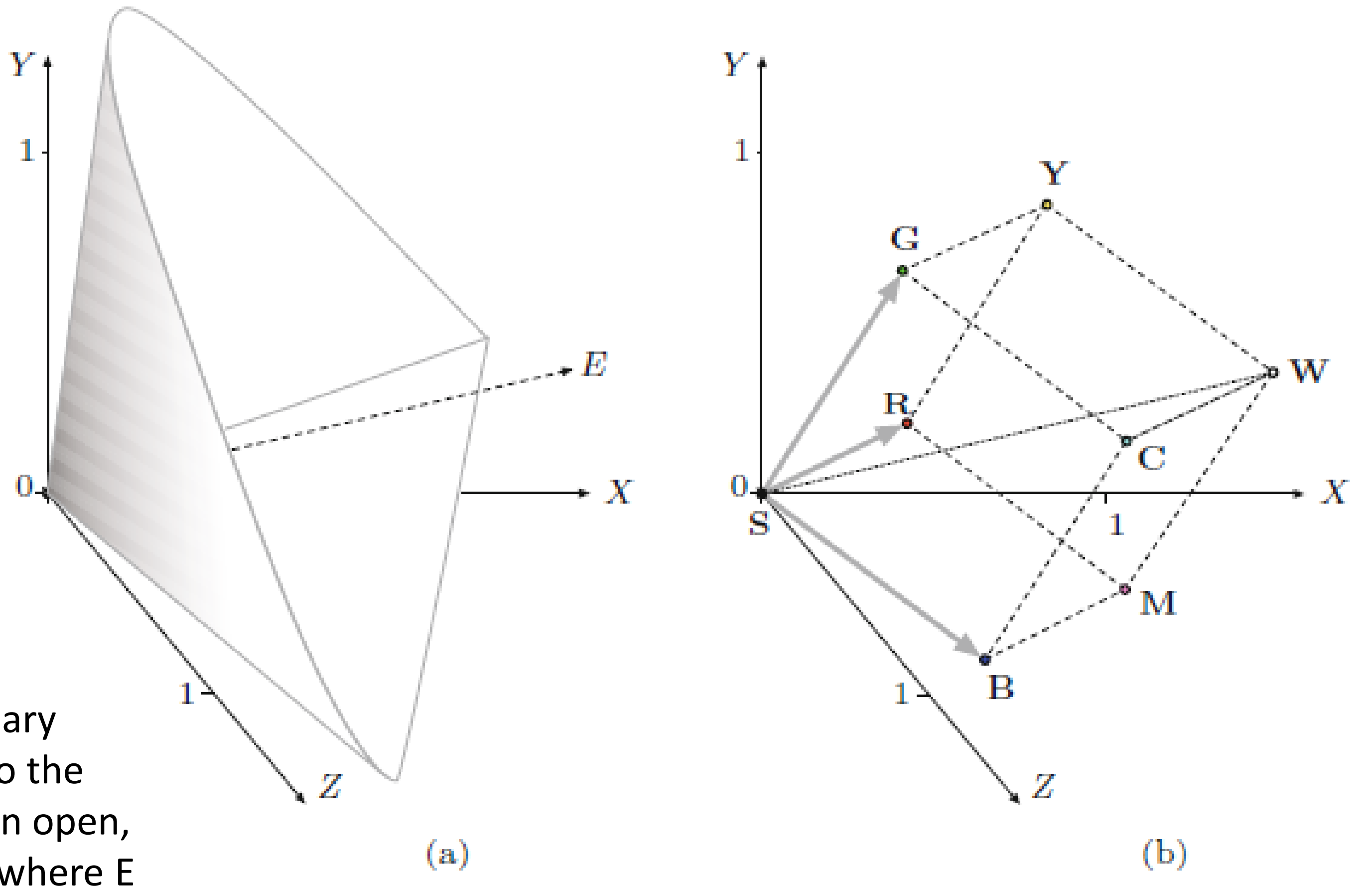


Fig. 14.1 - The XYZ color space is defined by the three imaginary primary colors X, Y , Z, where the Y dimension corresponds to the perceived luminance. All visible colors are contained inside an open, cone-shaped volume that originates at the black point S (a), where E denotes the axis of neutral (gray) colors. The RGB color space maps to the XYZ space as a linearly distorted cube (b).

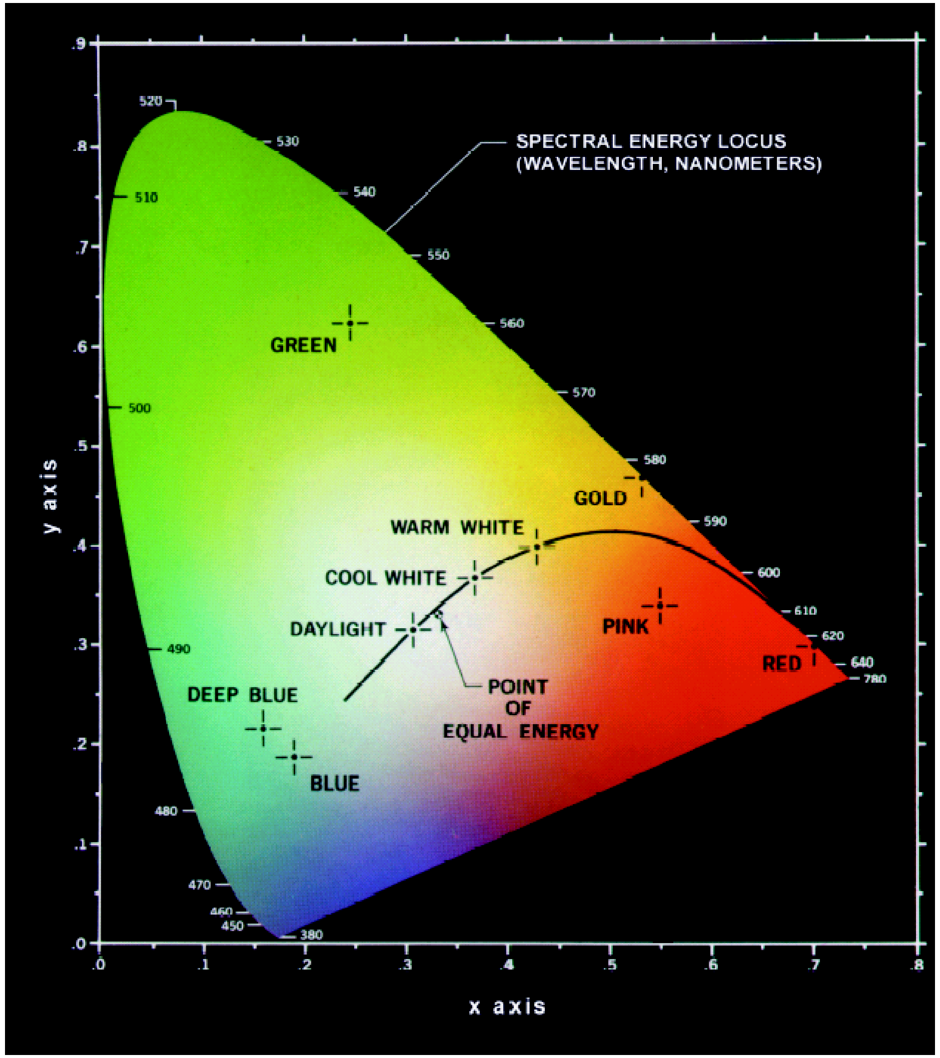
CIE chromaticity values are computed from the X,Y,Z values, and are a convenient pair of numbers to represent both hue and saturation

$$x = \frac{X}{X+Y+Z}, \qquad y = \frac{Y}{X+Y+Z}, \qquad z = \frac{Z}{X+Y+Z}$$

- Obviously, if we have x and y, z is redundant since $x + y + z = 1$
- So, Y is luminance (like intensity) and x and y encode hue and saturation

Point	Color	R	G	B	X	Y	Z	x	y	Y (luminance)
S	Black	0.00	0.00	0.00	0.0000	0.0000	0.0000	0.3127	0.3290	0.0000
R	Red	1.00	0.00	0.00	0.4125	0.2127	0.0193	0.6400	0.3300	0.2127
Y	Yellow	1.00	1.00	0.00	0.7700	0.9278	0.1385	0.4193	0.5052	0.9278
G	Green	0.00	1.00	0.00	0.3576	0.7152	0.1192	0.3000	0.6000	0.7152
C	Cyan	0.00	1.00	1.00	0.5380	0.7873	1.0694	0.2247	0.3288	0.7873
B	Blue	0.00	0.00	1.00	0.1804	0.0722	0.9502	0.1500	0.0600	0.0722
M	Magenta	1.00	0.00	1.00	0.5929	0.2848	0.9696	0.3209	0.1542	0.2848
W	White	1.00	1.00	1.00	0.9505	1.0000	1.0888	0.3127	0.3290	1.0000

The CIE chromaticity diagram plots all perceivable colors in terms of the two color coefficients x and y



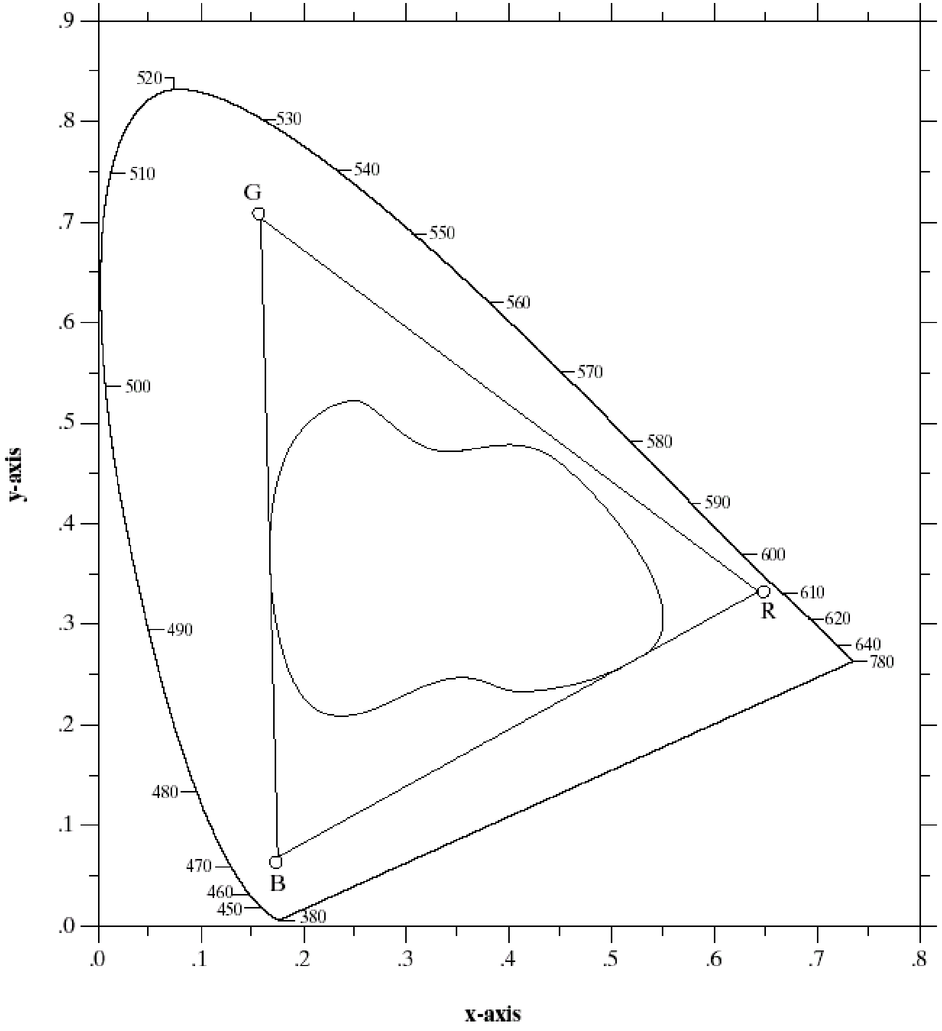
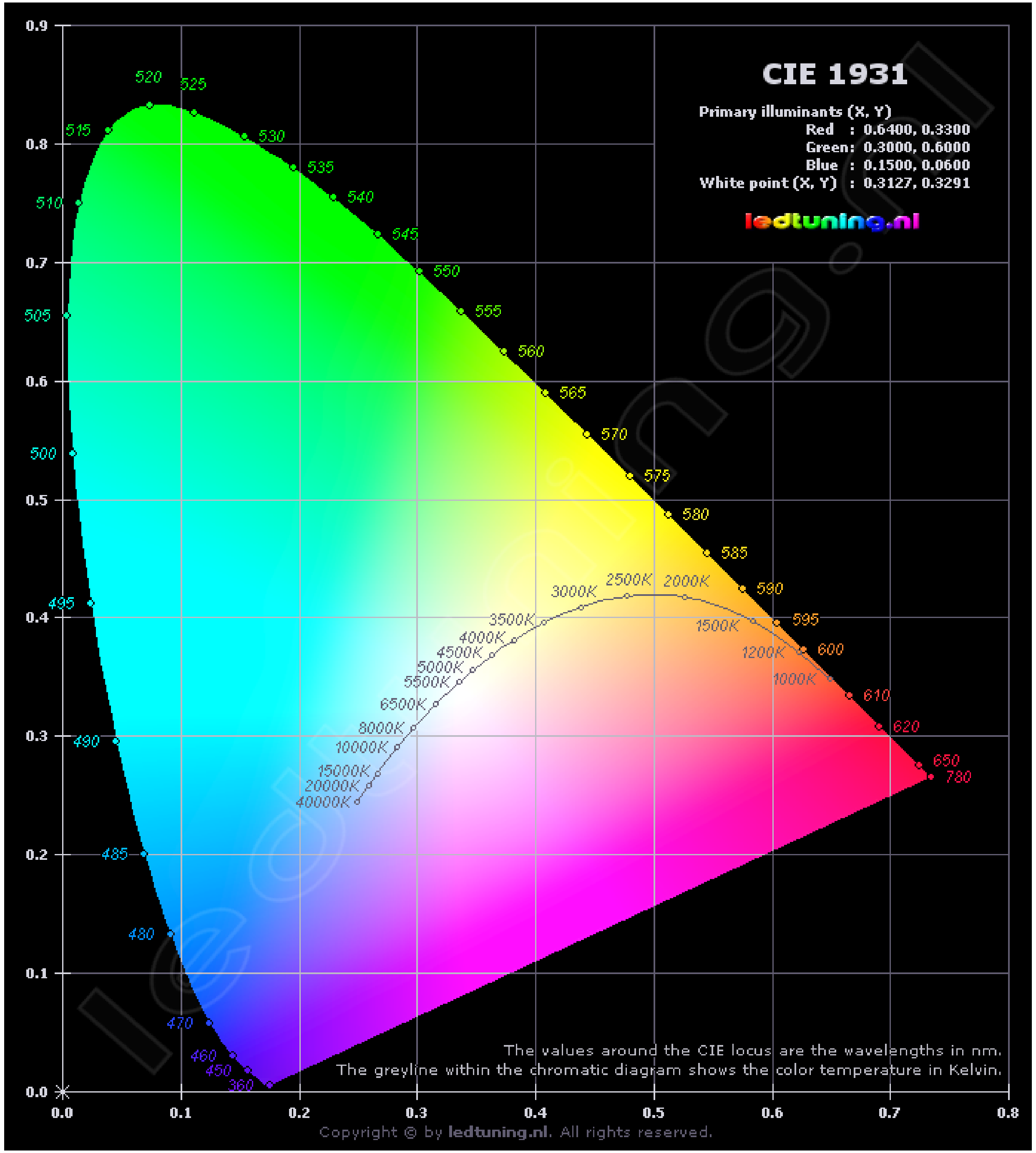


FIGURE 6.6 Typical color gamut of color monitors (triangle) and color printing devices (irregular region).

One use of the CIE system is to unambiguously specify the color of objects and light sources; here is a table of the CIE chromaticity measures for blackbodies at various temperatures



CIE XYZ is a good color representation to measure color irrespective of device characteristics, but it has some funny properties

- The fundamental colors X, Y and Z are not contained within the space, so they are not visible

- "The CIE XYZ scheme is (similar to the RGB color space) *nonlinear* with respect to human visual perception, that is, a particular fixed distance in XYZ is not perceived as a uniform color change throughout the entire color space."

- It can be cumbersome for use in electronic systems

sRGB is an attempt to define a convenient color space similar to RGB that is nonetheless precisely specified and can be used for colorimetric purposes

- JPEG and PNG are actually based on use of sRGB for color images
- It includes detailed description of:
  - the primary colors Red, Green and Blue, and pure White
  - illumination source(s)
  - specified gamma correction
- Usually if we are working with RGB images, they are in fact sRGB

Point	Color	R	G	B	X_{65}	Y_{65}	Z_{65}	x_{65}	y_{65}	Y_{65} (luminance)
R	**Red**	1.00	0.00	0.00	0.4125	0.2127	0.0193	0.6400	0.3300	0.2127
G	**Green**	0.00	1.00	0.00	0.3576	0.7152	0.1192	0.3000	0.6000	0.7152
B	**Blue**	0.00	0.00	1.00	0.1804	0.0722	0.9502	0.1500	0.0600	0.0722
W	**White**	1.00	1.00	1.00	0.9505	1.0000	1.0888	0.3127	0.3290	1.0000

*in reference to the white point D_{65}

Conversion from sRGB to and from CIE XYZ

- Raw color components R',G',B' from a camera are corrected by an exponential contrast stretching (with $\gamma = 2.2$ or so) for printing and display
  - The results are R, G, B

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \boldsymbol{M}^{-1} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

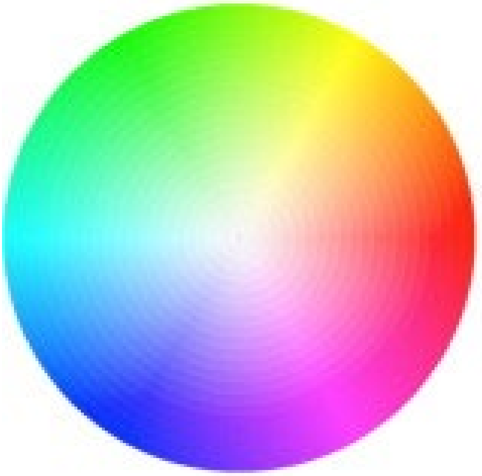
$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \boldsymbol{M} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

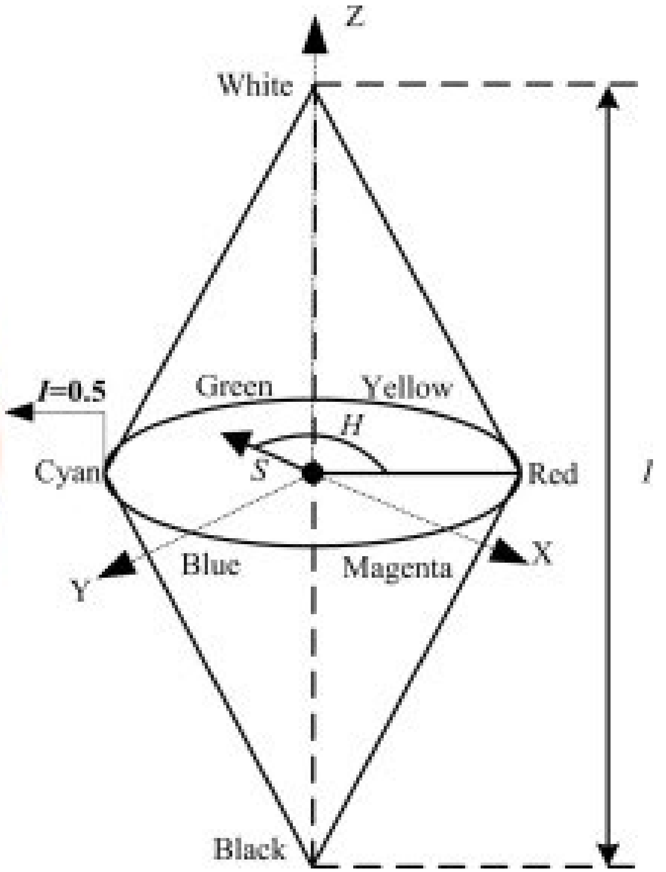
There are other colorimetric spaces used for certain applications and needs

- Adobe RGB – an alternative RGB representation (calculation from CIE) that allows more colors

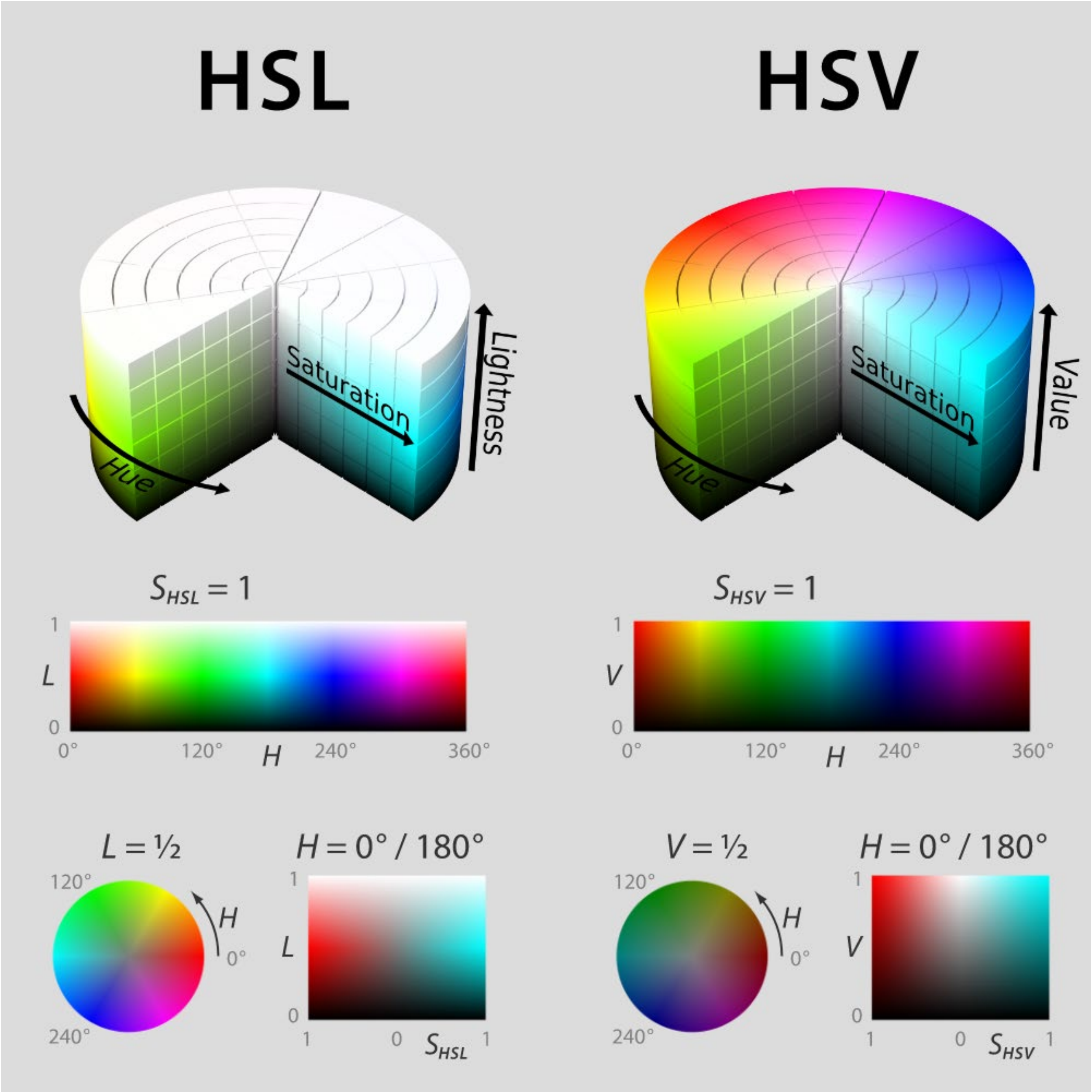
- YUV is used for analog color television
  - $Y = 0.299R + 0.587G + 0.114B$
  - $U = 0.492(B - Y)$
  - $V = 0.877(R - Y)$
  - YC_rC_b and YIQ are similar to it

- HSV and HLS are enhancements to HSI





Z
White
I=0.5
Green
Yellow
H
Cyan
S
Red
I
Blue
Magenta
X
Y
Black



HSL
HSV
Hue
Saturation
Lightness
Value
$S_{HSL} = 1$
$S_{HSV} = 1$
L
V
H
0° 120° 240° 360°
$L = ½$
$H = 0° / 180°$
$V = ½$
S_{HSL}
S_{HSV}

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