

IA725 – Computação Gráfica I

Modelos de Cor

Watt: Capítulo 15
Redbook: Capítulo 4

Imagens Coloridas



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Cores

Cores perceptíveis pela visão humana

X

Cores exibíveis pelos dispositivos

X

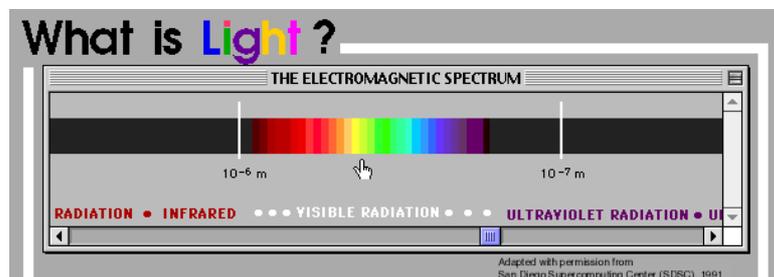
Cores processáveis pelo computador

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Cor



Ondas Eletromagnéticas Visíveis

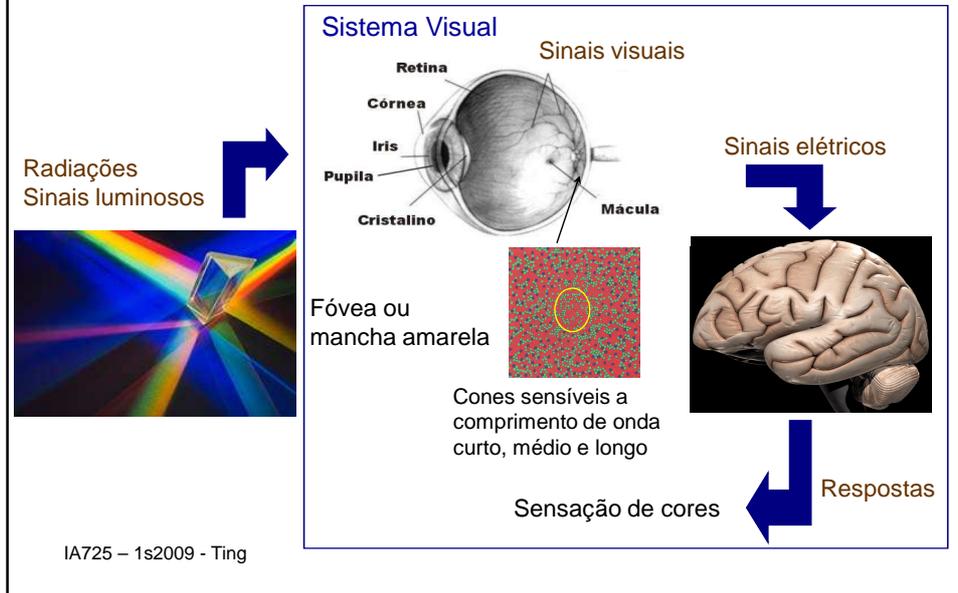


380nm

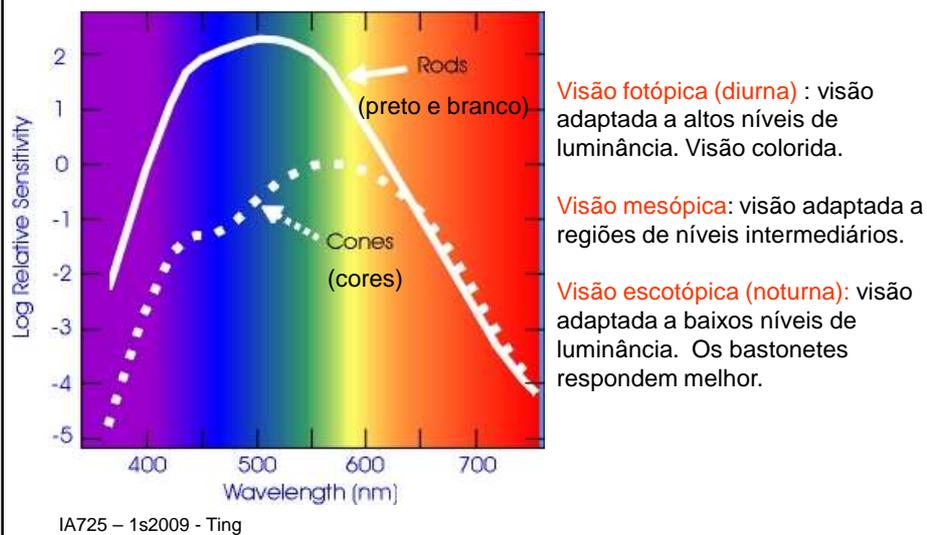
750nm

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Percepção de Cores



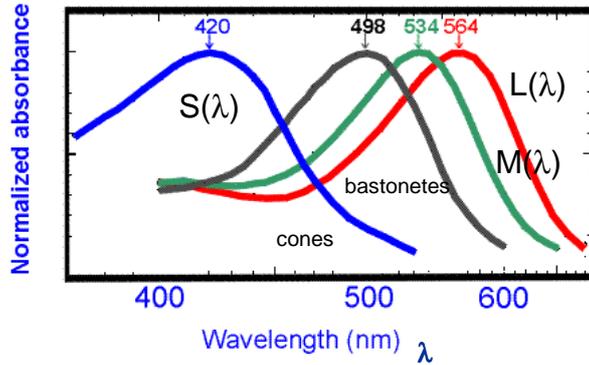
Células Fotossensíveis Cones e Bastonetes



Teoria Tricromática

Young, Helmholtz, Maxwell

Funções de Sensibilidade Espectral



3 tipos de cones

After Bowmaker & Dartnall, 1980



380nm

750nm

Especificação

Grandezas colorimétricas

Comprimento de onda dominante

Pureza na excitação

Luminância

Grandezas fisiológicas

Matiz: cor

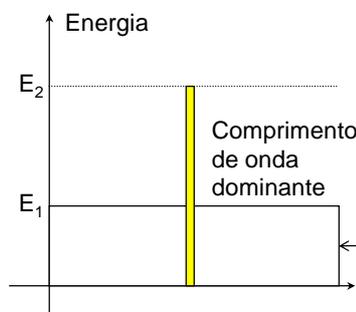
Saturação: tonalidade da cor

Brilho: brilho da cor

Distribuição de energia de uma cor "monocromática": só há um comprimento dominante

$$\text{Pureza} = \frac{E_2 - E_1}{E_2}$$

Luminância \propto Energia

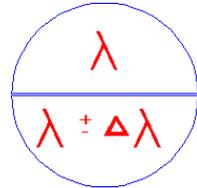


BRANCO = radiações de todos os comprimentos com a mesma energia

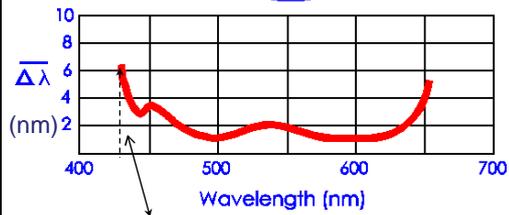
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Percepção Visual

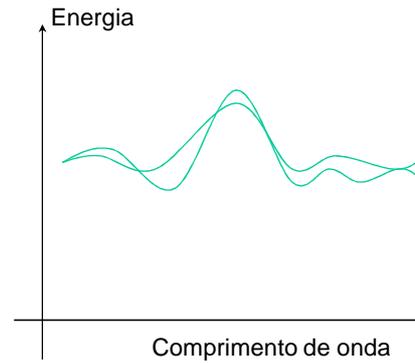
Metâmeras



Distintas distribuições espectrais, porém
mesma percepção colorida

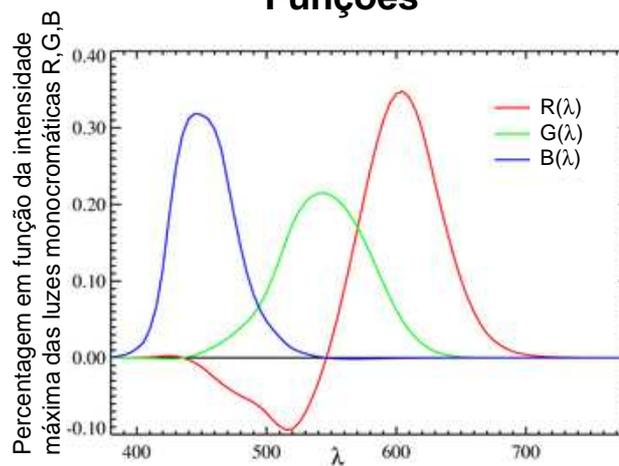


Diferença mínima para
que duas cores sejam
perceptualmente distintas



Reconstrução Espectral

Funções



$$A(\lambda) = rR(\lambda) + gG(\lambda) + bB(\lambda)$$

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Modelos de Cor

Leis de Grassman

1. Qualquer cor pode ser especificada como mistura aditiva de **3 cores independentes**.
2. A cor de uma mistura aditiva não se altera quando substituirmos as cores componentes pelas suas metâmeras.
3. Se uma componente de uma mistura aditiva é alterada numa dada proporção **continuamente**, a cor da mistura é modificada na mesma proporção **continuamente**, obedecendo as leis de simetria, transitividade e linearidade.

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Modelos de Cor

Funções de Reconstrução Espectral com 3 cores



Leis de Grassman



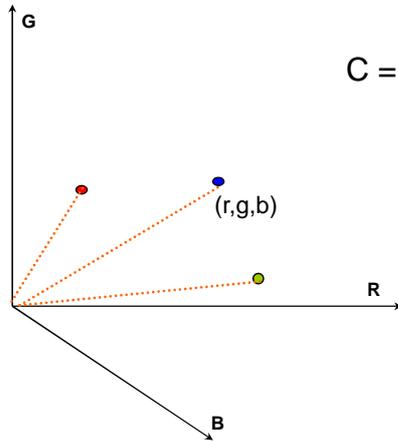
Espaço Vetorial de Cores

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Modelos de Cor

Espaço de Cores RGB



$$C = rR + gG + bB$$

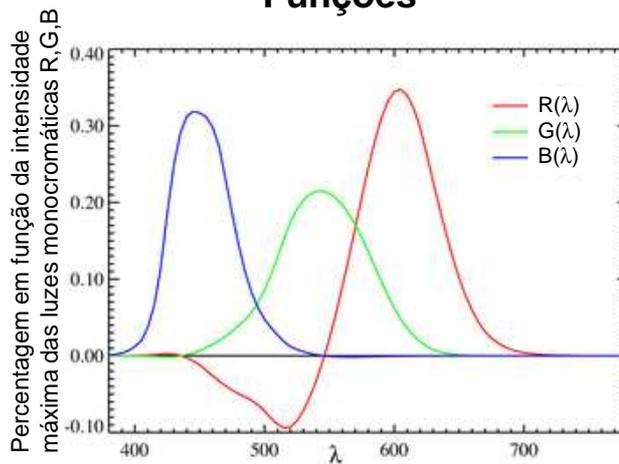
Uma cor pode ser obtida como soma ponderada de somente três tipos de radiações.

Representação de uma cor: vetor de 3 valores reais (r,g,b)
É única?

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Reconstrução Espectral

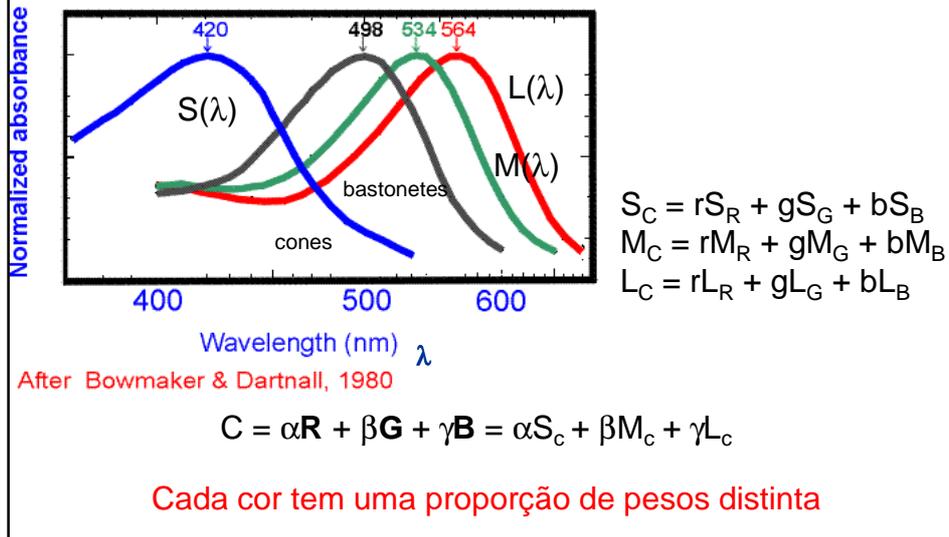
Funções



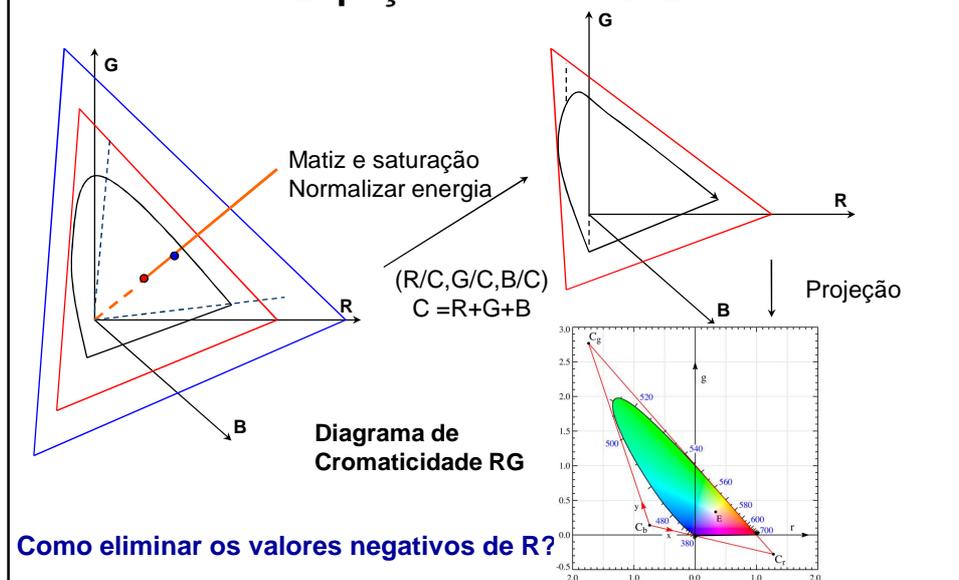
$$A(\lambda) = rR(\lambda) + gG(\lambda) + bB(\lambda)$$

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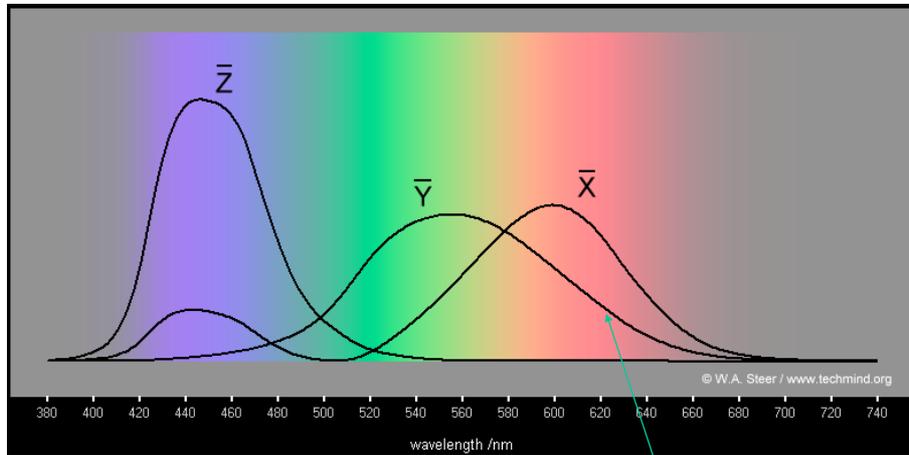
Modelos de Cores Unicidade



Modelos de Cor Espaço de Cores RGB



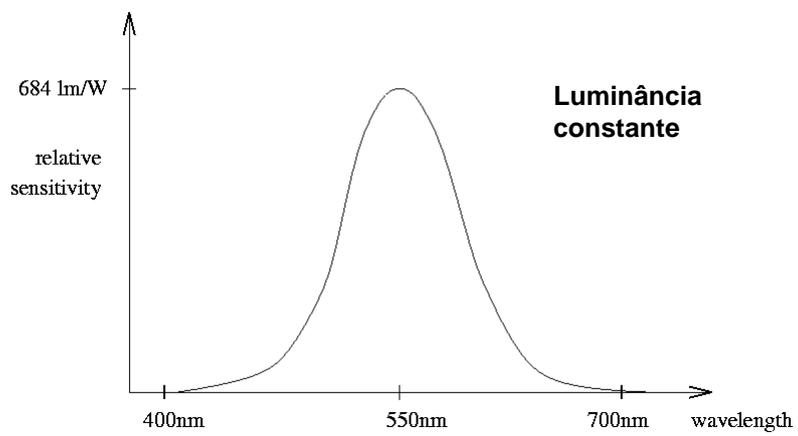
Espaço de Cores XYZ



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Função de eficiência luminosa

Modelos de Cor Função de Eficiência Luminosa



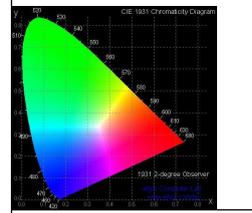
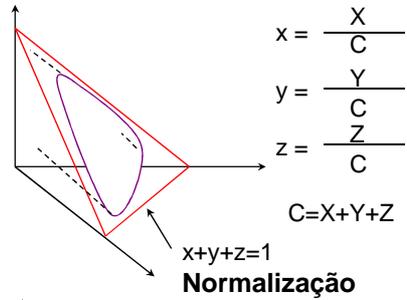
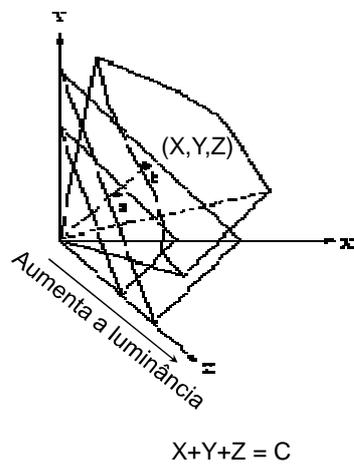
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380nm

750nm

Modelos de Cores

Espaço de Cores XYZ



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Modelos de Cor

Mistura de Cor

Determine as coordenadas de cromaticidade CIE do resultado da mistura das 3 cores $C_1=(0.1,0.3,10)$, $C_2 = (0.35,0.2,10)$ e $C_3 = (0.2, 0.05,10)$.

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Modelos de Cor

Mistura de Cor

Determine as coordenadas de cromaticidade CIE do resultado da mistura das 3 cores $C_1=(0.1,0.3,10)$, $C_2 = (0.35,0.2,10)$ e $C_3 = (0.2, 0.05,10)$.

$$C_1 = Y_1/y_1; X_1 = x_1C_1; Z_1 = (1-x_1-y_1)C_1$$

$$C_2 = Y_2/y_2; X_2 = x_2C_2; Z_2 = (1-x_2-y_2)C_2$$

$$C_3 = Y_3/y_3; X_3 = x_3C_3; Z_3 = (1-x_3-y_3)C_3$$

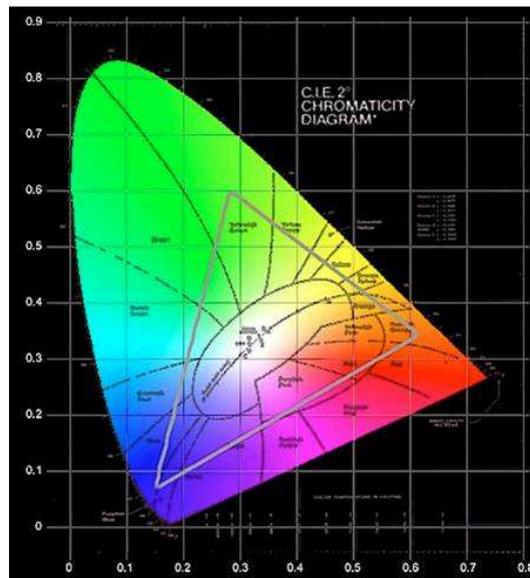
$$X_{123} = (x_1C_1 + x_2C_2 + x_3C_3)/(C_1+C_2+C_3)$$

$$Y_{123} = (y_1C_1 + y_2C_2 + y_3C_3)/(C_1+C_2+C_3)$$

$$Y_{123} = Y_1 + Y_2 + Y_3$$

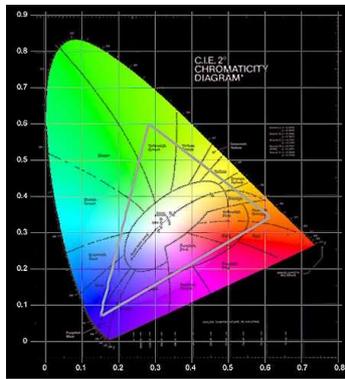
Resposta: (0.215,0.106,30)

Diagrama de Cromaticidade CIE

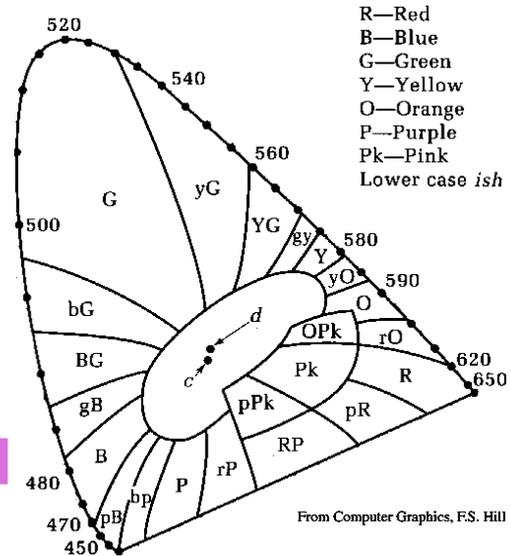


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Diagrama de Cromaticidade Metâmeras

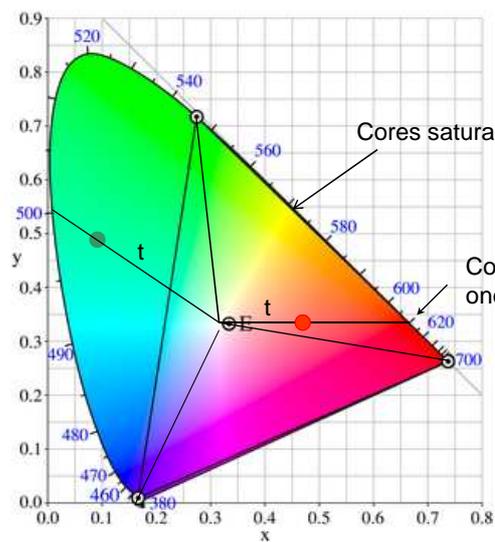


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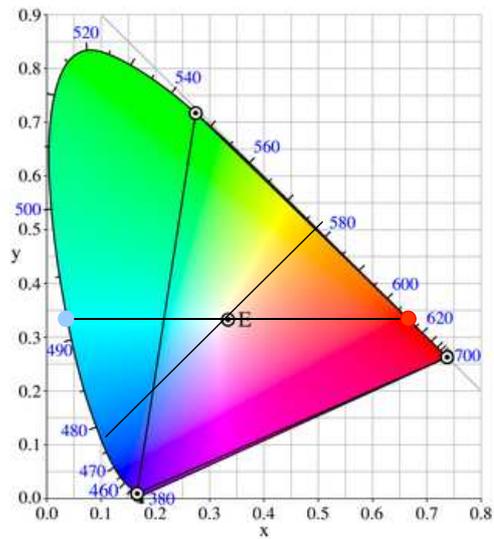
From Computer Graphics, F.S. Hill

Diagrama de Cromaticidade Saturação/Pureza de Cor



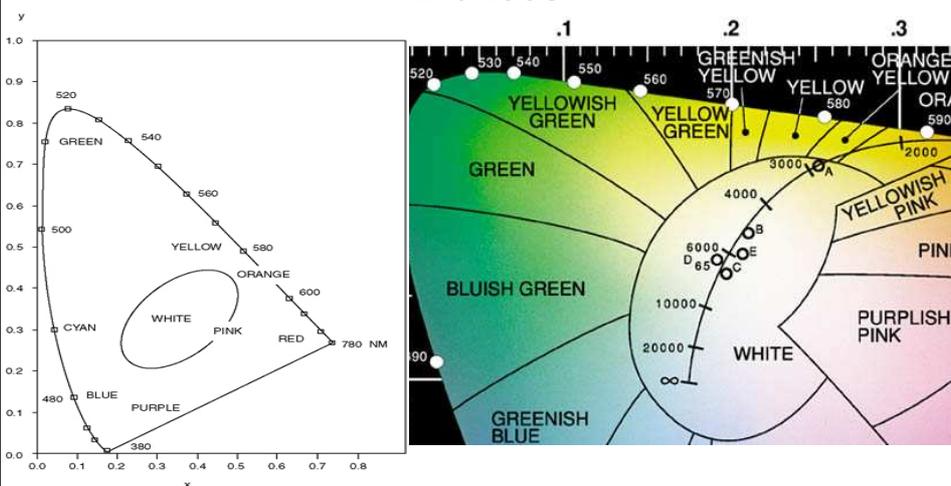
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Diagrama de Cromaticidade Cor Complementar



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Diagrama de Cromaticidade “Branco”



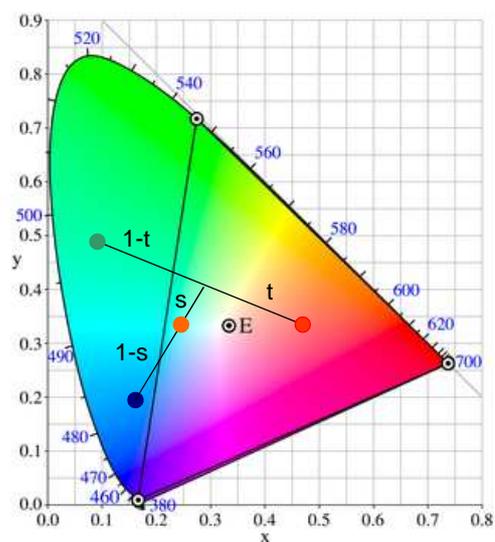
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Diagrama de Cromaticidade Branco de Referência

Nome	Temperatura	Coordenadas	Fonte
Illuminant A	2856	(0.44757,0.40745)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant B	4874	(0.34842,0.35161)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant C	6774	(0.31006,0.31616)	[Wyszecki82, p 139] [Agoston87, p. 103]
Illuminant D65	6504	(0.3127,0.3291)	[Walker98] [Agoston87, p. 103]
Direct Sunlight	5335	(0.3362,0.3502)	[Agoston87, p. 103]
Light from overcast sky	6500	(0.3134,0.3275)	[Agoston87, p. 103]
Light from north sky on a 45-degree plane	10,000	(0.2773,0.2934)	[Agoston87, p. 103]
Illuminant E	5400	(1/3,1/3)	[Wyszecki82, p 139] [Agoston87, p. 103]

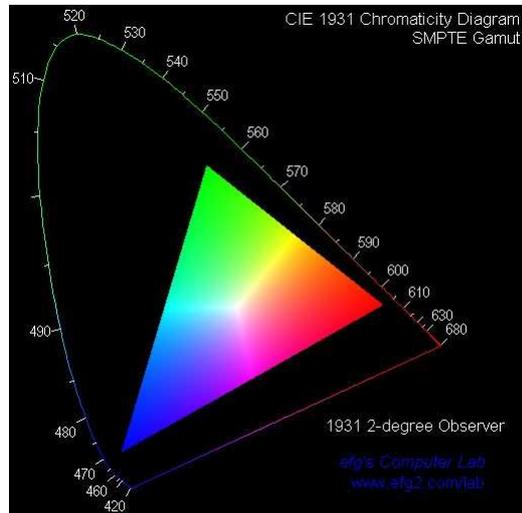
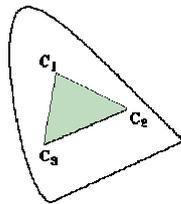
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Diagrama de Cromaticidade Mistura de Cores



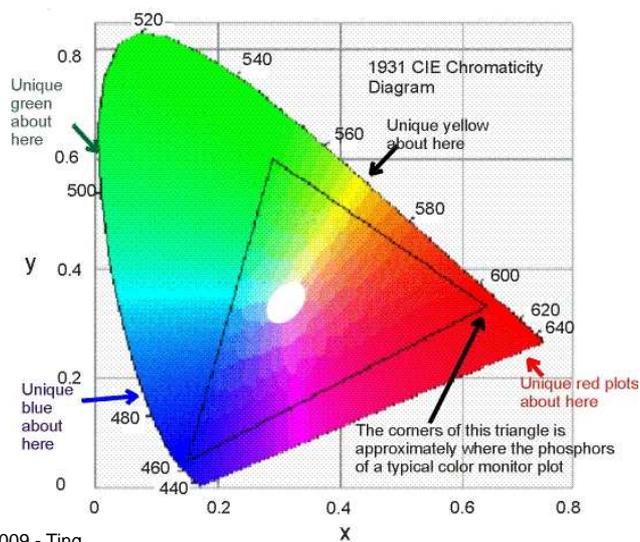
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Diagrama de Cromaticidade Gamute de Cores



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Diagrama de Cromaticidade Gamute de Monitores

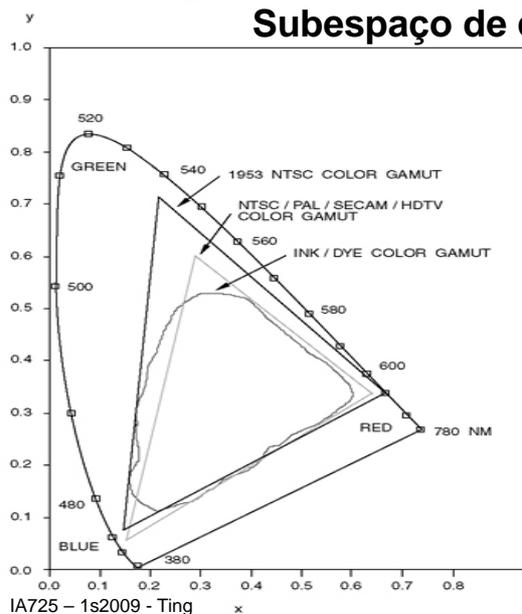


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Diagrama de Cromaticidade Cromaticidade dos Fósforos de Monitores

Nome	R	G	B	Branco
Short-Persistence	(0.61,0.35)	(0.29,0.59)	(0.15,0.063)	
Long-Persistence	(0.62,0.33)	(0.21,0.685)	(0.15,0.063)	
NTSC	(0.67,0.33)	(0.21,0.71)	(0.14,0.08)	Iluminante C
EBU	(0.64,0.33)	(0.30,0.60)	(0.15,0.06)	Iluminante D65
Dell (all monitors except 21" Mitsubishi p/n 65532)	(0.625,0.340)	(0.275,0.605)	(0.150,0.065)	9300K
SMPTE	(0.630,0.340)	(0.310,0.595)	(0.155,0.070)	Iluminante D65
P22 phosphor in NEC Multisync C400	(0.610,0.350)	(0.307,0.595)	(0.150,0.065)	(0.280,0.315)
P22 phosphor in KDS VS19	(0.625,0.340)	(0.285,0.605)	(0.150,0.065)	(0.281,0.311)
High-Brightness LEDs	(0.700,0.300)	(0.170,0.700)	(0.130,0.075)	(0.310,0.320)

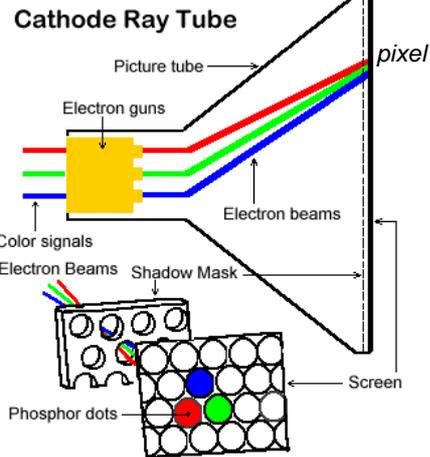
Diagrama de Cromaticidade Subespaço de cores



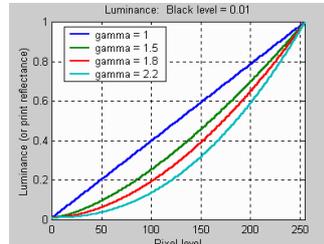
Todas as cores de um dispositivo são reproduzíveis noutro dispositivo?

Espaço de Cores

Dispositivo de Exibição



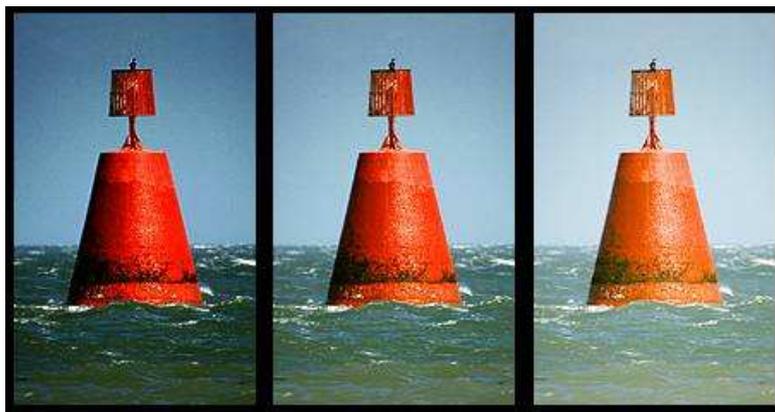
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$$L = KV^\gamma$$

L: luminância em cada *pixel*
 K: constante, ajustado pelo controle de contraste
 V: tensão de excitação dos feixes de elétrons
 γ : gamma, tipicamente entre [1.4,2.5]
 $V = V_s^{(1/\gamma)}$: correção gamma

Influência de γ

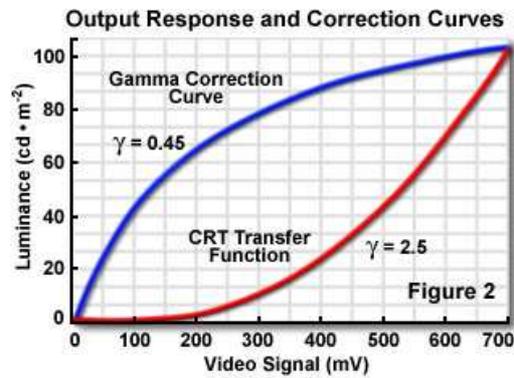


$\gamma = 1.8$

$\gamma = 1.0$

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Correção de γ

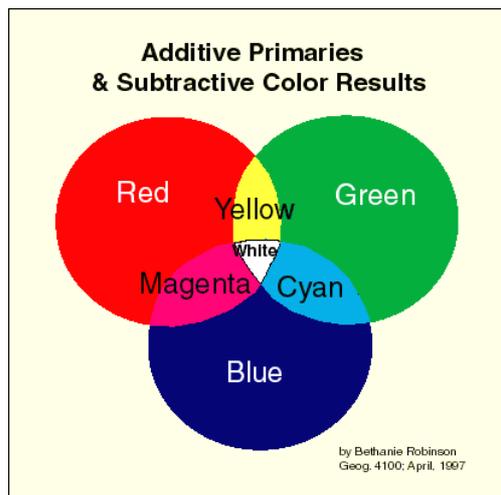


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Formação de Cores

Aditiva - Cores Primárias

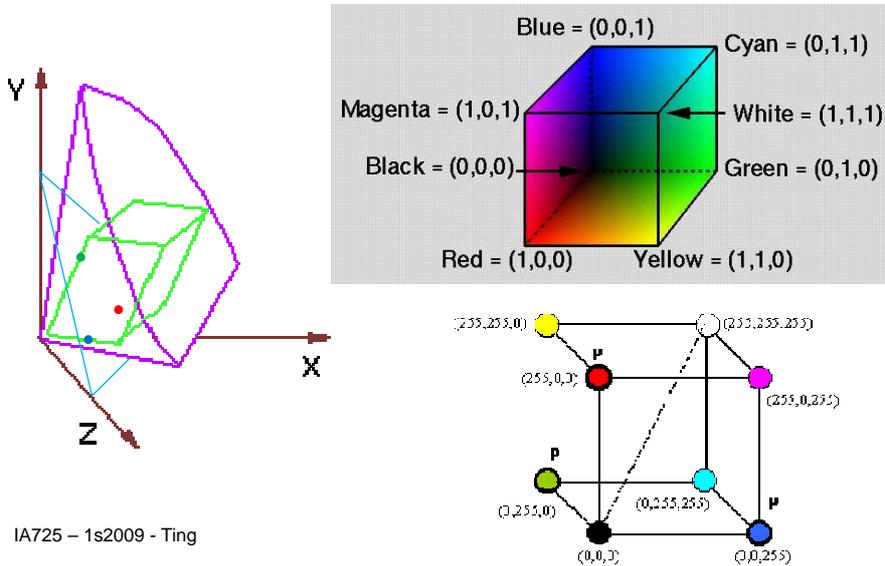
Vermelho
Verde
Azul



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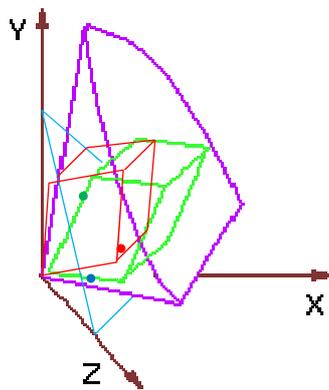
Modelo de Cor

RGB: Gamute de monitores



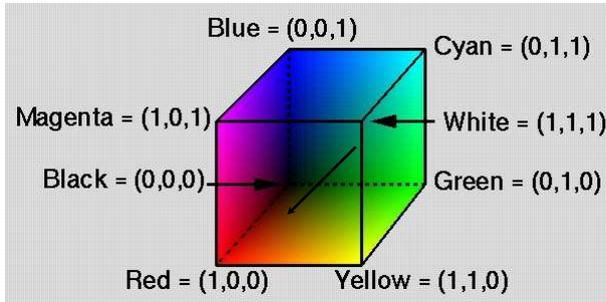
Modelo de Cor

Conversão entre Dispositivos



Modelos de Cor

Modelo HSV



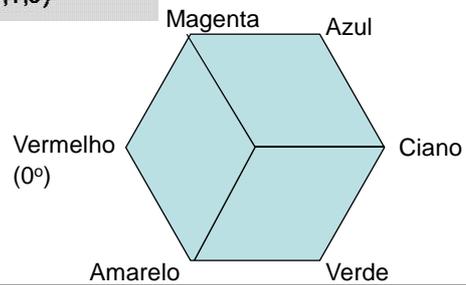
$$V = \max(R,G,B)$$

$$S = (V - \min(R,G,B)) / V$$

$$Cr = (V - R) / (V - \min(R,G,B))$$

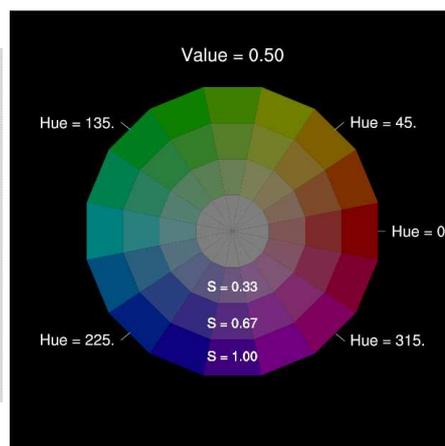
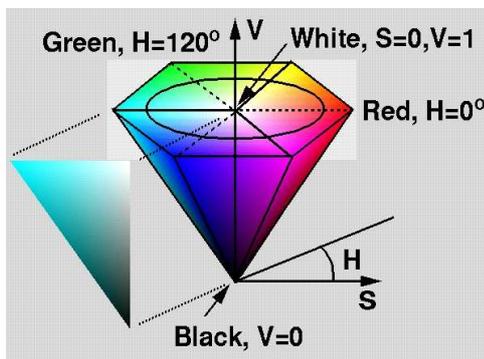
$$Cg = (V - G) / (V - \min(R,G,B))$$

$$Cb = (V - B) / (V - \min(R,G,B))$$



Modelos de Cor

Modelo HSV



Modelos de Cor

RGB → HSV

```
HSVType RGB_to_HSV( RGBType RGB ) {
    // RGB are each on [0, 1]. S and V are returned on [0, 1] and H is
    // returned on [0, 6]. Exception: H is returned UNDEFINED if S==0.
    float R = RGB.R, G = RGB.G, B = RGB.B, v, x, f;
    int i;
    HSVType HSV;

    x = min(R, G, B);
    v = max(R, G, B);
    if(v == x) RETURN_HSV(UNDEFINED, 0, v);
    f = (R == x) ? G - B : ((G == x) ? B - R : R - G);
    i = (R == x) ? 3 : ((G == x) ? 5 : 1);
    RETURN_HSV(i - f / (v - x), (v - x) / v, v);
}
```

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Modelos de Cor

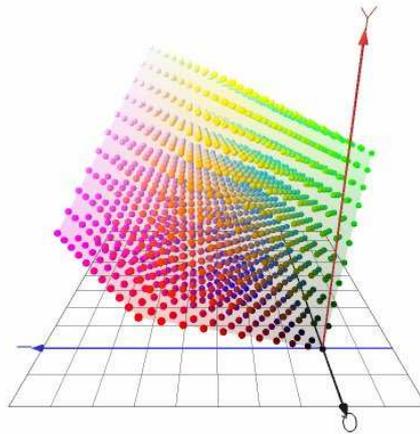
HSV → RGB

```
RGBType HSV_to_RGB( RGBType RGB ) {
    // H is given on [0, 6] or UNDEFINED. S and V are given on [0, 1].
    // RGB are each returned on [0, 1].
    float h = HSV.H, s = HSV.S, v = HSV.V, m, n, f;
    int i; RGBType RGB; if (h == UNDEFINED) RETURN_RGB(v, v, v);
    i = floor(h); f = h - i;
    if ( !(i&1) ) f = 1 - f; // if i is even
    m = v * (1 - s); n = v * (1 - s * f);
    switch (i) {
        case 6:
        case 0:
            RETURN_RGB(v, n, m);
        case 1: RETURN_RGB(n, v, m);
        case 2: RETURN_RGB(m, v, n);
        case 3: RETURN_RGB(m, n, v);
        case 4: RETURN_RGB(n, m, v);
        case 5: RETURN_RGB(v, m, n);
    }
}
```

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Modelo de Cor

YIQ: Sistema de televisão NTSC



I : faixa laranja - azul
 Q: faixa verde violeta
 Y: luminância

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$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.275 & -0.321 \\ 0.212 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Modelos de Cores

(r,g,b) → (x,y,z)

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \frac{1}{b_{21}} \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} = \frac{1}{0.17697} \begin{bmatrix} 0.49 & 0.31 & 0.20 \\ 0.17697 & 0.81240 & 0.01063 \\ 0.00 & 0.01 & 0.99 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

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Conversão entre Dispositivos

Mudança de base

$$(R_1, G_1, B_1) \xrightarrow{M_1} (X, Y, Z)$$

$$r = (x_{r,1}C_{r,1}, y_{r,1}C_{r,1}, z_{r,1}C_{r,1})$$

$$g = (x_{g,1}C_{g,1}, y_{g,1}C_{g,1}, z_{g,1}C_{g,1})$$

$$b = (x_{b,1}C_{b,1}, y_{b,1}C_{b,1}, z_{b,1}C_{b,1})$$

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \xleftrightarrow{M_1} \begin{pmatrix} x_{r,1}C_{r,1} & x_{g,1}C_{g,1} & x_{b,1}C_{b,1} \\ y_{r,1}C_{r,1} & y_{g,1}C_{g,1} & y_{b,1}C_{b,1} \\ z_{r,1}C_{r,1} & z_{g,1}C_{g,1} & z_{b,1}C_{b,1} \end{pmatrix}$$

$$M_1 = \begin{pmatrix} x_{r,1}C_{r,1} & x_{g,1}C_{g,1} & x_{b,1}C_{b,1} \\ y_{r,1}C_{r,1} & y_{g,1}C_{g,1} & y_{b,1}C_{b,1} \\ z_{r,1}C_{r,1} & z_{g,1}C_{g,1} & z_{b,1}C_{b,1} \end{pmatrix}$$

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Conversão entre Dispositivos

Mudança de base

$$(R_1, G_1, B_1) \xrightarrow{M_1} (X, Y, Z) \xleftarrow{M_2}$$

$$M_1 = \begin{pmatrix} x_{r,1}C_{r,1} & x_{g,1}C_{g,1} & x_{b,1}C_{b,1} \\ y_{r,1}C_{r,1} & y_{g,1}C_{g,1} & y_{b,1}C_{b,1} \\ z_{r,1}C_{r,1} & z_{g,1}C_{g,1} & z_{b,1}C_{b,1} \end{pmatrix} \begin{pmatrix} x_{r,2}C_{r,2} & x_{g,2}C_{g,2} & x_{b,2}C_{b,2} \\ y_{r,2}C_{r,2} & y_{g,2}C_{g,2} & y_{b,2}C_{b,2} \\ z_{r,2}C_{r,2} & z_{g,2}C_{g,2} & z_{b,2}C_{b,2} \end{pmatrix} = M_2$$

1. As luminâncias máximas das 3 cores são conhecidas: $Y_{r,1}$, $Y_{g,1}$ e $Y_{b,1}$

$$C_{r,1} = \frac{Y_{r,1}}{y_{r,1}} \quad C_{g,1} = \frac{Y_{g,1}}{y_{g,1}} \quad C_{b,1} = \frac{Y_{b,1}}{y_{b,1}}$$

2. A cor de referência branca é conhecida (X_w, Y_w, Z_w)

$$\begin{pmatrix} x_{r,1} & x_{g,1} & x_{b,1} \\ y_{r,1} & y_{g,1} & y_{b,1} \\ z_{r,1} & z_{g,1} & z_{b,1} \end{pmatrix}^{-1} \begin{pmatrix} X_w \\ Y_w \\ Z_w \end{pmatrix} = \begin{pmatrix} C_r \\ C_g \\ C_b \end{pmatrix} \quad \text{Em RGB} = (1, 1, 1)$$

Modelos de Cor

Seja um monitor com as seguintes características:

Branco: D65 (0.313,0.329,1.0)

Vermelho: (0.62,0.34)

Verde: (0.29, 0.59)

Azul: (0.15, 0.06)

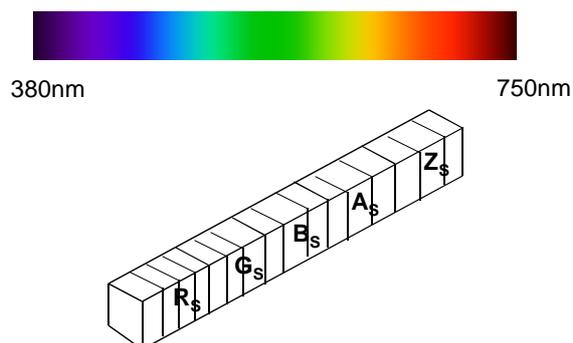
Qual é a matriz de transformação das coordenadas RGB para as coordenadas XYZ?

Resposta:

0.437	0.339	0.175
0.240	0.690	0.070
0.028	0.140	0.920

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Espaço Discreto de Cores



Quantidade de cores limitada pelo número de bits associado a cada *pixel*!

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