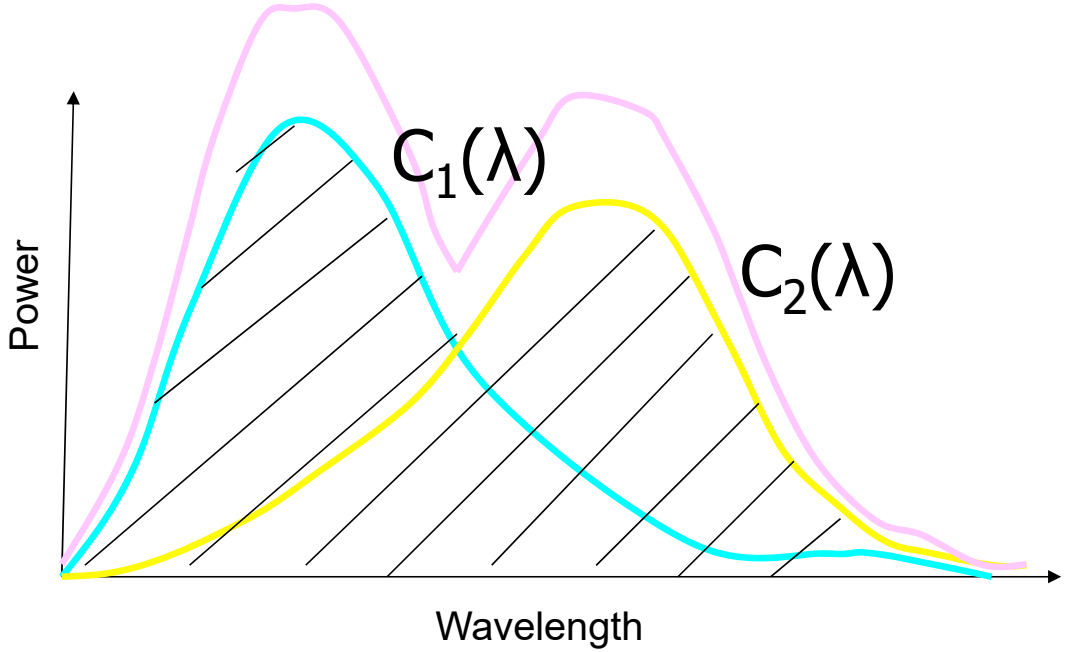
Color Reproduction

Additive Color Mixture

- Additive color mixtures modeled by addition in XYZ space
- When spectrums get added
  - Displays



Additive Color Mixture

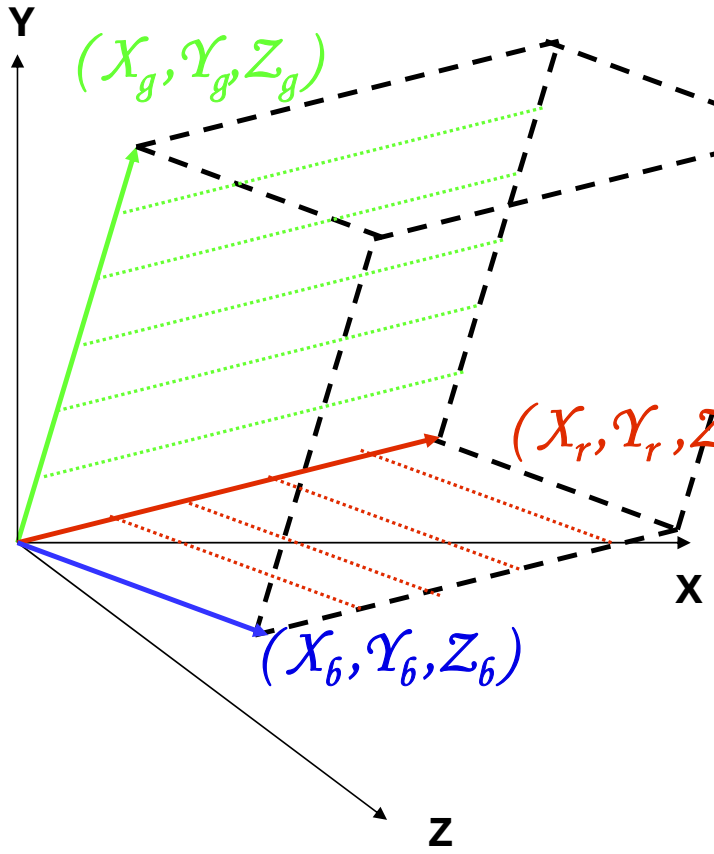
- Add (X,Y,Z) coordinates

$$C_s = (X_s, Y_s, Z_s) = (X_1 + X_2, Y_1 + Y_2, Z_1 + Z_2)$$

- What does this mean in terms of brightness and chrominance?
  - Add brightness
  - Linear combination of chrominance in proportion of the brightness

$$(x_s, y_s) = (x_1, y_1)\frac{I_1}{I_1 + I_2} + (x_2, y_2)\frac{I_2}{I_1 + I_2}$$

What is the RGB color?



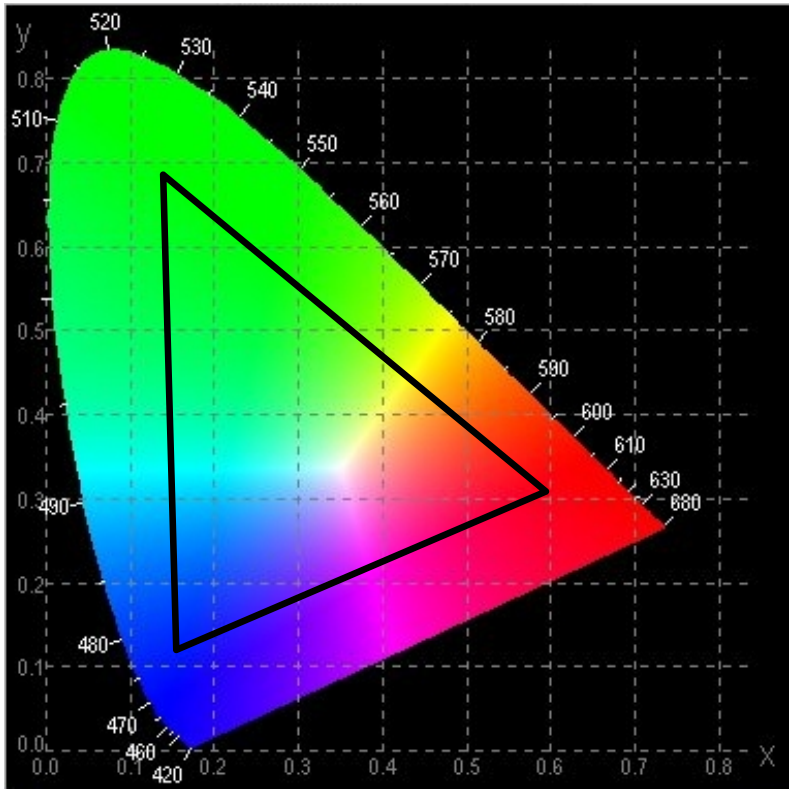
$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} i_r \\ i_g \\ i_b \end{bmatrix}$$

Color reproducibility

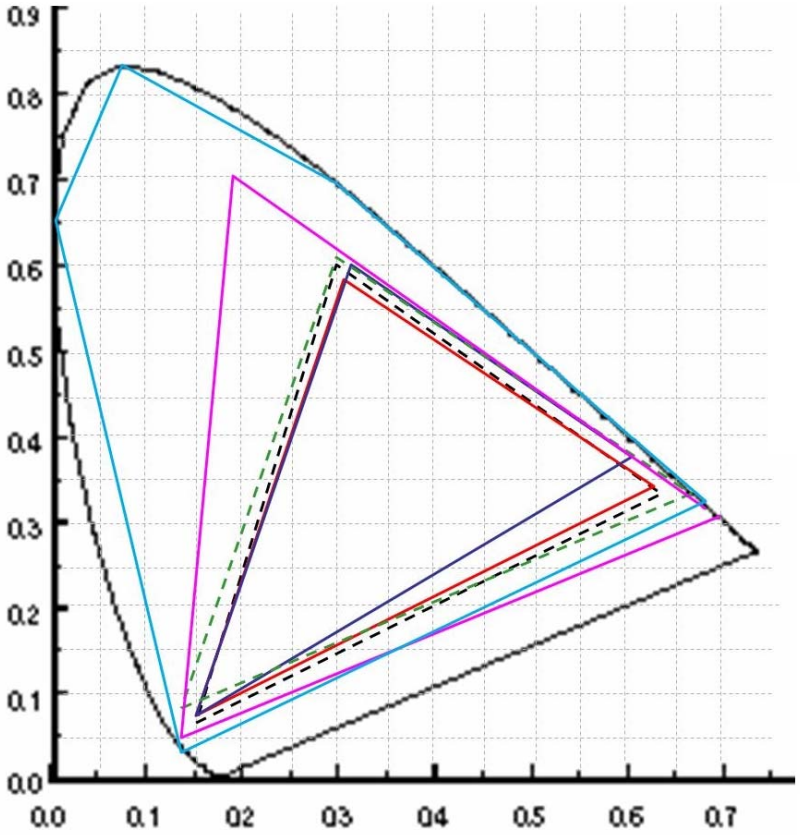
- Only a subset of the 3D CIE XYZ space called 3D color gamut
- Projection of the 3D color gamut on the same plane with normal (1,1,1)
  - Triangle
  - 2D color gamut
    - Cannot describe brightness range reproducibility

Specification Protocols

- Brightness or Luminance
- 2D gamut
  - Large if using more saturated primaries



Current standards and devices



NTSC

HDTV

LCD panels/ Traditional Single Source LCD projectors

Traditional Single Source DLP projectors

Multiple LED Source DLP projectors

Multiple Laser Source DLP projectors

Gamut Transformation

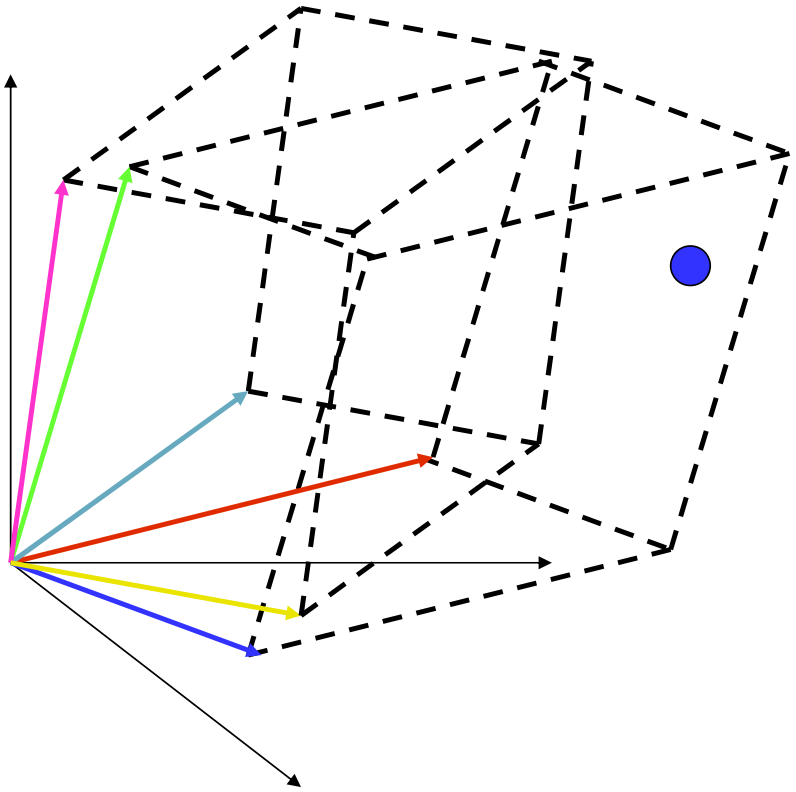
- Assume linear gamma
- $[X\ Y\ Z\ 1]^T = M\ [R\ G\ B\ 1]^T$
- Two devices
  - $[X\ Y\ Z\ 1]^T = M_1\ [R_1\ G_1\ B_1\ 1]^T$
  - $[X\ Y\ Z\ 1]^T = M_2\ [R_2\ G_2\ B_2\ 1]^T$
- $[R_2\ G_2\ B_2\ 1]^T = M_2^{-1}[X\ Y\ Z\ 1]$

$$= M_2^{-1}M_1[R_1\ G_1\ B_1\ 1]^T$$

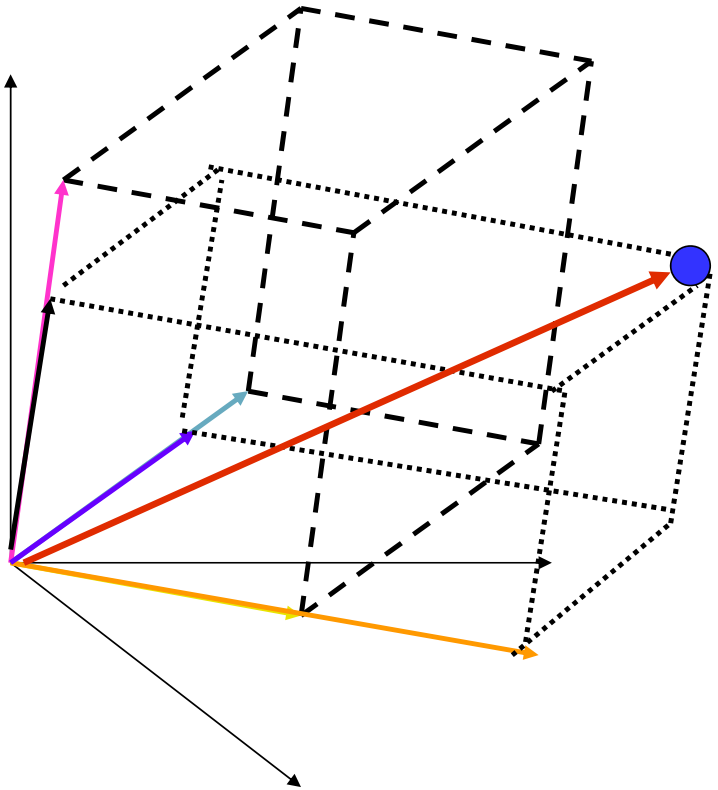
Gamut Transformation

- How to get the matrix from the standard spec?
- Given (Y,x,y) or (I,x,y) for the three vectors, you can compute (X,Y,Z)
  - (x. Y/y, Y, (1-x-y). Y/y)
  - (x.I, y.I, (1-x-y).I)
- **Does not change the color**, finds the new coordinates when using the new basis

Problem



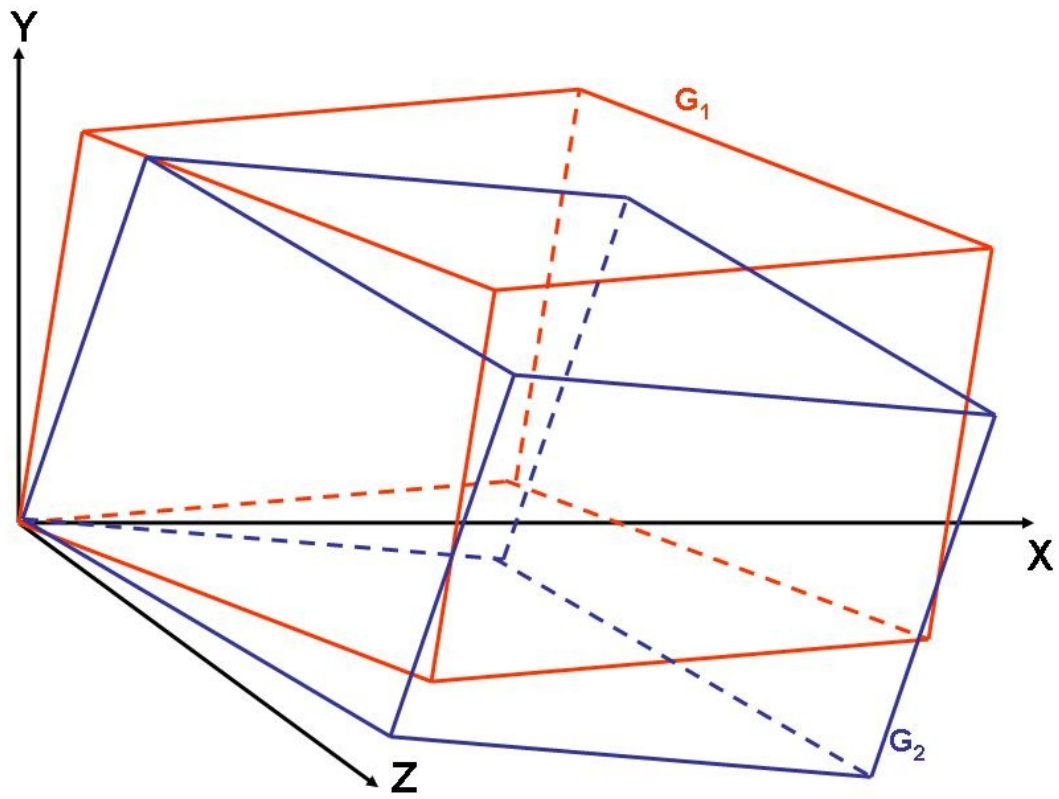
Problem: Out of Gamut colors



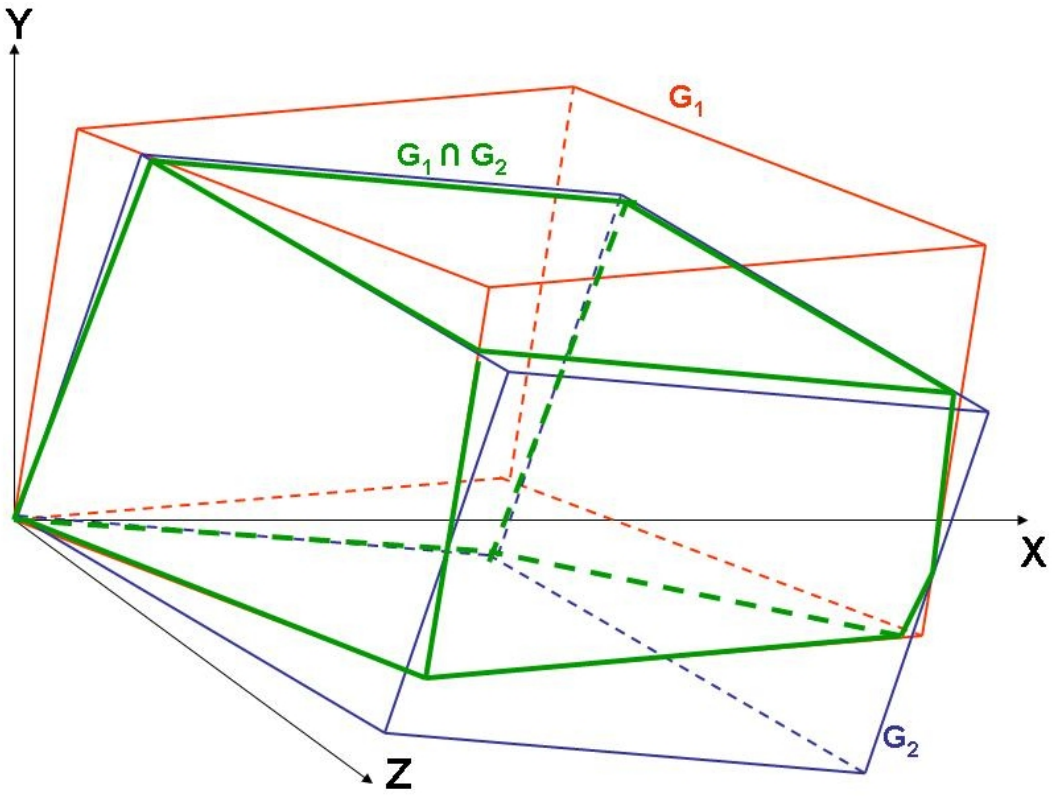
Gamut Matching

- Find a common color gamut defined by R_c, G_c, B_c
- Find the common function M_c
  - $[X\ Y\ Z\ 1]^T = M_c\ [R_c\ G_c\ B_c\ 1]^T$
- For any device i
  - $[R_i\ G_i\ B_i\ 1]^T = M_i^{-1} M_c\ [R_c\ G_c\ B_c\ 1]^T$

Two gamut

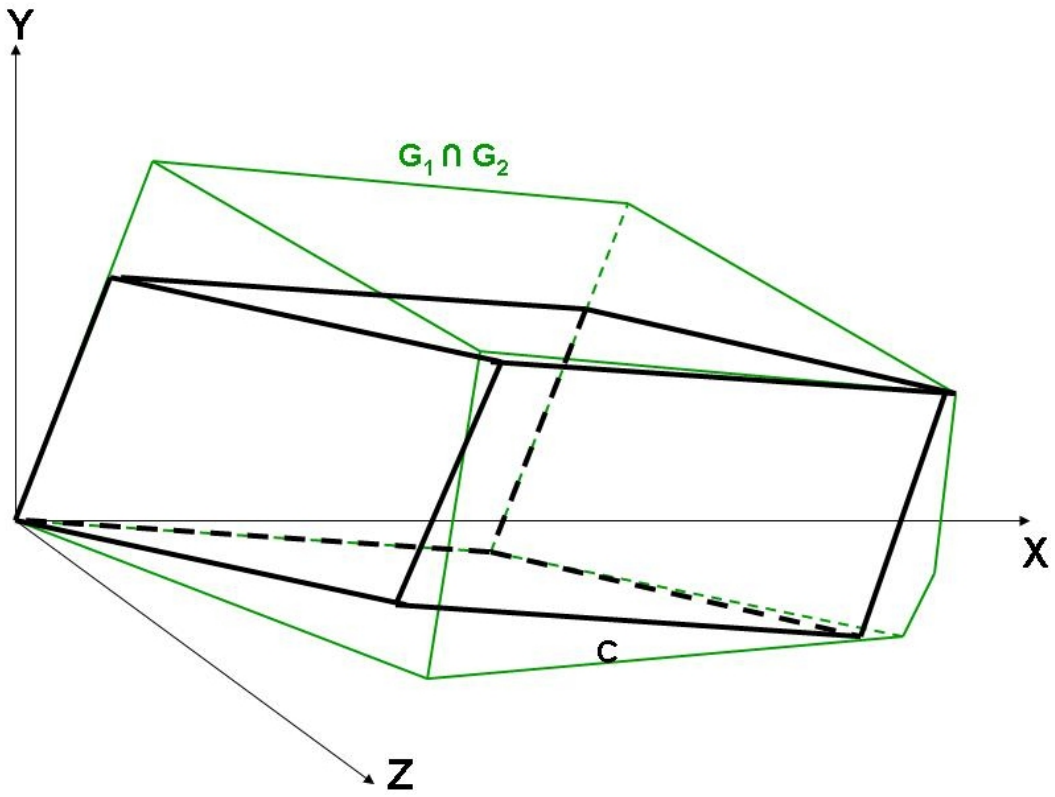


Find their intersection

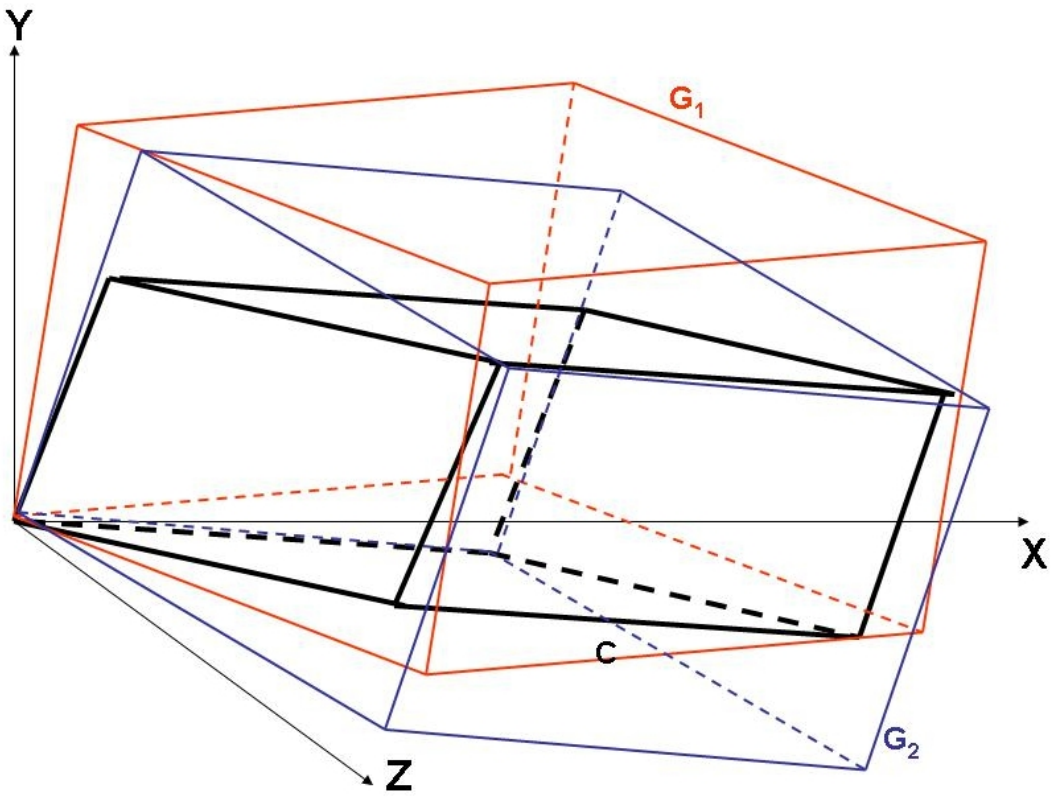


Need not be a parallelopipped

Find the common gamut



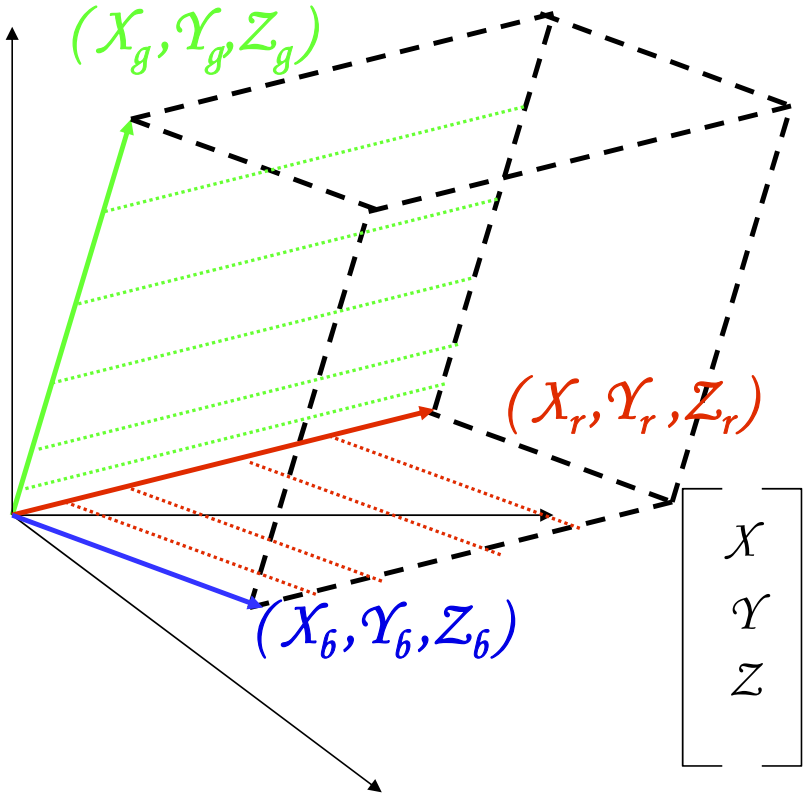
Find the mapping function



Gamut Mapping

- Changing the actual colors
  - Mapping color in one gamut to another in the new gamut
- If just dealing with two devices, may choose to move colors from one gamut to another

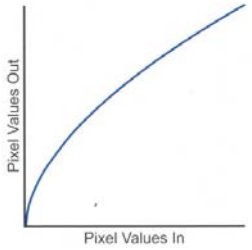
What is gamma function?

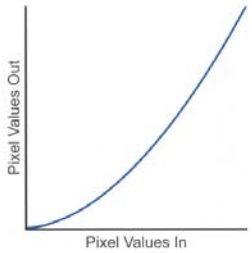


$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_r & X_g & X_b \\ Y_r & Y_g & Y_b \\ Z_r & Z_g & Z_b \end{bmatrix} \begin{bmatrix} h_r(i_r) \\ h_g(i_g) \\ h_b(i_b) \end{bmatrix}$$

Tone Mapping Operator

- How the input value maps to output intensity
- Affects brightness, contrast and saturation



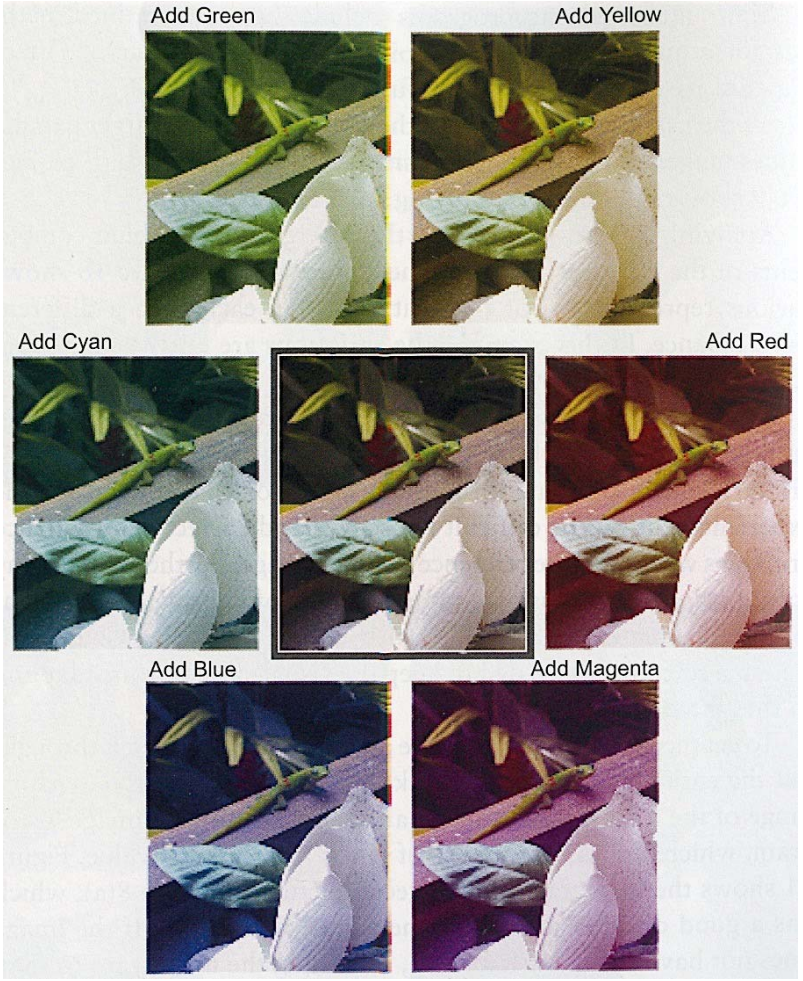


Transfer Function

- Monotonic, smooth with no flat regions
- Brightness and contrast controls

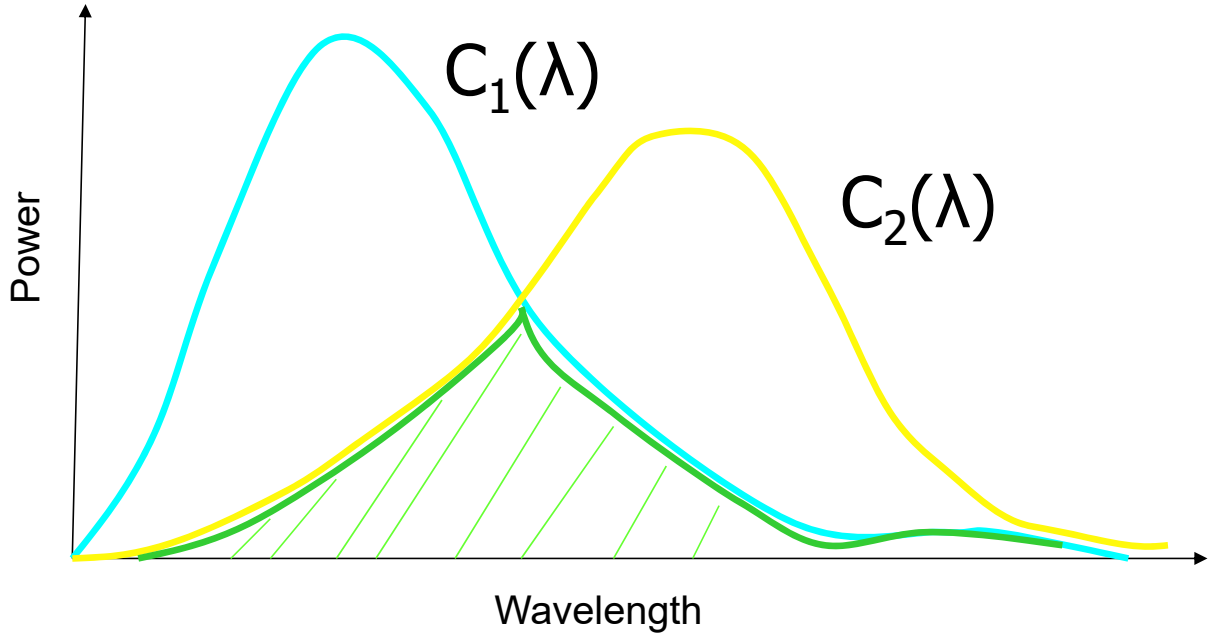
Color Balance

- Relative proportions of primaries while forming a color
- Affects hue, saturation and brightness
- Can be changed by changing the transfer function



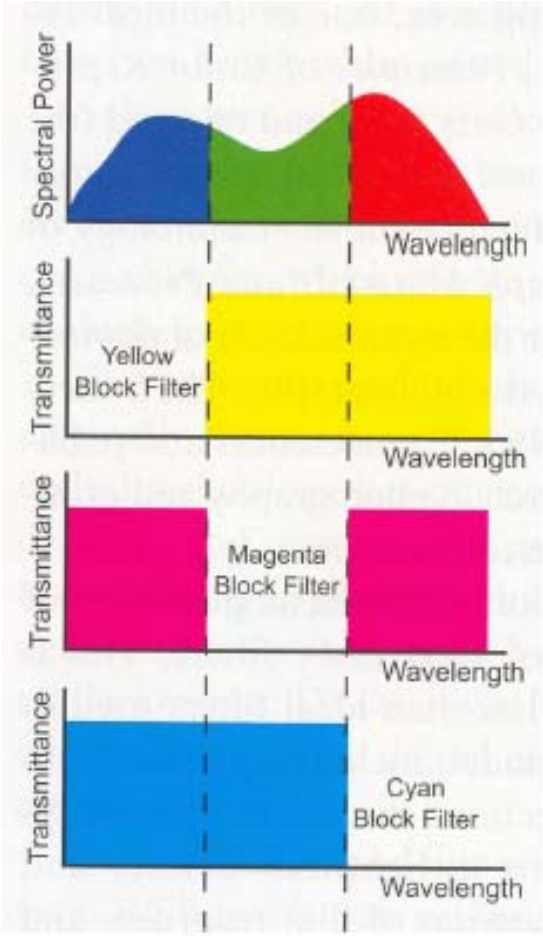
Subtractive Color

- Subtractive like paint
- Cannot be modeled by CIE XYZ space



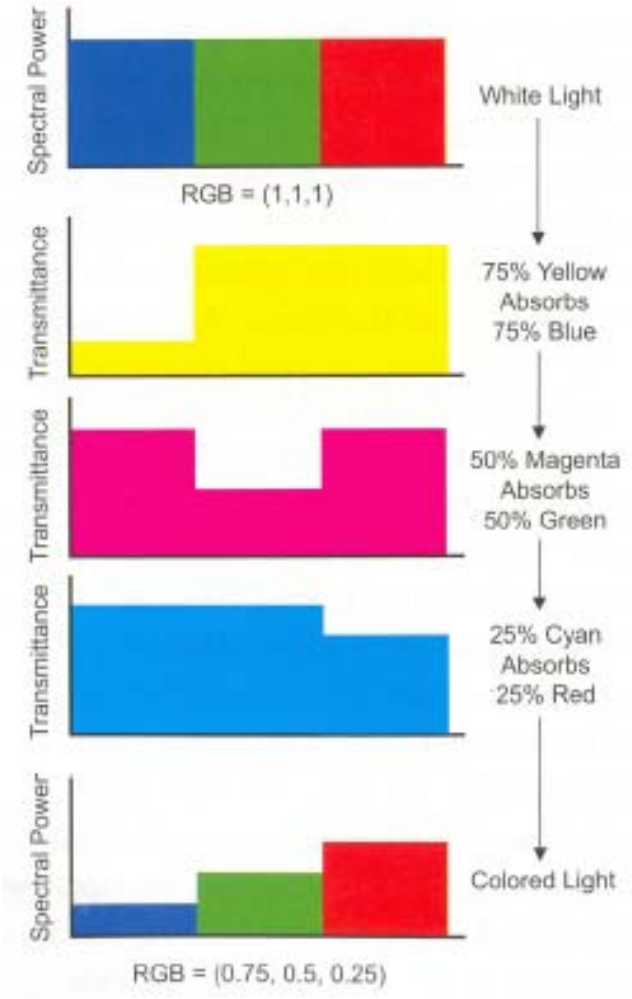
Subtractive Color System

- Layers of cyan, yellow and magenta dyes
  - Absorb red, blue and green light
- Depends on the illuminant
- Act as absorption filter
  - Ideally block filters
- Overlaying all the three dyes absorbs all wavelengths creating black



Creation of a color

- CMY = (1, 1, 1) – RGB
- (0.25, 0.5, 0.75) = (1, 1, 1) – (0.75, 0.5, 0.25)
- This works only for block filters



Real Filters

- Are not block filters
- Cross talk across different filters
- Due to ink impurities
- Grays should be formed by equal amount of three primaries
  - Seldom happens