

Prelucrarea Imaginilor

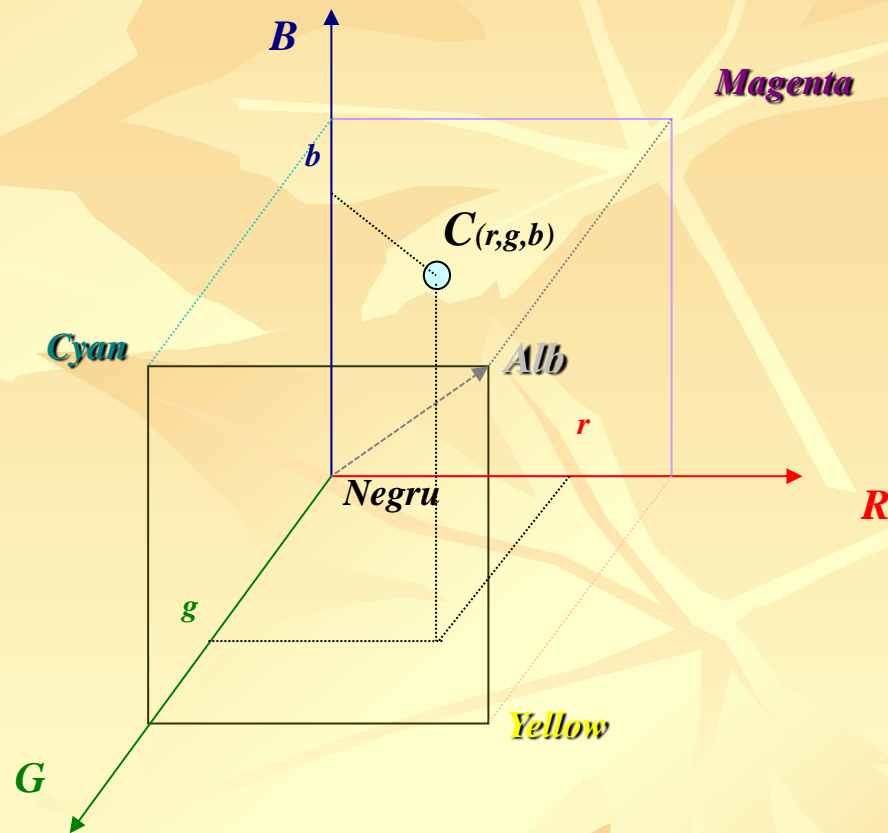
Curs 9

Spatii de culoare RGB / CIE Lab, Luv, HSL, HSV, ...

28 Noiembrie 2019

Sistemul RGB

Este posibil să reprezentăm o culoare prin trei coordonate (numere naturale) reprezentând cantitățile culorilor de bază, de exemplu roșu, verde și albastru (**R**ed, **G**reen, **B**lue), deci în spațiul **RGB** (vezi figura 2.2.5) sau cel complementar (**C**yan, **Y**ellow, **M**agenta). Utilizând opt bit pentru reprezentarea fiecărei coordonate (valori a componentei **red**, **green** sau **blue**) vom obține un spațiu al culorilor cu valori din domeniul $[0..255]^3$, adică 2^{24} valori distincte, deci peste 16 milioane de nuanțe .



Spațiul culorilor în sistemul **RGB**

Spectrul este o bandă continuă de lungimi de undă emisă, reflectată sau transmisă de diverse obiecte. Ochiul uman nu poate vedea întregul spectru, doar culori cu valori din domeniul [400nm-700nm] corespunzător [albastru-roșu]. În practică, spectrul este reprezentat ca un vector de numere care măsoară intensitatea diferitelor lungimi de undă. Usual, un spectrofotometru are o rezoluție de 1-3 nm, măsurând de la 100 la 300 de valori pentru a măsura domeniul vizibil. Presupunând că un aparat foarte simplu scanează un spectru la fiecare 3 nm (100 de puncte pentru 300 nm) și măsoară fiecare punct cu o precizie de doar 8 bit. Aceasta înseamnă că aparatul poate distinge mai mult de 10^{240} de spectre diferite (atâtea numere pot fi codificate pe 8 bit x 100 puncte = 800 bit de date). Dar oamenii pot distinge doar în jur de 10 milioane de culori. Aceasta se întâmplă pentru că ochiul are doar trei tipuri de conuri receptoare în retină care răspund diferitelor lungimi de undă a luminii. Astfel, creierul receptează doar trei semnale pentru fiecare spectru, acestea dându-ne percepția culorii.

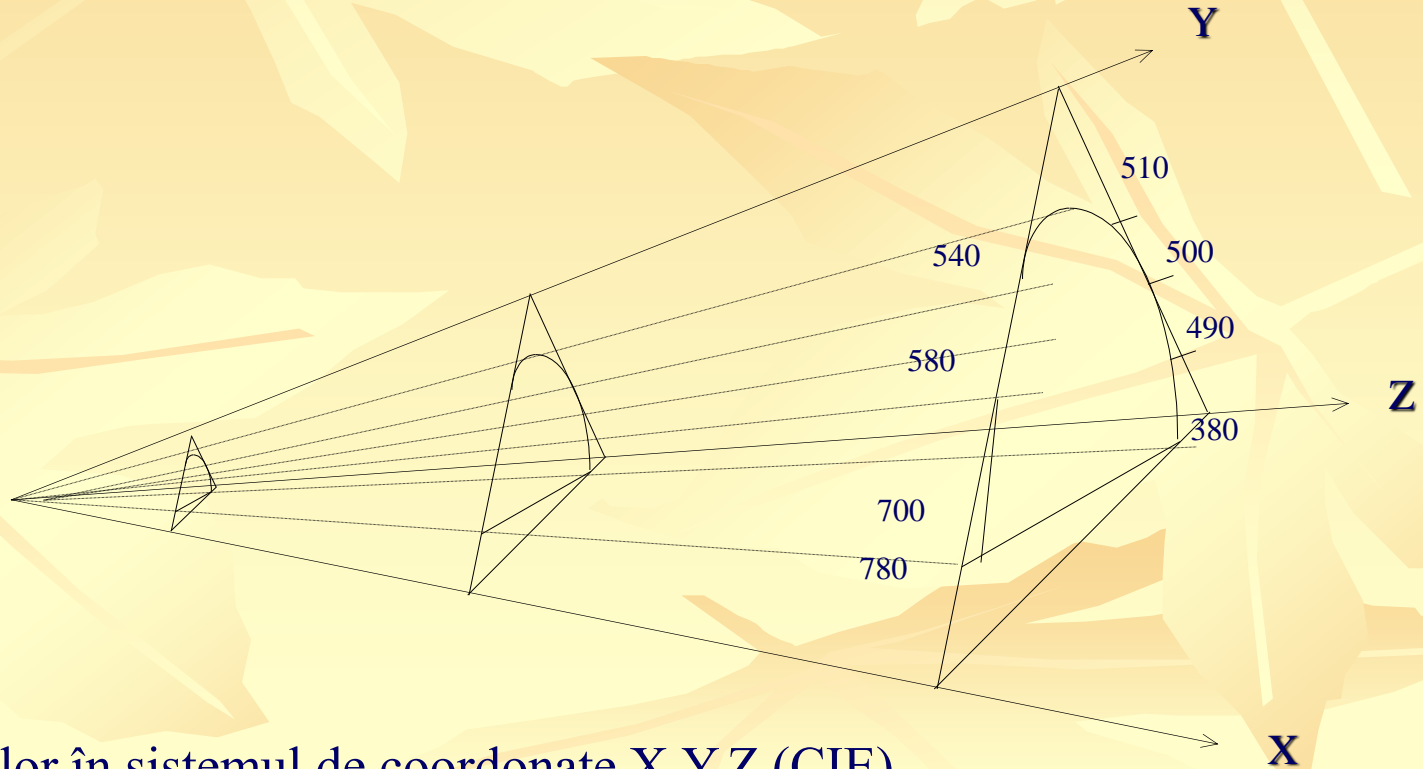
Interpretări colorimetrice computerizate

Un sistem tricromatic poate defini orice culoare combinația a trei culori de bază în cantități unic precizate (culorile fundamentale sunt alese astfel încât nici una să nu poată fi obținută prin amestecul celorlalte două). Cel mai cunoscut sistem tricromatic este sistemul RVI (R-roșu, V-verde, I-indigo) caracterizat prin cele trei culori de bază având următoarele lungimi de undă: roșu $\lambda = 700$ nm; verde $\lambda = 546,1$ nm; indigo $\lambda = 435$ nm.

Orice culoare monocromatică spectrală, într-un sistem tricromatic este caracterizată prin trei valori numite valori spectrale sau coeficienți de distribuție. În sistemul RVI, există culori care sunt caracterizate și prin coeficienți negativi (coordonate negative ale culorilor de bază). Pentru a elimina valorile negative la precizarea unei culori, s-au definit trei culori virtuale (notate cu X, Y, Z) care nu mai prezintă inconvenientul precizat. Aceste culori constituie valorile fundamentale ale culorii în sistemul tricromatic CIE (Commission Internationale De L'Eclairage), fiind denumite și coordonate tricromatice sau valori tristimu.

Caracterizarea și măsurarea culorilor în sisteme tricromatice

În sistemul CIE, o culoare poate fi reprezentată grafic într-un sistem tridimensional prin punctul de coordonate (X,Y,Z). Totalitatea punctelor ce corespund tuturor culorilor posibile constituie *spațiul culorilor*.



Spațiul culorilor în sistemul de coordonate X,Y,Z (CIE).

Caracterizarea și măsurarea culorilor în sisteme tricromatice

Măsurarea culorilor în sistemul **CIE** constă în determinarea valorilor **X, Y, Z**. În acest scop se consideră cei trei factori care caracterizează culoarea, și anume:

- *iluminantul*, reprezentat prin *curba de distribuție a energiei* $\mathbf{E}(\lambda)$;
- *corpul colorat*, reprezentat prin *curbele de remisiune (reflexie)* $\mathbf{R}(\lambda)$;
- *ochiul omenesc* caracterizat prin *curbele de distribuție spectrală* pentru observatorul normal $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$.

Pentru o lungime de undă λ , *energia transmisă de corpul colorat* este egală cu produsul $\mathbf{E}(\lambda) \cdot \mathbf{R}(\lambda)$.

Energia transmisă pentru toate lungimile de undă ale spectrului vizibil (φ) este egală cu $\sum_{\lambda} \mathbf{E}(\lambda) \cdot \mathbf{R}(\lambda)$, și reprezintă *interacțiunea iluminant-corp*.

Caracterizarea și măsurarea culorilor în sisteme tricromatice

Pentru a se determina interacțiunea iluminant-corp colorat-ochi, funcția φ trebuie înmulțită cu fiecare din cele trei funcții $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$. Se obțin astfel pentru X, Y, și Z următoarele formule de calcul:

$$X = \sum_{\lambda=380}^{770} E(\lambda) \cdot R(\lambda) \cdot \bar{x}(\lambda)$$

$$Y = \sum_{\lambda=380}^{770} E(\lambda) \cdot R(\lambda) \cdot \bar{y}(\lambda)$$

$$Z = \sum_{\lambda=380}^{770} E(\lambda) \cdot R(\lambda) \cdot \bar{z}(\lambda)$$

Pentru calcule, mărimile $E(\lambda) \cdot \bar{x}(\lambda)$; $E(\lambda) \cdot \bar{y}(\lambda)$; $E(\lambda) \cdot \bar{z}(\lambda)$, sunt normate și înscrise în tabele, astfel încât la o măsurare rămâne de determinat doar curba de remisiune $R(\lambda)$.

Caracterizarea și măsurarea culorilor în sisteme tricromatice

Pentru sistemul CIELAB 76, coordonatele tricromatice X, Y, Z sunt transformate în alte trei coordonate:

L^* (coordonata luminozitate),
 a^* (coordonata roșu-verde) și
 b^* (coordonata galben-albastru) :

unde X_0 , Y_0 și Z_0 sunt coordonatele tricromatice care se obțin în cazul unui material cu suprafață reflectantă perfect albă:

$$\begin{cases} L^* = 116 \cdot f(Y/Y_0); \\ a^* = 500 \cdot [f(X/X_0) - f(Y/Y_0)] \\ b^* = 200 \cdot [f(Y/Y_0) - f(Z/Z_0)] \end{cases}$$

$$X_0 = \sum_{\lambda=380}^{770} E(\lambda) \cdot \bar{x}(\lambda)$$

$$Y_0 = \sum_{\lambda=380}^{770} E(\lambda) \cdot \bar{y}(\lambda)$$

$$Z_0 = \sum_{\lambda=380}^{770} E(\lambda) \cdot \bar{z}(\lambda)$$

iar $f(\Phi) = \Phi^{1/3} - 16/116$.

Diferența de culoare ΔE^* dintre două culori (probe) reprezintă distanța geometrică (*Euclidiană*) dintre punctele corespunzătoare (celor două probe) din spațiul culorilor. În sistemul **CIELAB**, aceasta se calculează cu ajutorul formulei:

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

unde:

ΔL^* reprezintă diferența de *luminozitate* dintre cele două probe,

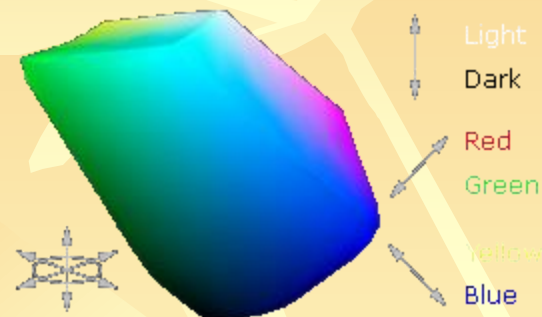
Δa^* reprezintă diferența dintre coordonatele *roșu-verde*,

Δb^* reprezintă diferența dintre coordonatele *galben-albastru*.

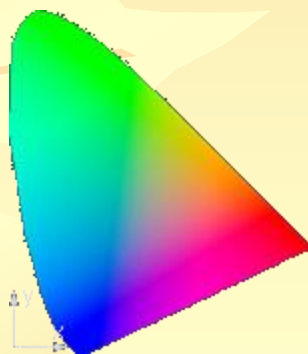
Vizualizarea culorilor

(<http://www.cambridgeincolour.com/tutorials.htm>)

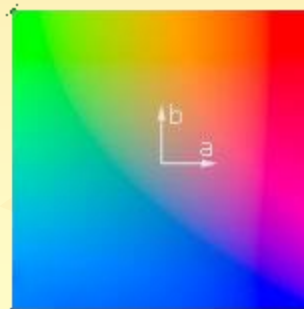
Pe *verticala* este masurata **luminozitatea**, iar pe *orizontala* **rosu-verde**, respectiv **galben-albastru**:



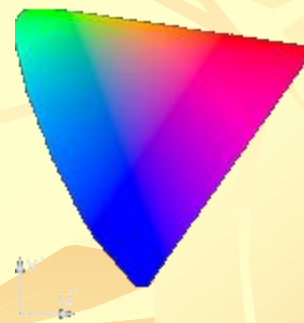
Spatiul **CIE** al
culorilor vizibile:



CIE XYZ (1931)



CIE L*a*b*



CIE Lu'v' (1976)

RGB \rightarrow L a* b* & L a* b* \rightarrow RGB

$$\text{RGB} \rightarrow \text{XYZ} \quad \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{pmatrix} * \begin{pmatrix} R \\ G \\ B \end{pmatrix}.$$

$$\text{XYZ} \rightarrow \text{RGB} \quad \begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 3.240479 & -1.537150 & -0.498535 \\ -0.969256 & 1.875992 & 0.041556 \\ 0.055648 & -0.204043 & 1.057311 \end{pmatrix} * \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}.$$

$$\begin{aligned} \text{XYZ} \rightarrow \text{L a* b*} \\ L^* &= 116 * (Y/Y_n)^{1/3} - 16 && \text{pentru } Y/Y_n > 0.008856 \\ L^* &= 903.3 * Y/Y_n && \text{altfel} \\ a^* &= 500 * (f(X/X_n) - f(Y/Y_n)) \\ b^* &= 200 * (f(Y/Y_n) - f(Z/Z_n)) \\ \text{unde } f(t) &= t^{1/3} && \text{pentru } t > 0.008856 \\ &= 7.787 * t + 16/116 && \text{altfel} \end{aligned}$$

$$\begin{aligned} \text{L a* b*} \rightarrow \text{XYZ} \\ X &= X_n * (P + a^* / 500)^3 \\ Y &= Y_n * P^3 \\ Z &= Z_n * (P - b^* / 200)^3 \\ \text{unde } P &= (L^* + 16) / 116 \end{aligned}$$

RGB → XYZ → L a* b*

```
void Tr(float& C)
{
    C/=255.;
    if (C>0.04045) C=x_la_y((C+0.055)/1.055,2.4); else C/=12.92;
    C=C*100;
}
```

RGB_XYZ(R,G,B, vX,vY,vZ); → void RGB_XYZ(float R,float G,float B, float& X, float& Y,float& Z)

```
{
    Tr(R); Tr(G); Tr(B);
    X=R * 0.4124 + G * 0.3576 + B * 0.1805;
    Y=R * 0.2126 + G * 0.7152 + B * 0.0722;
    Z=R * 0.0193 + G * 0.1192 + B * 0.9505;
}
```

```
float f(float t)
{
    float e=0.008856;
    if (t>e) return x_la_y(t,1/3.); else return 7.787*t+16./116.;
}
```

XYZ_Lab(vX,vY,vZ, LL,aa,bb); → void XYZ_Lab(float X, float Y, float Z, float& L, float& a, float& b)

```
{
    float Xn, Yn, Zn;          float W=255.;
    float e=0.008856;
    RGB_XYZ(W,W,W,Xn,Yn,Zn);
    X=X/Xn; Y=Y/Yn; Z=Z/Zn;    if (Y>e)
    L=116.*x_la_y(Y,1/3.)-16;   else L=903.3*Y;
    a=500.*(f(X)-f(Y));
    b=200.*(f(Y)-f(Z));
}
```

$L a^* b^* \rightarrow XYZ \rightarrow RGB$

<http://www.easyrgb.com/index.php?X=MATH>

```
void Tr1(float& C)
{ if ( C3 > 0.008856 ) C = C3 else C = ( C - 16 / 116 ) / 7.787 }
```

$L a^* b^* \rightarrow XYZ$

```
var_Y = ( CIE-L* + 16 ) / 116 // Observer= 2°, Illuminant= D65
var_X = CIE-a* / 500 + var_Y
var_Z = var_Y - CIE-b* / 200
Tr1(Var_X); Tr1(Var_Y); Tr1(Var_Z);
X = ref_X * var_X //ref_X = 95.047
Y = ref_Y * var_Y //ref_Y = 100.000
Z = ref_Z * var_Z //ref_Z = 108.883
```

$XYZ \rightarrow RGB$

```
void Tr2(float& C)
{ if ( C > 0.0031308 ) C = 1.055 * C1/2.4 - 0.055 else C = 12.92 * C }

var_X = X / 100 //X from 0 to 95.047 (Observer = 2°, Illuminant = D65)
var_Y = Y / 100 //Y from 0 to 100.000
var_Z = Z / 100 //Z from 0 to 108.883

var_R = var_X * 3.2406 + var_Y * -1.5372 + var_Z * -0.4986
var_G = var_X * -0.9689 + var_Y * 1.8758 + var_Z * 0.0415
var_B = var_X * 0.0557 + var_Y * -0.2040 + var_Z * 1.0570
Tr2(var_R); Tr2(var_G); Tr2(var_B);
R = var_R * 255; G = var_G * 255; B = var_B * 255
```

RGB \rightarrow Luv & Luv \rightarrow RGB

RGB \rightarrow CIE-Luv

După conversia din spațiul RGB în XYZ (descrisă anterior) se va efectua conversia în spațiul CIE Luv astfel:

$$L = 116 * (Y/Y_n)^{1/3} - 16$$

$$U = 13 * L * (u - u_n)$$

$$V = 13 * L * (v - v_n)$$

unde:

$$u = 4 * X / (X + 15 * Y + 3 * Z)$$

$$v = 9 * Y / (X + 15 * Y + 3 * Z)$$

$$u_n = 4 * x_n / (-2 * x_n + 12 * y_n + 3)$$

$$v_n = 9 * y_n / (-2 * x_n + 12 * y_n + 3)$$

CIE-Luv → RGB

Mai întâi vom efectua conversia din spațiul CIE Luv în spațiul XYZ:

$$Y = Y_n * ((L+16) / 116)^3$$

$$X = -9 * Y * u / ((u-4) * v - u * v)$$

$$Z = (9 * Y - 15 * v * Y - v * X) / 3 * v$$

unde:

$$u = U / (13 * L) + u_n$$

$$v = V / (13 * L) + v_n$$

apoi, se va efectua conversia în spațiul RGB (descrisă anterior).

Color space

A color model is an abstract mathematical model describing the way colors can be represented as tuples of numbers, typically as three or four values or *color components* (e.g. RGB and CMYK are color models). However, a color model with no associated mapping function to an absolute color space is a more or less arbitrary color system with no connection to any globally-understood system of color interpretation.

Adding a certain mapping function between the color model and a certain reference color space results in a definite "footprint" within the reference color space. This "footprint" is known as a gamut, and, in combination with the color model, defines a new **color space**. For example, Adobe RGB and sRGB are two different absolute color spaces, both based on the RGB model.

In the most generic sense of the definition above, color spaces can be defined without the use of a color model. These spaces, such as Pantone, are in effect a given set of names or numbers which are defined by the existence of a corresponding set of physical color swatches. This article focuses on the mathematical model concept.

Understanding the concept

A wide range of colors can be created by the primary colors of pigment (cyan (C), magenta (M), yellow (Y), and black (K)). Those colors then define a specific color space. To create a three-dimensional representation of a color space, we can assign the amount of magenta color to the representation's Xaxis, the amount of cyan to its Y axis, and the amount of yellow to its Z axis. The resulting 3-D space provides a unique position for every possible color that can be created by combining those three pigments.

However, this is not the only possible color space. For instance, when colors are displayed on a computer monitor, they are usually defined in the RGB (red, green and blue) color space. This is another way of making nearly the same colors (limited by the reproduction medium, such as the phosphor (CRT) or filters and backlight (LCD)), and red, green and blue can be considered as the X, Y and Z axes. Another way of making the same colors is to use their Hue (X axis), their Saturation (Y axis), and their brightness Value (Z axis). This is called the HSV color space. Many color spaces can be represented as three-dimensional (X,Y,Z) values in this manner, but some have more, or fewer dimensions, and some cannot be represented in this way at all..

Conversion

When formally defining a color space, the usual reference standard is the CIELAB or CIEXYZ color spaces, which were specifically designed to encompass all colors the average human can see.

Since "color space" is a more specific term for a certain *combination* of a color model plus a mapping function, the term "color space" tends to be used to also identify color models, since identifying a color space automatically identifies the associated color model. Informally, the two terms are often used interchangeably, though this is strictly incorrect. For example, although several specific color spaces are based on the RGB model, there is no such thing as *the* RGB color space.

Since any color space defines colors as a function of the absolute reference frame, color spaces, along with device profiling, allow reproducible representations of color, in both analogue and digital representations.

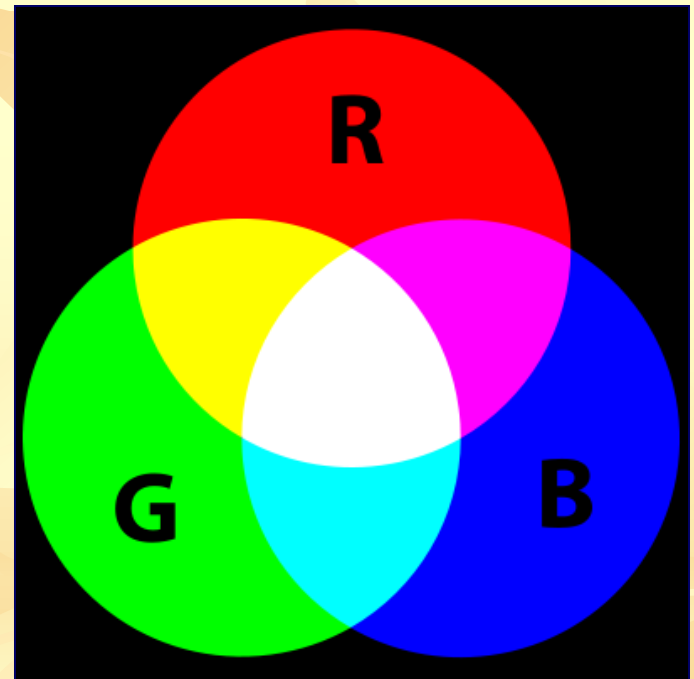
Color space conversion is the translation of the representation of a color from one basis to another. This typically occurs in the context of converting an image that is represented in one color space to another color space, the goal being to make the translated image look as similar as possible to the original.

Some color spaces

CIE 1931 XYZ color space was one of the first attempts to produce a color space based on measurements of human color perception (earlier efforts were by James Clerk Maxwell, König & Dieterici, and Abney at Imperial College)[1] and it is the basis for almost all other color spaces. Derivatives of the CIE XYZ space include CIELUV, CIEUVW, and CIELAB.

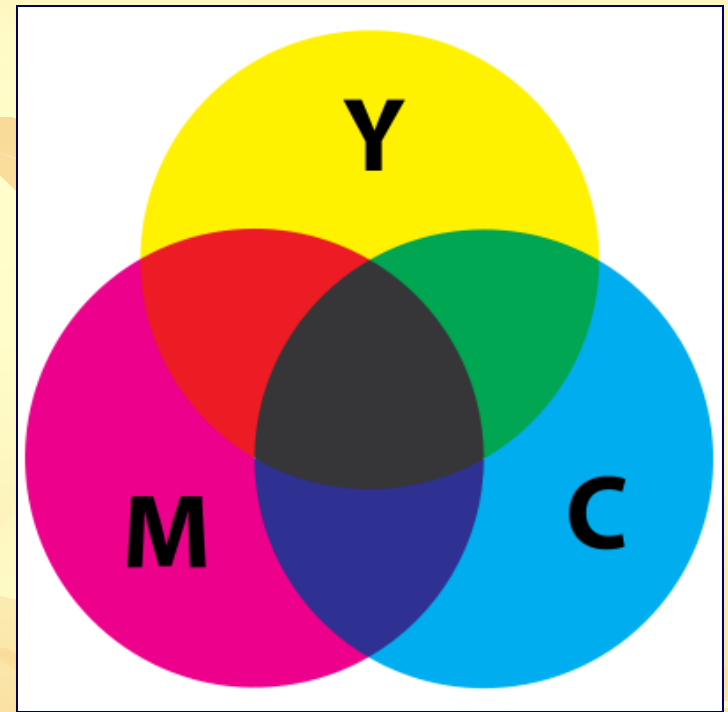
RGB uses additive color mixing, because it describes what kind of *light* needs to be *emitted* to produce a given color. Light is added together to create form from out of the darkness. RGB stores individual values for red, green and blue. RGBA is RGB with an additional channel, alpha, to indicate transparency.

Common color spaces based on the RGB model include sRGB, Adobe RGB and ProPhoto RGB.



Some color spaces

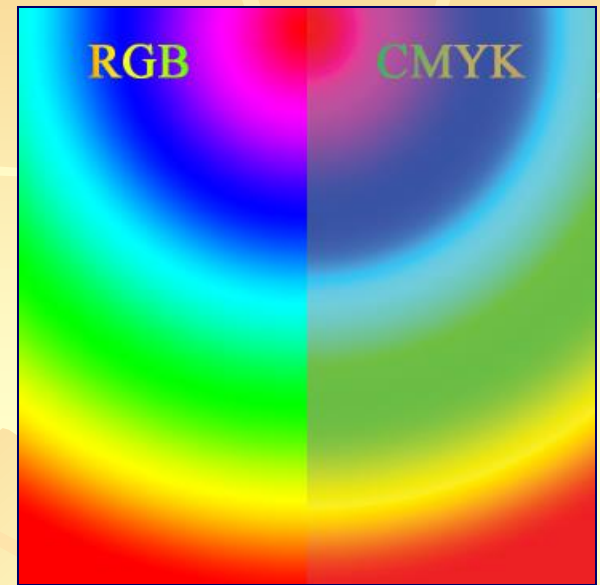
CMYK uses subtractive color mixing used in the printing process, because it describes what kind of inks need to be applied so the light *reflected* from the substrate and through the inks produces a given color. One starts with a white substrate (canvas, page, etc), and uses ink to subtract color from white to create an image. CMYK stores ink values for cyan, magenta, yellow and black. There are many CMYK color spaces for different sets of inks, substrates, and press characteristics (which change the dot gain or transfer function for each ink and thus change the appearance).



Some color spaces

A comparison of RGB and CMYK color spaces.

The image demonstrates the difference between the RGB and CMYK color gamuts. The CMYK color gamut is much smaller than the RGB color gamut, thus the CMYK colors look muted. If you were to print the image on a CMYK device (an offset press or maybe even a ink jet printer) the two sides would likely look much more similar, since the combination of cyan, yellow, magenta and black cannot reproduce the range (gamut) of color that a computer monitor displays. This is a constant issue for those who work in print production. Clients produce bright and colorful images on their computers and are disappointed to see them look muted in print. (An exception is photo processing. In photo processing, like snapshots or 8x10 glossies, most of the RGB gamut is reproduced.)



A comparison of RGB and CMYK color models. This image demonstrates the difference between how colors will look on a computer monitor (RGB) compared to how they will reproduce in a CMYK print process.

Generic color spaces

YIQ was formerly used in NTSC (North America, Japan and elsewhere) television broadcasts for historical reasons. This system stores a luminance value with two chrominance values, corresponding approximately to the amounts of blue and red in the color. It is similar to the YUV scheme used in most video capture systems[2] and in PAL (Australia, Europe, except France, which uses SECAM) television, except that the YIQ color space is rotated 33° with respect to the YUV color space. The YDbDr scheme used by SECAM television is rotated in another way.

YPbPr is a scaled version of YUV. It is most commonly seen in its digital form, YCbCr, used widely in video and image compression schemes such as MPEG and JPEG.

xvYCC is a new international digital video color space standard published by the IEC (IEC 61966-2-4). It is based on the ITU BT.601 and BT.709 standards but extends the gamut beyond the R/G/B primaries specified in those standards.

HSV (hue, saturation, value), also known as HSB (hue, saturation, brightness) is often used by artists because it is often more natural to think about a color in terms of hue and saturation than in terms of additive or subtractive color components. HSV is a transformation of an RGB colorspace, and its components and colorimetry are relative to the RGB colorspace from which it was derived.

HSL (hue, saturation, lightness/luminance), also known as HLS or HSI (hue, saturation, intensity) is quite similar to HSV, with "lightness" replacing "brightness". The difference is that the *brightness* of a pure color is equal to the brightness of white, while the *lightness* of a pure color is equal to the lightness of a medium gray.

HSL and HSV

HSL and **HSV** are the two most common cylindrical-coordinate representations of points in an RGB color model, which rearrange the geometry of RGB in an attempt to be more perceptually relevant than the cartesian representation. They were developed in the 1970s for computer graphics applications, and are used for color pickers, in color-modification tools in image editing software, and less commonly for image analysis and computer vision.

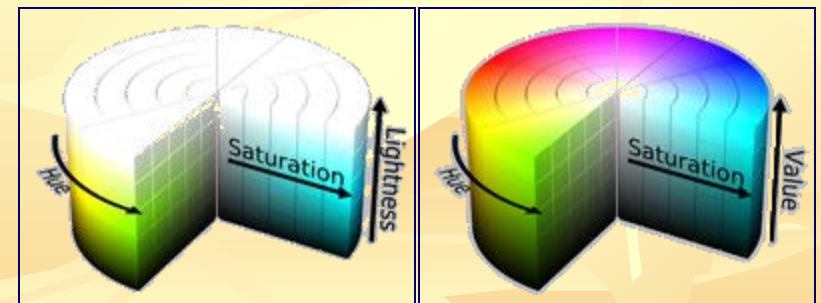
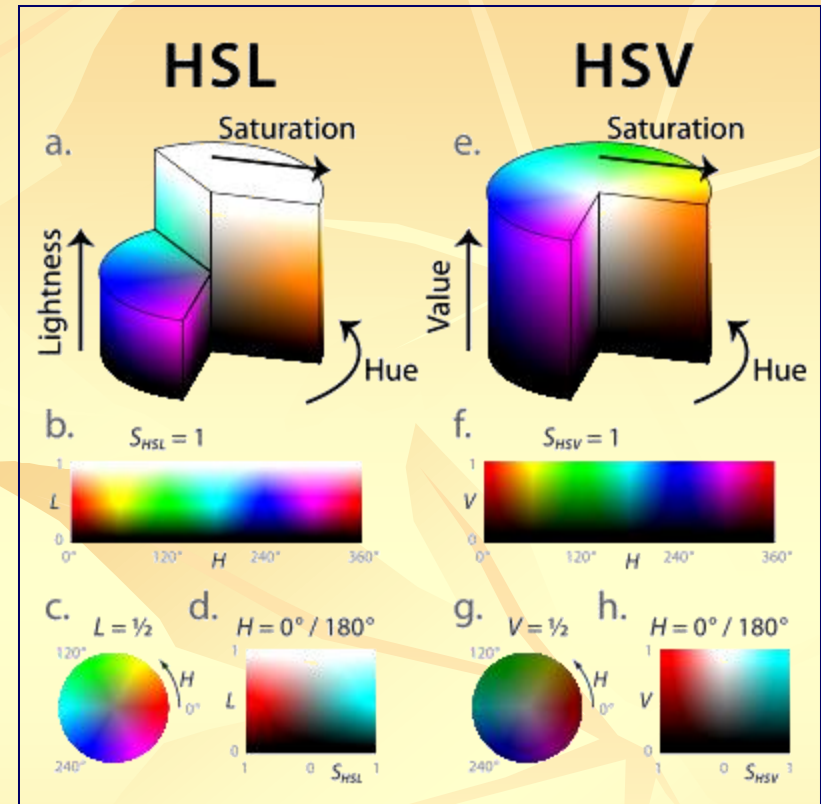
HSL stands for *hue*, *saturation*, and *lightness*, and is often also called **HLS**. HSV stands for *hue*, *saturation*, and *value*, and is also often called **HSB** (*B* for *brightness*). A third model, common in computer vision applications, is **HSI**, for *hue*, *saturation*, and *intensity*. Unfortunately, while typically consistent, these definitions are not standardized, and any of these abbreviations might be used for any of these three or several other related cylindrical models. (For technical definitions of these terms, see below.)

Both of these representations are used widely in computer graphics, and one or the other of them is often more convenient than RGB, but both are also commonly criticized for not adequately separating color-making attributes, or for their lack of perceptual uniformity. Other more computationally intensive models, such as CIELAB or CIECAM02 better achieve these goals.

HSL and HSV

In each cylinder, the angle around the central vertical axis corresponds to “hue”, the distance from the axis corresponds to “saturation”, and the distance along the axis corresponds to “lightness”, “value” or “brightness”. Note that while “hue” in HSL and HSV refers to the same attribute, their definitions of “saturation” differ dramatically.

Because HSL and HSV are simple transformations of device-dependent RGB models, the physical colors they define depend on the colors of the red, green, and blue primaries of the device or of the particular RGB space, and on the gamma correction used to represent the amounts of those primaries. Each unique RGB device therefore has unique HSL and HSV spaces to accompany it, and numerical HSL or HSV values describe a different color for each basis RGB space.



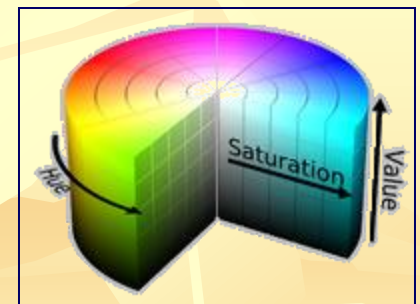
HSL and HSV cylinder

Basic idea

HSL and HSV are both cylindrical geometries, with hue, their angular dimension, starting at the red primary at 0°, passing through the green primary at 120° and the blue primary at 240°, and then wrapping back to red at 360°. In each geometry, the central vertical axis comprises the *neutral*, *achromatic*, or *gray* colors, ranging from black at lightness 0 or value 0, the bottom, to white at lightness 1 or value 1, the top. In both geometries, the additive primary and secondary colors – red, yellow, green, cyan, blue, and magenta – and linear mixtures between adjacent pairs of them, sometimes called *pure colors*, are arranged around the outside edge of the cylinder with saturation 1; in HSV these have value 1 while in HSL they have lightness ½. In HSV, mixing these pure colors with white – producing so-called tints – reduces saturation, while mixing them with black – producing shades – leaves saturation unchanged. In HSL, both tints and shades have full saturation, and only mixtures with both black and white – called *tones* – have saturation less than 1.



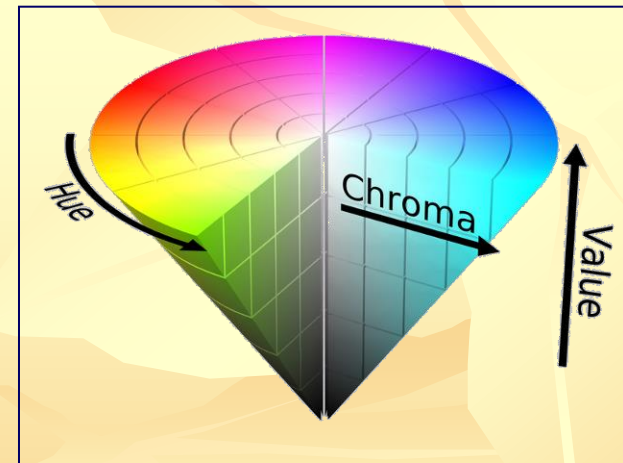
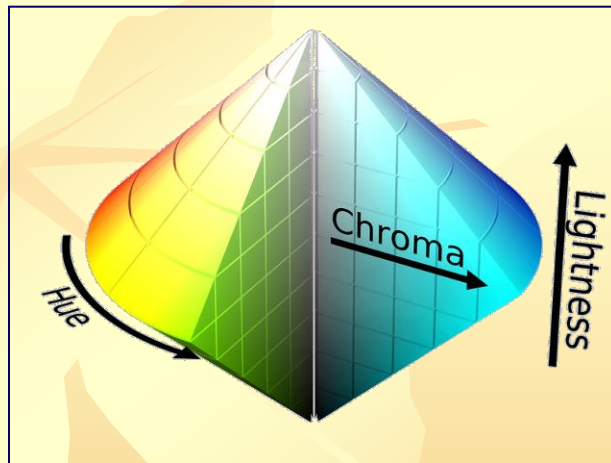
HSL cylinder



HSV cylinder

Basic idea

Because these definitions of saturation – in which very dark (in both models) or very light (in HSL) near-neutral colors, for instance Black or White, are considered fully saturated – conflict with the intuitive notion of color purity, often a conic or bi-conic solid is drawn instead, with what this article calls *chroma* as its radial dimension, instead of saturation. Confusingly, such diagrams usually label this radial dimension “saturation”, blurring or erasing the distinction between saturation and chroma. As described below, computing chroma is a helpful step in the derivation of each model. Because such an intermediate model – with dimensions hue, chroma, and HSV value or HSL lightness – takes the shape of a cone or bicone, HSV is often called the “hexcone model” while HSL is often called the “bi-hexcone model”



If we plot hue and (a) HSL lightness or (b) HSV value against chroma rather than saturation, the resulting solid is a bicone or cone, not a cylinder. Such diagrams often claim to represent HSL or HSV directly, with the chroma dimension labeled “saturation”.

Lightness

While the definition of *hue* is relatively uncontroversial – it roughly satisfies the criterion that colors of the same perceived hue should have the same numerical hue – the definition of a *lightness* or *value* dimension is less obvious: there are several possibilities depending on the purpose and goals of the representation. Here are four of the most common :

- The simplest definition is just the average of the three components, in the HSI model called *intensity* (fig. 11a). This is simply the projection of a point onto the neutral axis – the vertical height of a point in our tilted cube. The advantage is that, together with Euclidean-distance calculations of hue and chroma, this representation preserves distances and angles from the geometry of the RGB cube.

$$I = (R + G + B) / 3$$

In the HSV “hexcone” model, *value* is defined as the largest component of a color, our *M* above (fig. 11b). This places all three primaries, and also all of the “secondary colors” – cyan, yellow, and magenta – into a plane with white, forming a hexagonal pyramid out of the RGB cube.

$$V = M$$

Lightness

- In the HSL “bi-hexcone” model, *lightness* is defined as the average of the largest and smallest color components (fig. 11c). This definition also puts the primary and secondary colors into a plane, but a plane passing halfway between white and black. The resulting color solid is a double-cone similar to Ostwald’s, shown above.

$$L = (M + m) / 2$$

- A more perceptually relevant alternative is to use luma, Y' , as a lightness dimension (fig. 11d). Luma is the weighted average of gamma-corrected R , G , and B , based on their contribution to perceived luminance, long used as the monochromatic dimension in color television broadcast.
- For the Rec. 709 primaries used in sRGB, $Y'_{709} = .21R + .72G + .07B$;
- for the Rec. 601 NTSC primaries, $Y'_{601} = .30R + .59G + .11B$;
- for other primaries different coefficients should be used.

$$Y'_{601} = 0.3 * R + 0.59 * G + 0.11 * B$$

All four of these leave the neutral axis alone. That is, for colors with $R = G = B$, any of the four formulations yields a lightness equal to the value of R , G , or B .

Saturation

If we encode colors in a hue/lightness/chroma or hue/value/chroma model (using the definitions from the previous two sections), not all combinations of value (or lightness) and chroma are meaningful: that is, half of the colors we can describe using $H \in [0^\circ, 360^\circ)$, $C \in [0, 1]$, and $V \in [0, 1]$ fall outside the RGB gamut (the gray parts of the slices in the image to the right). The creators of these models considered this a problem for some uses. For example, in a color selection interface with two of the dimensions in a rectangle and the third on a slider, half of that rectangle is made of unused space. Now imagine we have a slider for lightness: the user's intent when adjusting this slider is potentially ambiguous: how should the software deal with out-of-gamut colors? Or conversely, If the user has selected as colorful as possible a dark purple, and then shifts the lightness slider upward, what should be done: would the user prefer to see a lighter purple still as colorful as possible for the given hue and lightness, or a lighter purple of exactly the same chroma as the original color ?

... Saturation

To solve problems such as these, the HSL and HSV models scale the chroma so that it always fits into the range $[0, 1]$ for every combination of hue and lightness or value, calling the new attribute *saturation* in both cases. To calculate either, simply divide the chroma by the maximum chroma for that value or lightness.

$$S_{HSV} = \begin{cases} 0, & \text{if } C = 0 \\ \frac{C}{V}, & \text{otherwise} \end{cases} \quad S_{HSL} = \begin{cases} 0, & \text{if } C = 0 \\ \frac{C}{2L}, & \text{if } L \leq \frac{1}{2} \\ \frac{C}{2-2L}, & \text{if } L > \frac{1}{2} \end{cases}$$

The HSI model commonly used for computer vision, which takes $H2$ as a hue dimension and the component average I (“intensity”) as a lightness dimension, does not attempt to “fill” a cylinder by its definition of saturation. Instead of presenting color choice or modification interfaces to end users, the goal of HSI is to facilitate separation of shapes in an image. Saturation is therefore defined in line with the psychometric definition: chroma relative to lightness. Specifically:

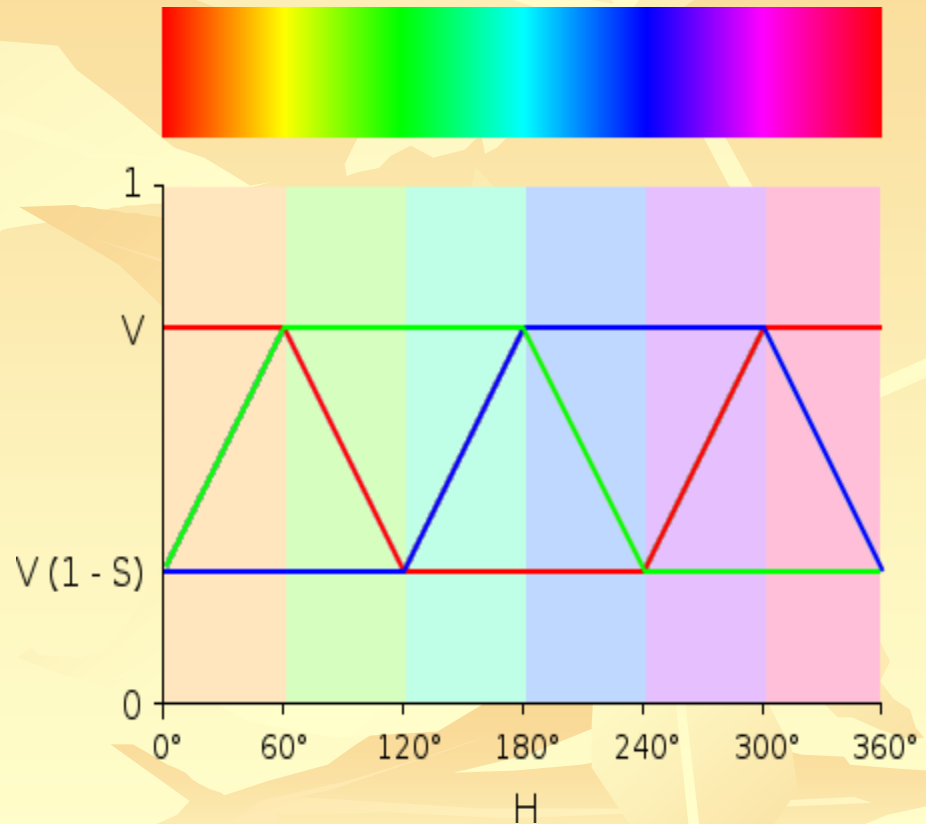
$$S_{HSI} = \begin{cases} 0, & \text{if } C = 0 \\ 1 - \frac{m}{I}, & \text{otherwise} \end{cases}$$

Using the same name for these three different definitions of saturation leads to some confusion, as the three attributes describe substantially different color relationships; in HSV and HSI, the term roughly matches the psychometric definition, of a the chroma of a color relative to its own lightness, but in HSL it does not come close. Even worse, the word *saturation* is also often used for one of the measurements we call chroma above (C or $C2$).

Converting to RGB

To convert from HSL or HSV to RGB, we essentially invert the steps listed above (as before, $R, G, B \in [0, 1]$). First, we compute chroma, by multiplying saturation by the maximum chroma for a given lightness or value. Next, we find the point on one of the bottom three faces of the RGB cube which has the same hue and chroma as our color (and therefore projects onto the same point in the chromaticity plane). Finally, we add equal amounts of $R, G,$ and B to reach the proper lightness or value.

HSV \rightarrow RGB



From HSV

Given a color with hue $H \in [0^\circ, 360^\circ)$, saturation $S_{HSV} \in [0, 1]$, and value $V \in [0, 1]$, we first find chroma:

$$C = V * S_{HSV}$$

Then we can find a point (R_1, G_1, B_1) along the bottom three faces of the RGB cube, with the same hue and chroma as our color (using the intermediate value X for the second largest component of this color):

$$H' = H / 60$$

$$X = C * (1 - |H' \text{ Mod } 2 - 1|)$$

$$(R_1, G_1, B_1) = \begin{cases} (0, 0, 0) & \text{if } H \text{ is undefined} \\ (C, X, 0) & \text{if } 0 \leq H' < 1 \\ (X, C, 0) & \text{if } 1 \leq H' < 2 \\ (0, C, X) & \text{if } 2 \leq H' < 3 \\ (0, X, C) & \text{if } 3 \leq H' < 4 \\ (X, 0, C) & \text{if } 4 \leq H' < 5 \\ (C, 0, X) & \text{if } 5 \leq H' < 6 \end{cases}$$

Finally, we can find R , G , and B by adding the same amount to each component, to match value:

$$m = V - C$$

$$(R, G, B) = (R_1 + m, G_1 + m, B_1 + m)$$

From HSL

Given an HSL color with hue $H \in [0^\circ, 360^\circ)$, saturation $S_{\text{HSL}} \in [0, 1]$, and lightness $L \in [0, 1]$, we find chroma:

$$C = (1 - |2 * L - 1|) * S_{\text{HSL}}$$

Then we can, again, find a point (R_1, G_1, B_1) along the bottom three faces of the RGB cube, with the same hue and chroma as our color (using the intermediate value X for the second largest component of this color):

$$H' = H / 60$$

$$X = C * (1 - |H' \text{ Mod } 2 - 1|)$$

$$(R_1, G_1, B_1) = \begin{cases} (0, 0, 0) & \text{if } H \text{ is undefined} \\ (C, X, 0) & \text{if } 0 \leq H' < 1 \\ (X, C, 0) & \text{if } 1 \leq H' < 2 \\ (0, C, X) & \text{if } 2 \leq H' < 3 \\ (0, X, C) & \text{if } 3 \leq H' < 4 \\ (X, 0, C) & \text{if } 4 \leq H' < 5 \\ (C, 0, X) & \text{if } 5 \leq H' < 6 \end{cases}$$

Finally, we can find R , G , and B by adding the same amount to each component, to match lightness:

$$m = V - C/2$$

$$(R, G, B) = (R_1 + m, G_1 + m, B_1 + m)$$

From luma/chroma/hue

Given a color with hue $H \in [0^\circ, 360^\circ)$, chroma $C \in [0, 1]$, and luma $Y'_{601} \in [0, 1]$, we can again use the same strategy. Since we already have H and C , we can straightaway find our point (R_1, G_1, B_1) along the bottom three faces of the RGB cube:

$$C = (1 - |2 * L - 1|) * S_{HSL}$$

Then we can, again, find a point (R_1, G_1, B_1) along the bottom three faces of the RGB cube, with the same hue and chroma as our color (using the intermediate value X for the second largest component of this color):

$$H' = H / 60$$

$$X = C * (1 - |H' \text{ Mod } 2 - 1|)$$

$$(R_1, G_1, B_1) = \begin{cases} (0, 0, 0) & \text{if } H \text{ is undefined} \\ (C, X, 0) & \text{if } 0 \leq H' < 1 \\ (X, C, 0) & \text{if } 1 \leq H' < 2 \\ (0, C, X) & \text{if } 2 \leq H' < 3 \\ (0, X, C) & \text{if } 3 \leq H' < 4 \\ (X, 0, C) & \text{if } 4 \leq H' < 5 \\ (C, 0, X) & \text{if } 5 \leq H' < 6 \end{cases}$$

Then we can find R , G , and B by adding the same amount to each component, to match luma:

$$m = Y'_{601} - 0.3 * R_1 - 0.59 * G_1 - 0.11 * B_1$$

$$(R, G, B) = (R_1 + m, G_1 + m, B_1 + m)$$

Tema

Lab. 6

Realizați următoarele *Transformări Spatiale* :

- a) $RGB \rightarrow La^*b^*$ apoi calculati diferenta de culoare (nuanta)
- b) $La^*b^* \rightarrow RGB$ si reprezentati spatiul RGB (vizualizarea culorilor)
- c) $RGB \rightarrow Luv \rightarrow RGB$
- d) $RGB \rightarrow HSL$ sau $HSV \rightarrow RGB$



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