Creative Computing II

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Autumn 2010, Wednesdays:
10:00–12:00: RHB307 & 14:00–16:00: WB316
Winter 2011, TBC

Systematization of Colour

Maxwell Triangle

Device to represent *chromaticity*

- which colour;
- how much colour.

Brightness or **luminance** not represented.

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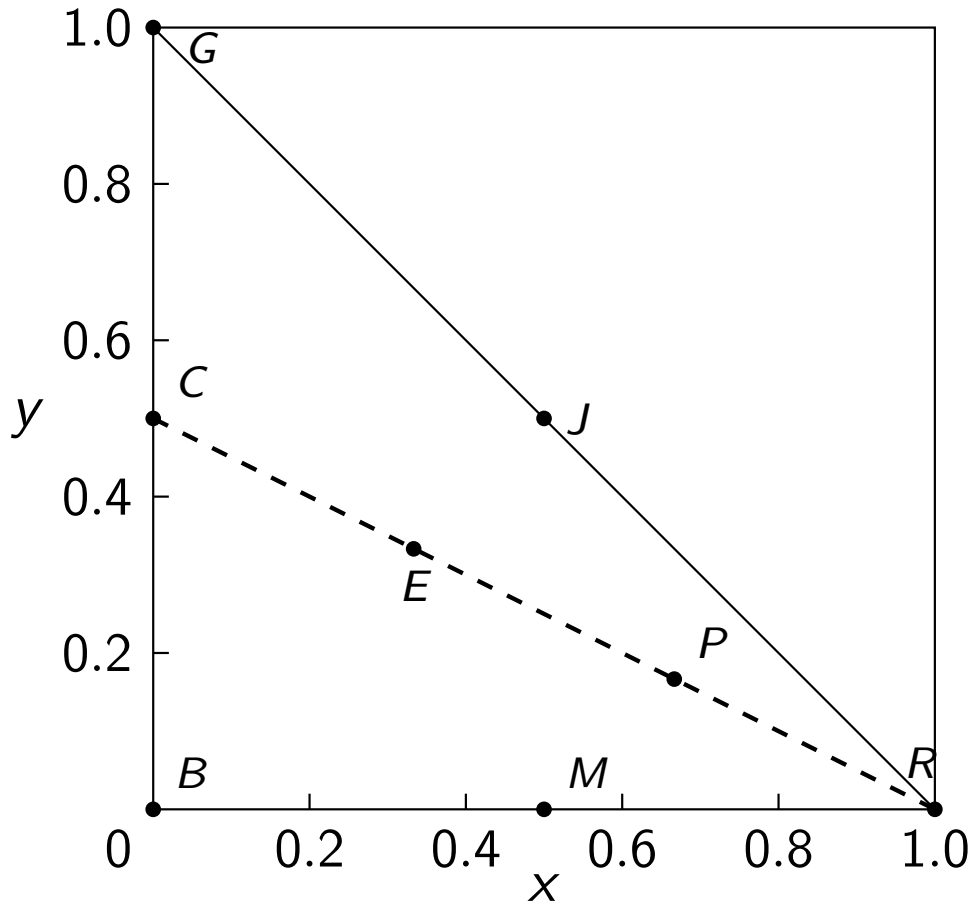
- $C = rR + gG + bB$
- $x = \frac{r}{r+g+b}$
- $y = \frac{g}{r+g+b}$

Together with *luminance* $r + g + b$, makes a new three-dimensional colour space.

Systematization of Colour

Maxwell Triangle



Systematization of Colour

CIE 1931 Standard Observer

Problem:

- positive mixtures of three colours cannot represent all visible colours.

Systematization of Colour

CIE 1931 Standard Observer

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Solution:

- do careful experiments with human observers
- use ‘imaginary’ primaries with useful properties.

Systematization of Colour

CIE 1931 Standard Observer

Properties of CIE 1931 XYZ primaries:

- Y represents **luminance** (brightness); X and Z independent of luminance;
- visible colours occupy as large a space as possible on the chromaticity diagram;
- 'equal-energy white' is at $x = y = z = \frac{1}{3}$.

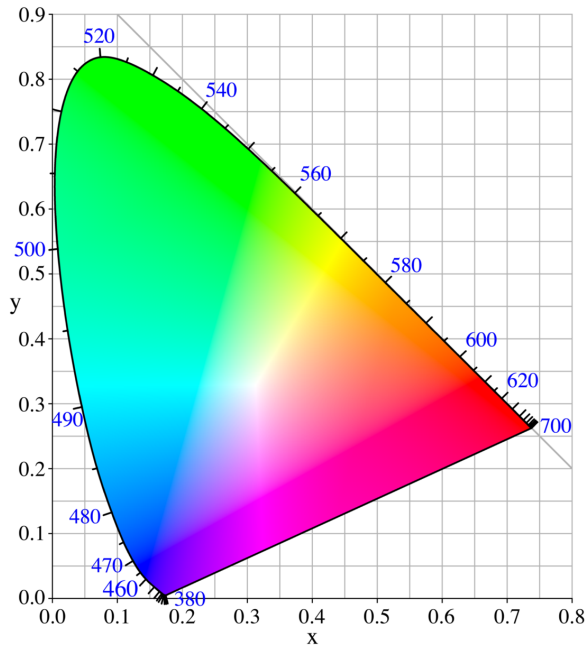
Note:

- pure-X, pure-Y and pure-Z are not visible colours.

Systematization of Colour

The CIE xyY Colour Space

- take colour specified in CIE XYZ space;
- convert to chromaticity:
  - $x = \frac{X}{X+Y+Z}$
  - $y = \frac{Y}{X+Y+Z}$



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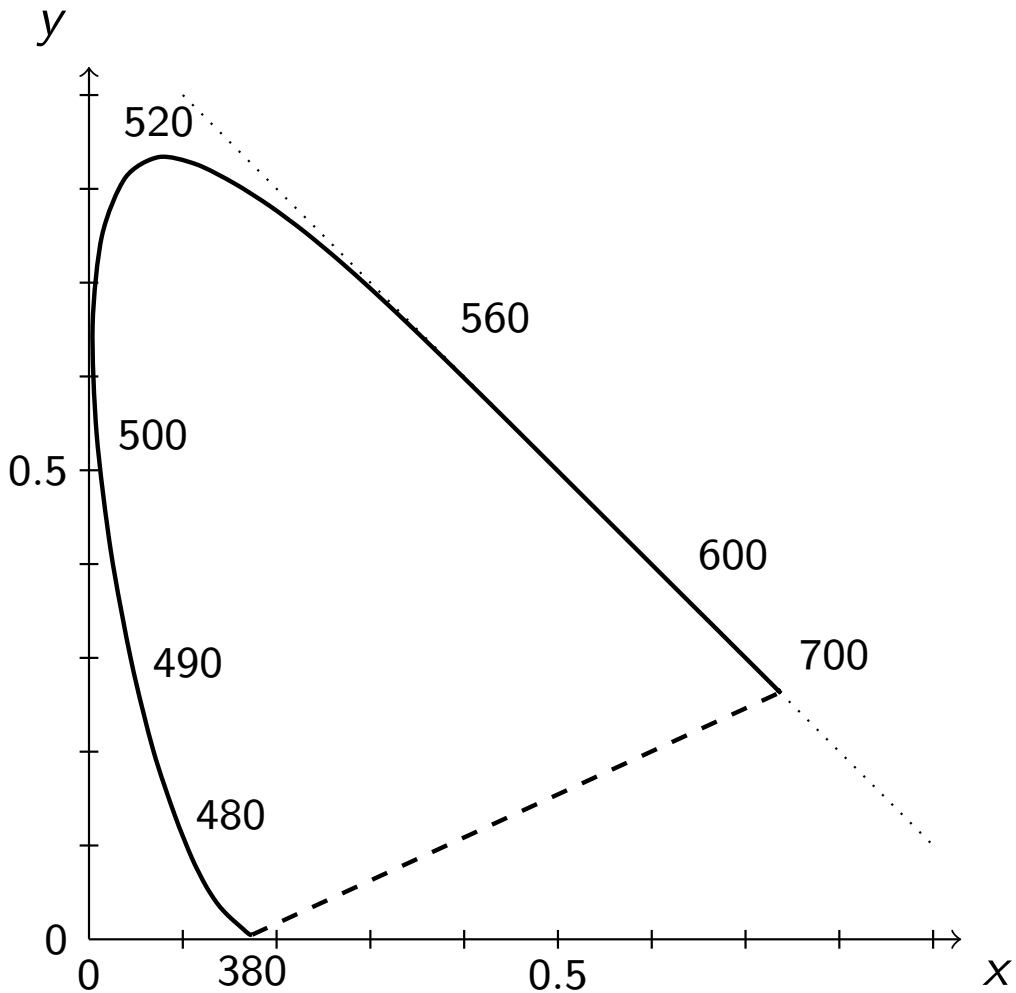
Systematization of Colour

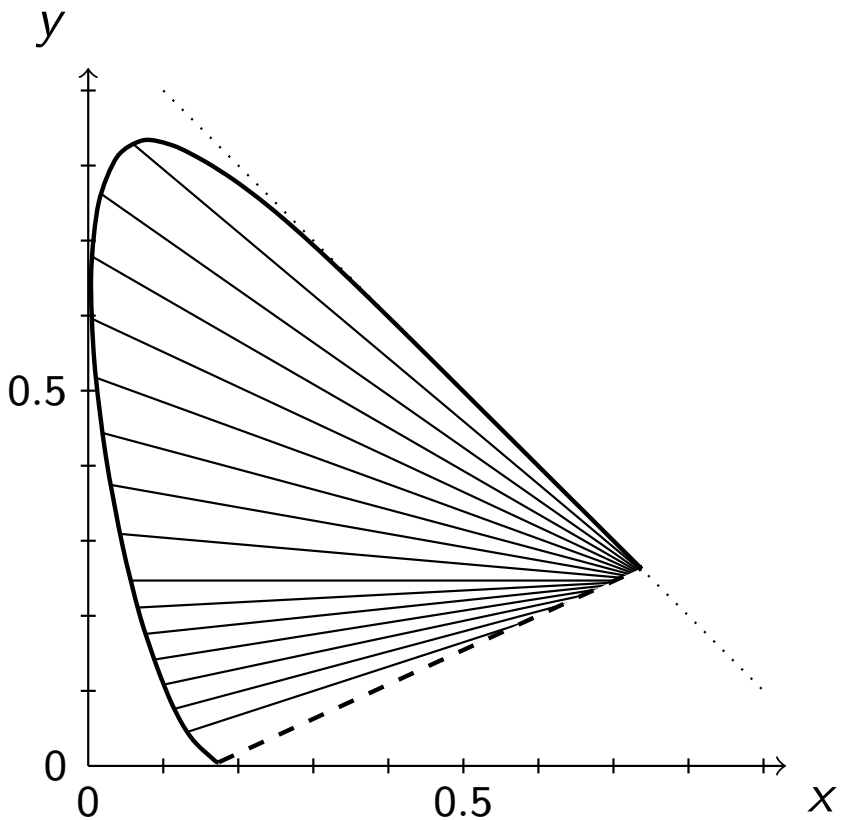
The CIE xyY Colour Space



Systematization of Colour

The CIE xyY Colour Space

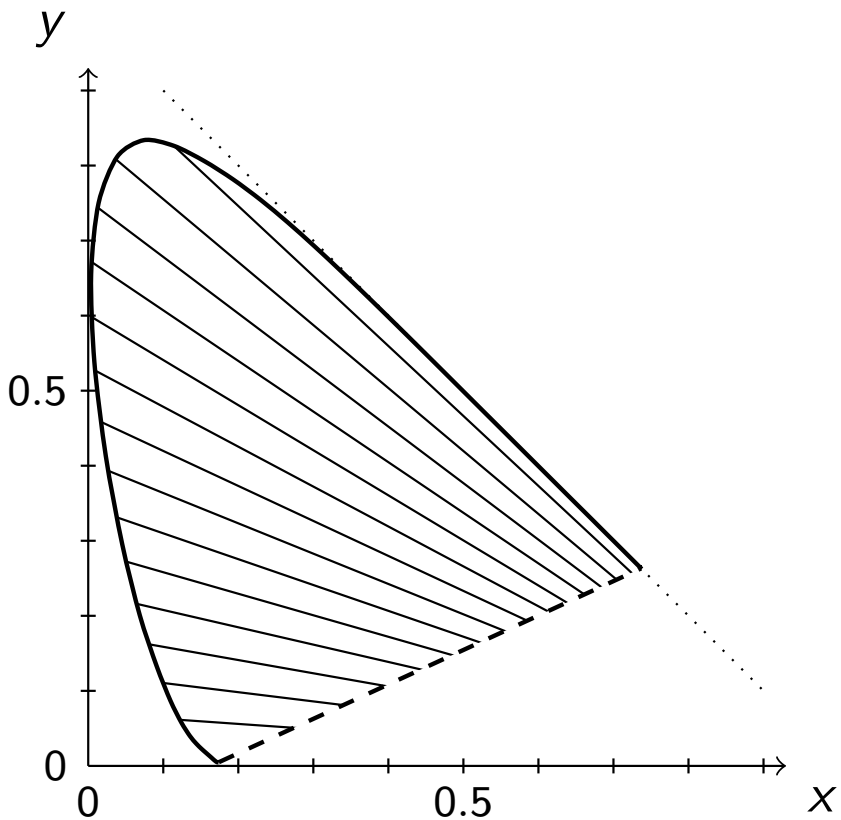
Confusion lines for *protanopes* meet at (0.75,0.25):



Systematization of Colour

The CIE xyY Colour Space

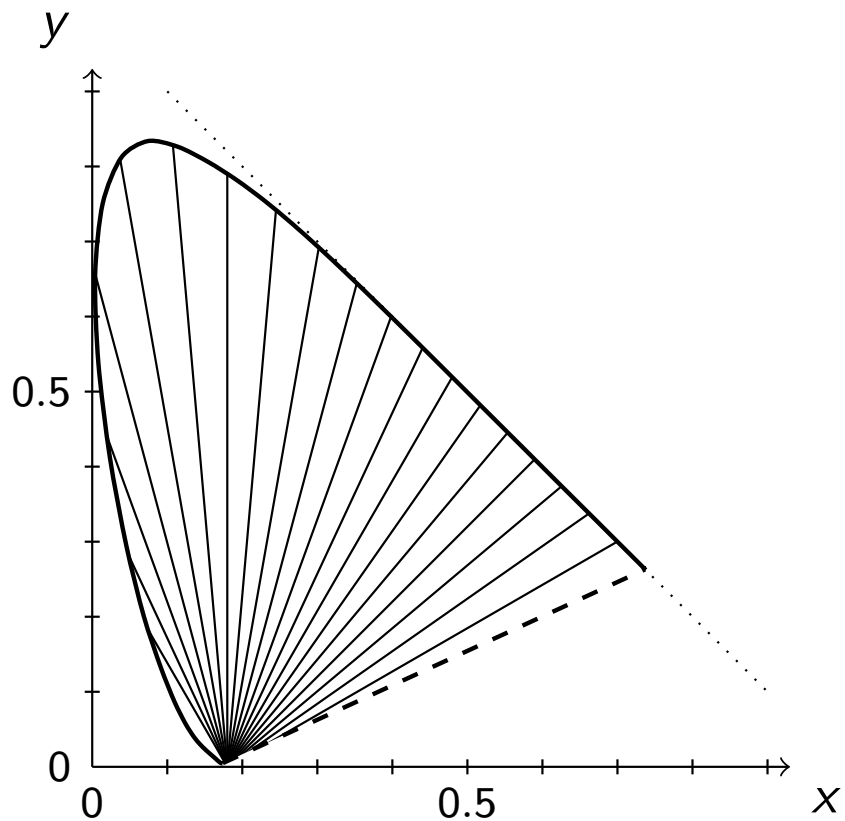
Confusion lines for *deuteranopes* meet at (1.0,0.0):



Systematization of Colour

The CIE xyY Colour Space

Confusion lines for *tritanopes* meet at (0.18,0.0):



data from Judd, D. B., *Fundamental Studies of Color Vision from 1860 to 1960*, Proc. Nat'l Acad. Sci. 55:6 (1966)

Systematization of Colour

Digital Displays and sRGB

sRGB Colour space:

- developed by Hewlett-Packard and Microsoft;
- primaries the same as that used in display hardware;
- *transfer function* typical of display hardware;
- used as default colour space on
  - monitors;
  - some printers;
  - many file formats (PNG, TIFF);
  - the Internet (HTML, CSS colour specifications).

Systematization of Colour

Digital Displays and sRGB

CIE XYZ $\rightarrow$ sRGB:

- $$\begin{pmatrix} R_l \\ G_l \\ B_l \end{pmatrix} = \begin{pmatrix} 3.2410 & -1.5374 & -0.4986 \\ -0.9692 & 1.8760 & 0.0416 \\ 0.0556 & -0.2040 & 1.0570 \end{pmatrix} \begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$$

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- $$C_{\text{sRGB}} = \begin{cases} 12.92 C_l & C_l < 0.00304 \\ 1.055 C_l^{1/2.4} - 0.055 & \text{otherwise} \end{cases}$$

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- $$C_{\text{sRGB}} = \begin{cases} 12.92 C_l & C_l < 0.00304 \\ 1.055 C_l^{1/2.4} - 0.055 & \text{otherwise} \end{cases}$$
- (for normal use)
  - clamp C_{sRGB} to be between 0 and 1;
  - scale to desired colour resolution (e.g. 0–255).

Systematization of Colour

Digital Displays and sRGB

sRGB $\rightarrow$ CIE XYZ:

- Scale C_{sRGB} values to be between 0 and 1;

Systematization of Colour

Digital Displays and sRGB

sRGB $\rightarrow$ CIE XYZ:

- Scale C_{sRGB} values to be between 0 and 1;
- $$C_l = \begin{cases} \frac{C_{\text{sRGB}}}{12.92} & C_{\text{sRGB}} < 0.04045 \\ \left(\frac{C_{\text{sRGB}}+0.055}{1.055}\right)^{2.4} & \text{otherwise} \end{cases}$$

Systematization of Colour

Digital Displays and sRGB

sRGB $\rightarrow$ CIE XYZ:

- Scale C_{sRGB} values to be between 0 and 1;
- $C_I = \begin{cases} \frac{C_{\text{sRGB}}}{12.92} & C_{\text{sRGB}} < 0.04045 \\ \left(\frac{C_{\text{sRGB}}+0.055}{1.055}\right)^{2.4} & \text{otherwise} \end{cases}$
- $\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 0.4124 & 0.3576 & 0.1805 \\ 0.2126 & 0.7152 & 0.0722 \\ 0.0193 & 0.1192 & 0.9505 \end{pmatrix} \begin{pmatrix} R_I \\ G_I \\ B_I \end{pmatrix}$

Systematization of Colour

The CIE LAB Colour Space

Problem with CIE XYZ:

- 'distances' in colour space are not perceptually relevant;
- (just like RGB, HSB)

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The CIE LAB Colour Space

Problem with CIE XYZ:

- 'distances' in colour space are not perceptually relevant;
- (just like RGB, HSB)

Solution:

- transform CIE XYZ into a colour space where distances correlate with perceived colour differences
- CIE $L^*a^*b^*$ (CIELAB)
- (different spaces with the same aim: CIE Luv, Hunter Lab)
- L^* matches **lightness** (*n*ot the same as brightness);
- a^* and b^* are chromaticity components:
  - a^*: red/magenta *vs* green;
  - b^*: yellow *vs* blue.

Systematization of Colour

The CIE LAB Colour Space

Euclidean distance between CIE LAB colours

$$\Delta C = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

correlates with perceptual colour difference.

Systematization of Colour

The CIE LAB Colour Space

CIE XYZ $\rightarrow$ CIE LAB:

- define $f(t) = \begin{cases} \sqrt[3]{t} & t > \left(\frac{6}{29}\right)^3 \\ \frac{1}{3}\left(\frac{29}{6}\right)^2 t + \frac{4}{29} & \text{otherwise} \end{cases}$

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- $L^* = 116 f\left(\frac{Y}{Y_0}\right) - 16$
- $a^* = 500\left[f\left(\frac{X}{X_0}\right) - f\left(\frac{Y}{Y_0}\right)\right]$
- $b^* = 200\left[f\left(\frac{Y}{Y_0}\right) - f\left(\frac{Z}{Z_0}\right)\right]$

Systematization of Colour

The CIE LAB Colour Space

CIE LAB $\rightarrow$ CIE XYZ:

- define $f^{-1}(z) = \begin{cases} z^3 & z > \frac{6}{29} \\ \left(z - \frac{4}{29}\right) 3 \left(\frac{6}{29}\right)^2 & \text{otherwise} \end{cases}$

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- $f_y = \frac{L^* + 16}{116}$
- $f_x = f_y + \frac{a^*}{500}$
- $f_z = f_y - \frac{b^*}{200}$

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- $f_y = \frac{L^* + 16}{116}$
- $f_x = f_y + \frac{a^*}{500}$
- $f_z = f_y - \frac{b^*}{200}$
- $X = X_0 f^{-1}(f_x)$
- $Y = Y_0 f^{-1}(f_y)$
- $Z = Z_0 f^{-1}(f_z)$