Color Models

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CS456

Main Color Spaces

- CIE XYZ, xyY
- RGB, CMYK
- HSV (Munsell, HSL, IHS)
- Lab, UVW, YUV, YCrCb, Luv,

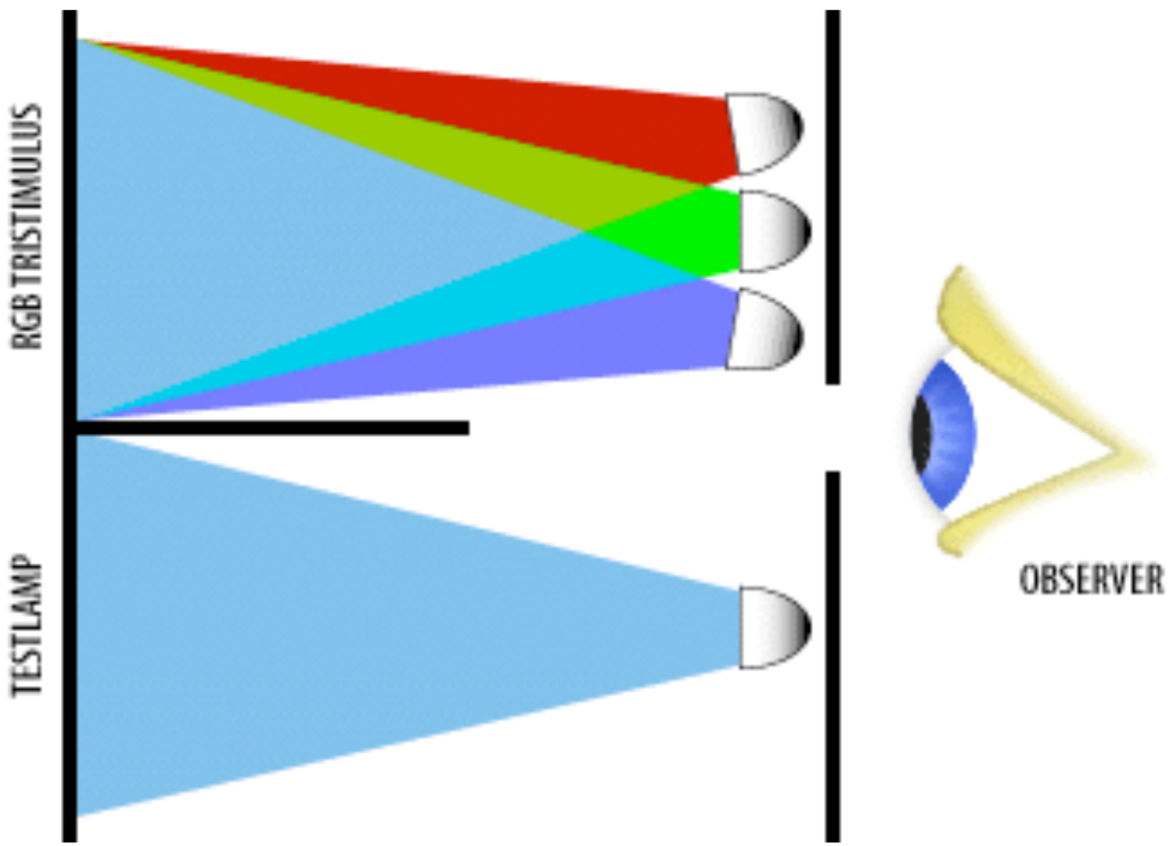
Differences in Color Spaces

- What is the use? For display, editing, computation, compression, …?
- Several key (very often conflicting) features may be sought after:
  - Additive (RGB) or subtractive (CMYK)
  - Separation of luminance and chromaticity
  - Equal distance between colors are equally perceivable

CIE Standard

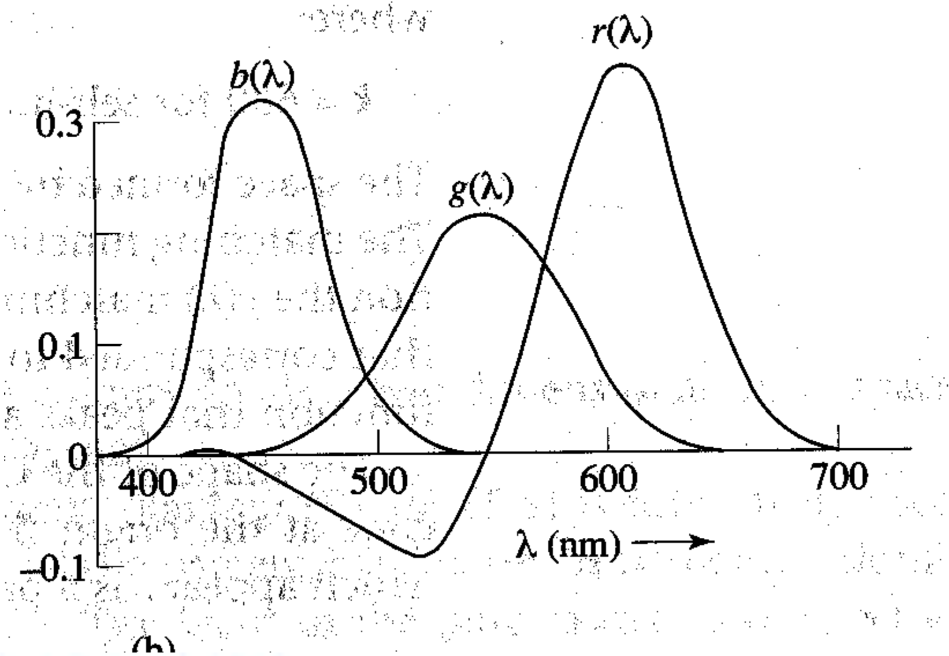
- CIE: International Commission on Illumination (Comission Internationale de l’Eclairage).
- Human perception based standard (1931), established with color matching experiment
- Standard observer: a composite of a group of 15 to 20 people

CIE Experiment



CIE Experiment Result

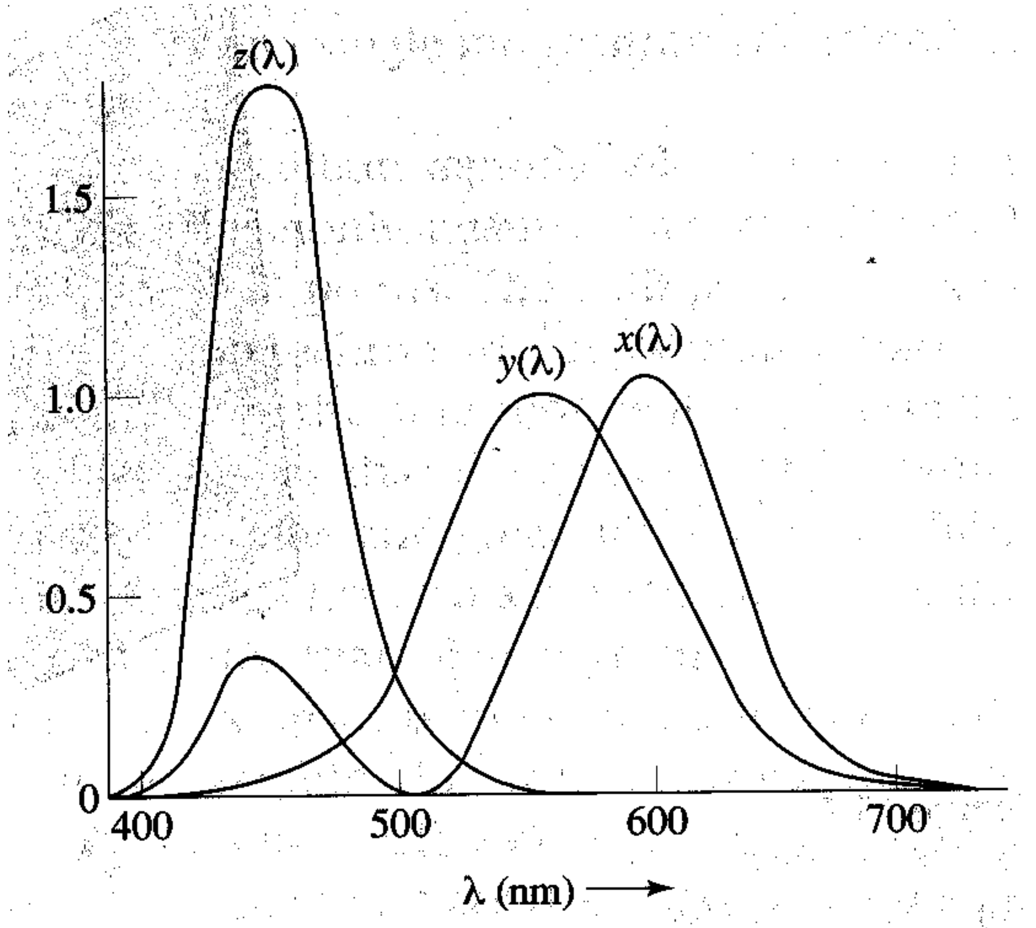
- Three pure light source: R = 700 nm, G = 546 nm, B = 436 nm.



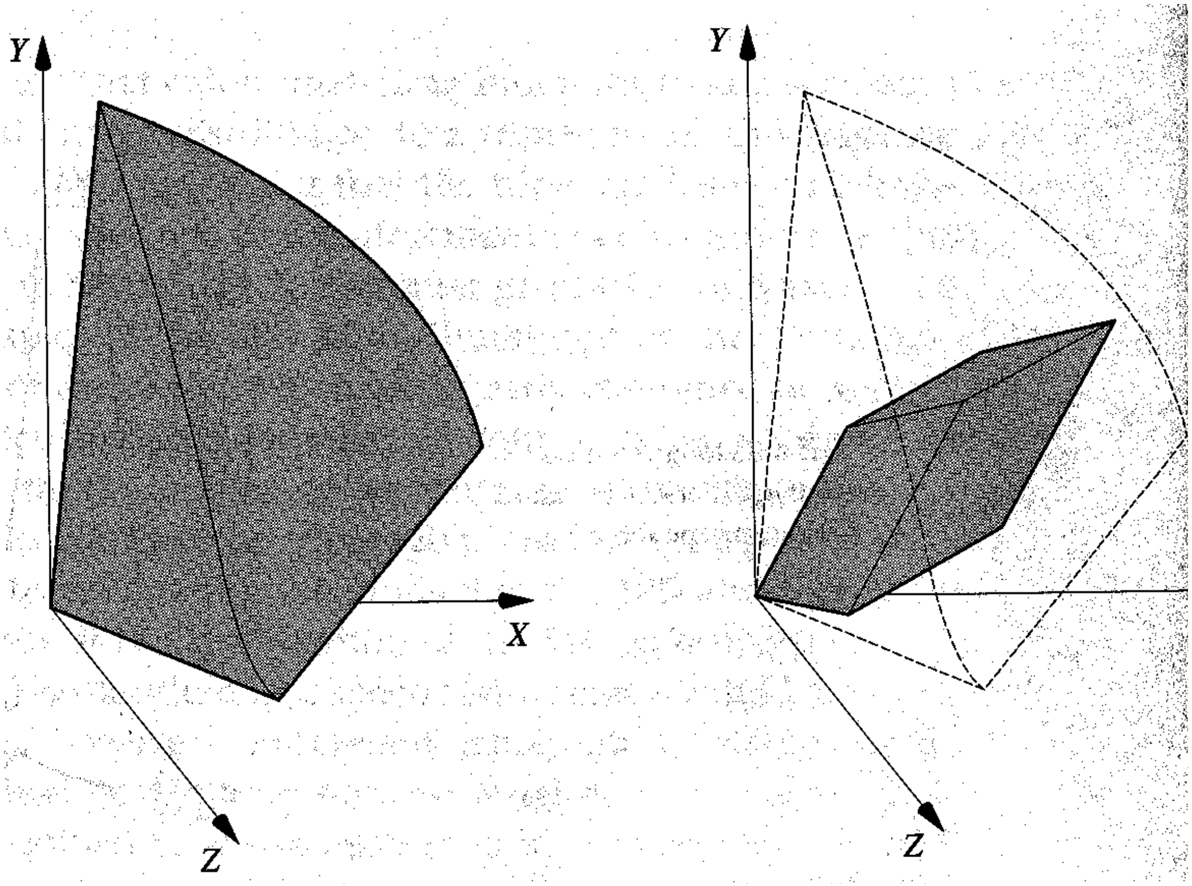
$$C_\lambda = r(\lambda) + g(\lambda) + b(\lambda)$$

CIE Color Space

- 3 hypothetical light sources, X, Y, and Z, which yield positive matching curves
- Y: roughly corresponds to luminous efficiency characteristic of human eye



CIE Color Space

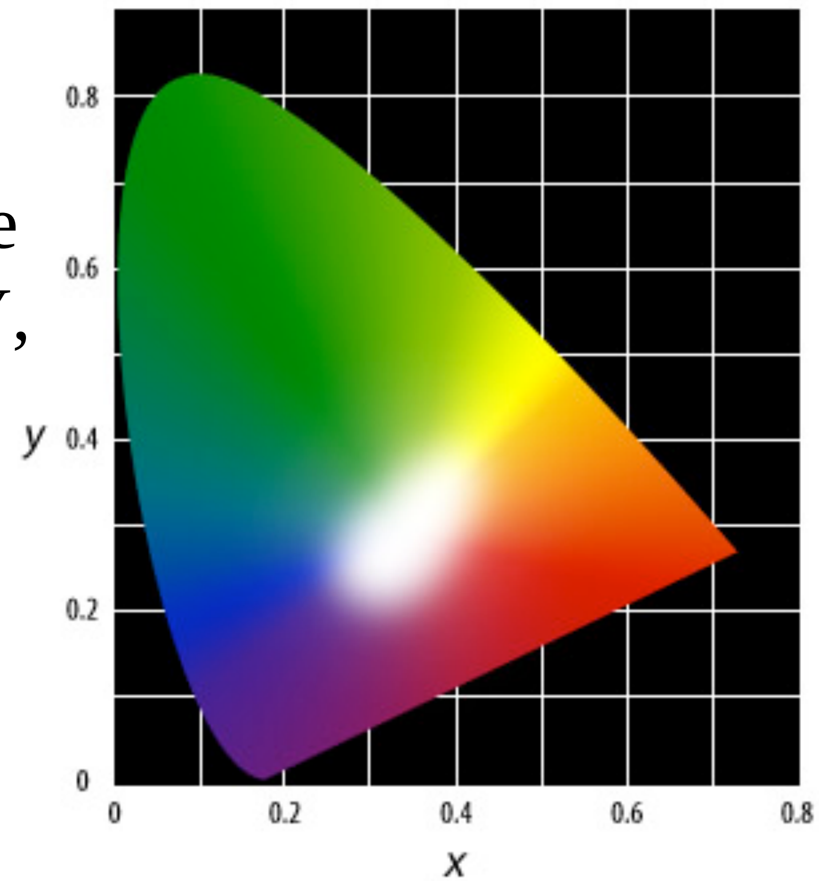


CIE xyY Space

- Irregular 3D volume shape is difficult to understand
- Chromaticity diagram (the same color of the varying intensity, Y, should all end up at the same point)

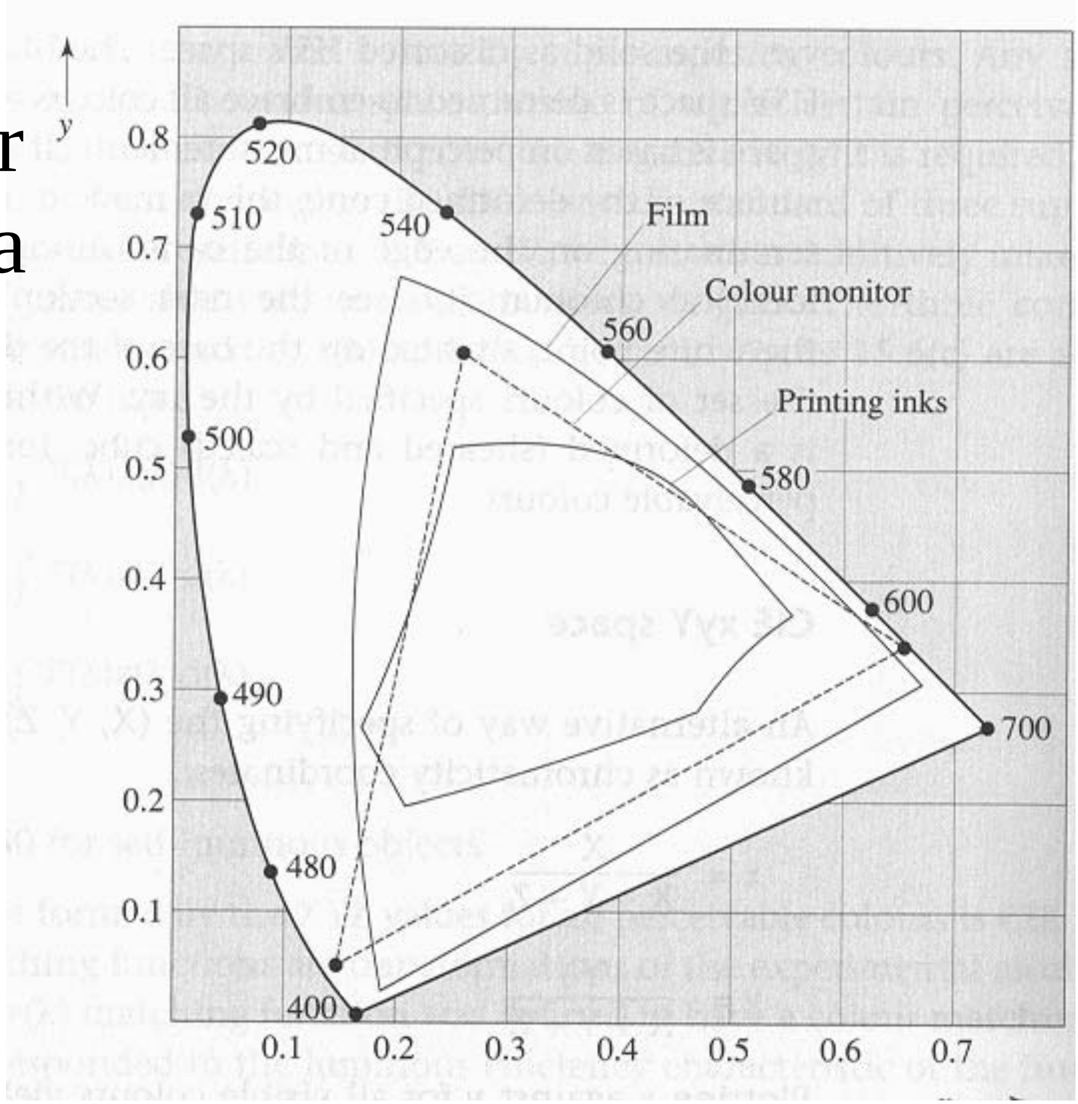
$$x = \frac{X}{X + Y + Z}$$

$$y = \frac{Y}{X + Y + Z}$$



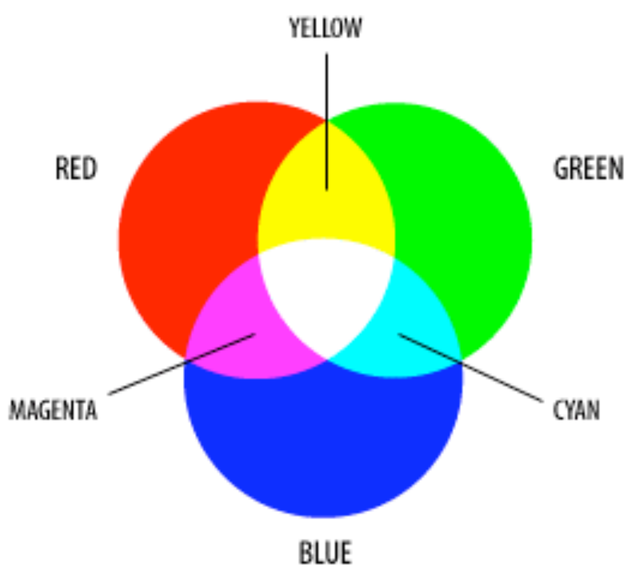
Color Gamut

- The range of color representation of a display device



RGB (monitors)

- The de facto standard



$$\mathbf{C} = r\mathbf{R} + g\mathbf{G} + b\mathbf{B}$$

The RGB Cube

- RGB color space is perceptually non-linear
- RGB space is a subset of the colors human can perceive
- Con: what is ‘bloody red’ in RGB?

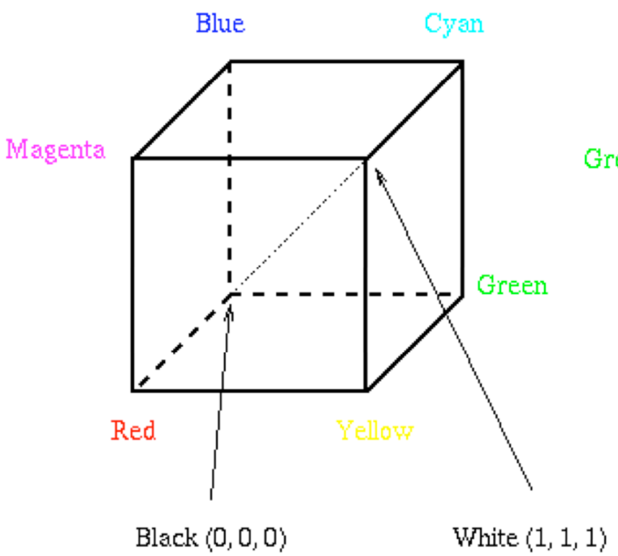
CMY(K): printing

- Cyan, Magenta, Yellow (Black) – CMY(K)
- A subtractive color model

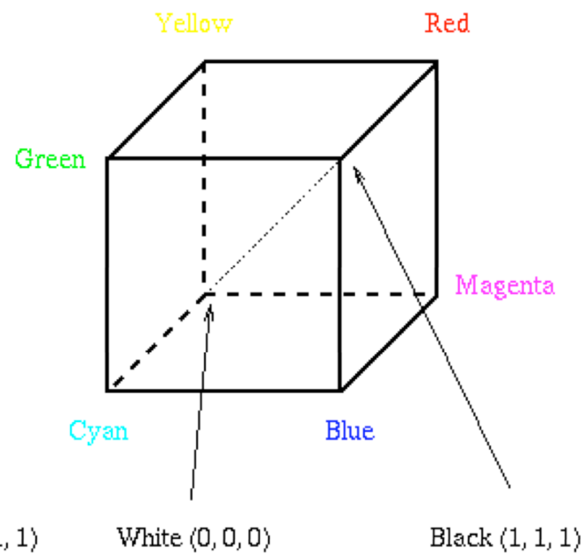
dye color	*absorbs*	*reflects*
cyan	red	blue and green
magenta	green	blue and red
yellow	blue	red and green
black	all	none

RGB and CMY

- Converting between RGB and CMY



The RGB Cube

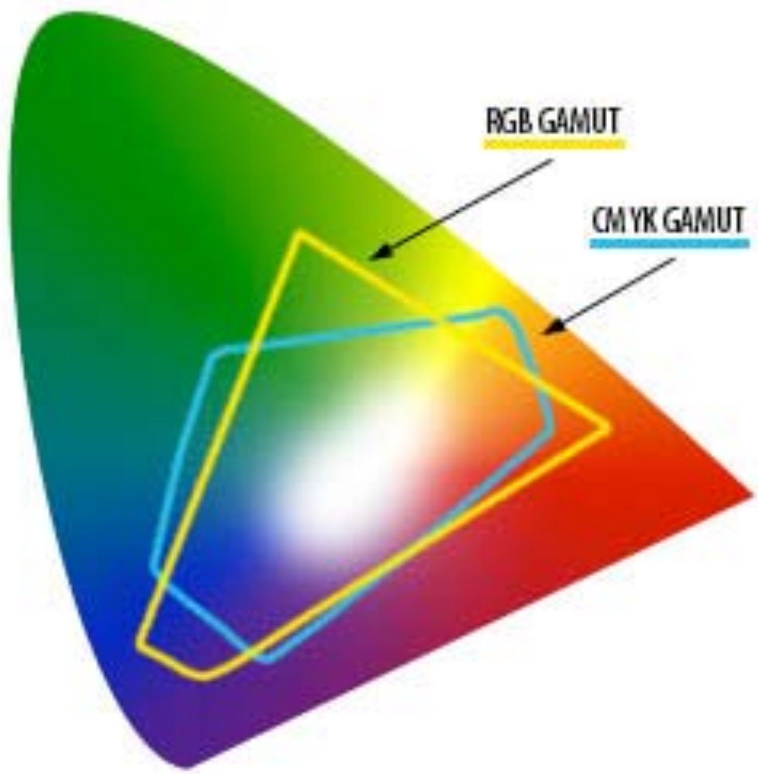


The CMY Cube

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} C \\ M \\ Y \end{bmatrix}$$

RGB and CMY

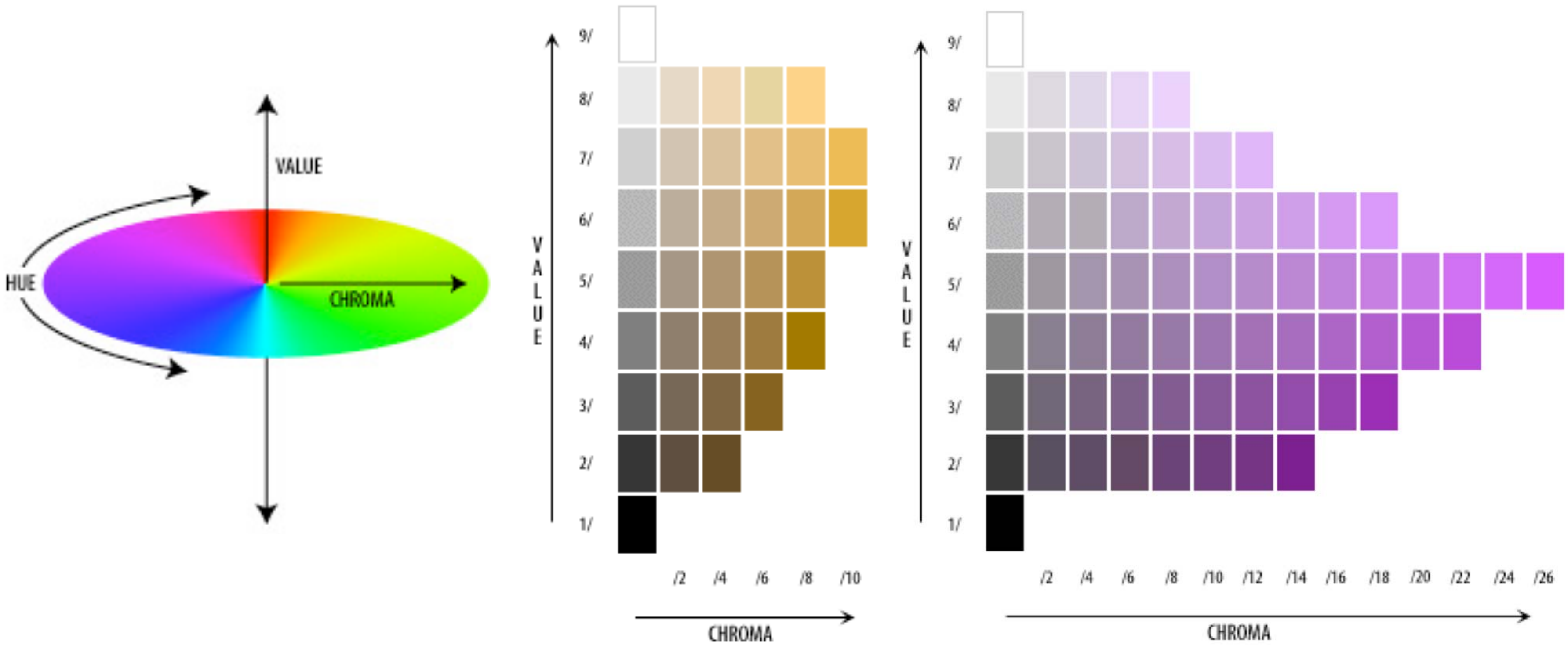


HSV

- This color model is based on polar coordinates, not Cartesian coordinates.
- HSV is a non-linearly transformed (skewed) version of RGB cube
  - Hue: quantity that distinguishes color family, say red from yellow, green from blue (what color?)
  - Saturation (Chroma): color intensity (strong to weak). Intensity of distinctive hue, or degree of color sensation from that of white or grey (what purity?)
  - Value (luminance): light color or dark color (what strength?)

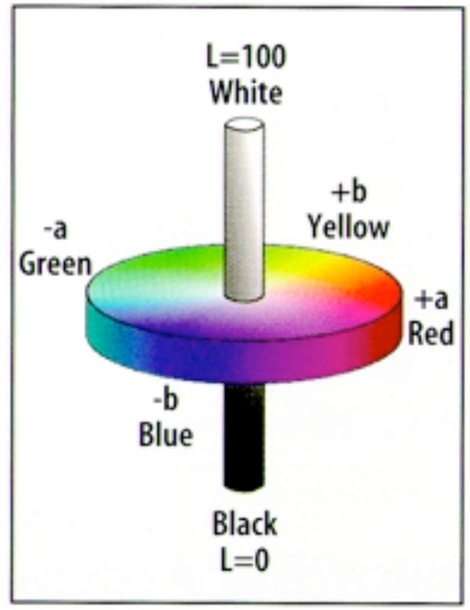
HSV Hexcone

- Intuitive interface to color



Lab: photoshop

- Photoshop uses this model to get more control over color
- It's named CIE Lab model (refined from the original CIE model
- Liminance: L
- Chrominance: a – ranges from green to red and b ranges from blue to yellow



Lab model

Luv and UVW

- A color model for which, a unit change in luminance and chrominance are uniformly perceptible

$U = 13\ W^* (u - u_o);\ V = 13\ W^* (v - v_o);\ W = 25\ (100\ Y)^{1/3} - 17$

where Y , u and v can be calculated from :

$\boldsymbol{X = O.607\ Rn + 0.174\ Gn + 0.200Bn}$

$Y = 0.299\ Rn + 0.587\ Gn + 0.114Bn$

$Z = 0.066\ Gn + 1.116\ Bn$

$x = X / (X + Y + Z)$

$y = Y / (X + Y + Z)$

$z = Z / (X + Y + Z)$

$u = 4x / (-2x + 12y + 3)$

$v = 6y / (-2x + 12y + 3)$

- Luv is derived from UVW and Lab, with all components guaranteed to be positive

Yuv and YCrCb: digital video

- Initially, for PAL analog video, it is now also used in CCIR 601 standard for digital video
- Y (luminance) is the CIE Y primary.

  $$Y = 0.299R + 0.587G + 0.114B$$

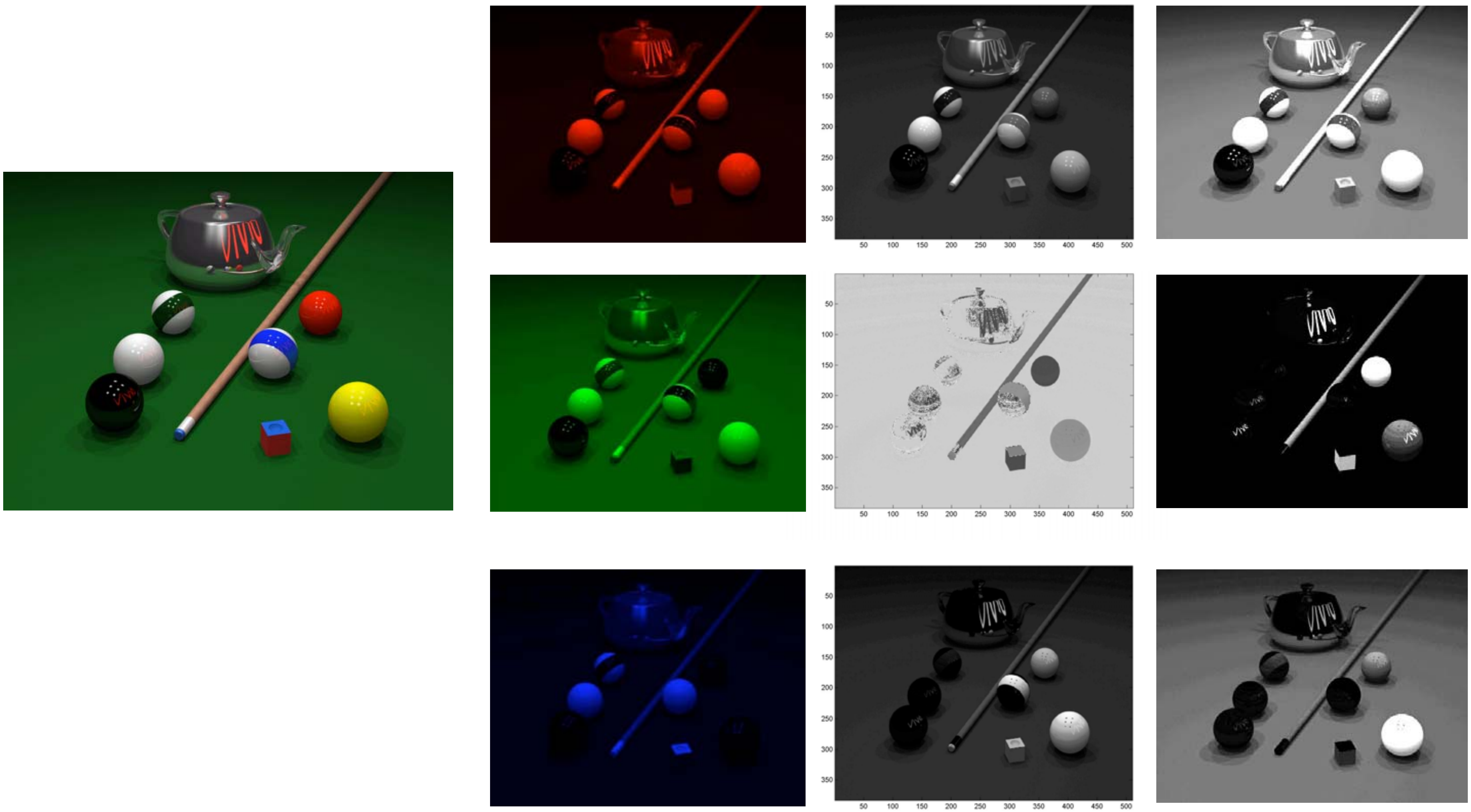
- *Chrominance* is defined as the difference between a color and a reference white at the same luminance. It can be represented by U and V -- the *color differences*.

  $$U = B - Y; V = R - Y$$

- YCrCb is a scaled and shifted version of YUV and used in JPEG and MPEG (all components are positive)

$$Cb = (B - Y) / 1.772 + 0.5; Cr = (R - Y) / 1.402 + 0.5$$

Examples (RGB, HSV, Luv)



Color Matching on Monitors

- Use CIE XYZ space as the standard

$$\begin{bmatrix} R' \\ G' \\ B' \end{bmatrix} = \begin{bmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- Use a simple linear conversion

$$\mathbf{C}_2 = \mathbf{M}_2^{-1}\mathbf{M}_1\mathbf{C}_1$$

- Color matching on printer is more difficult, approximation is needed (CMYK)

Gamut Mapping

- Negative RGB: add white (maintains hue, de-saturate)
- >1 RGB, scale down (in what space?)
- Not a trivial question (sometimes known as tone mapping)

Tone mapping

- Real scene: large range of luminance (from 10 -6 to 10 6 cd/m^2)
- Limitation of the display 1-100 cd/m^2

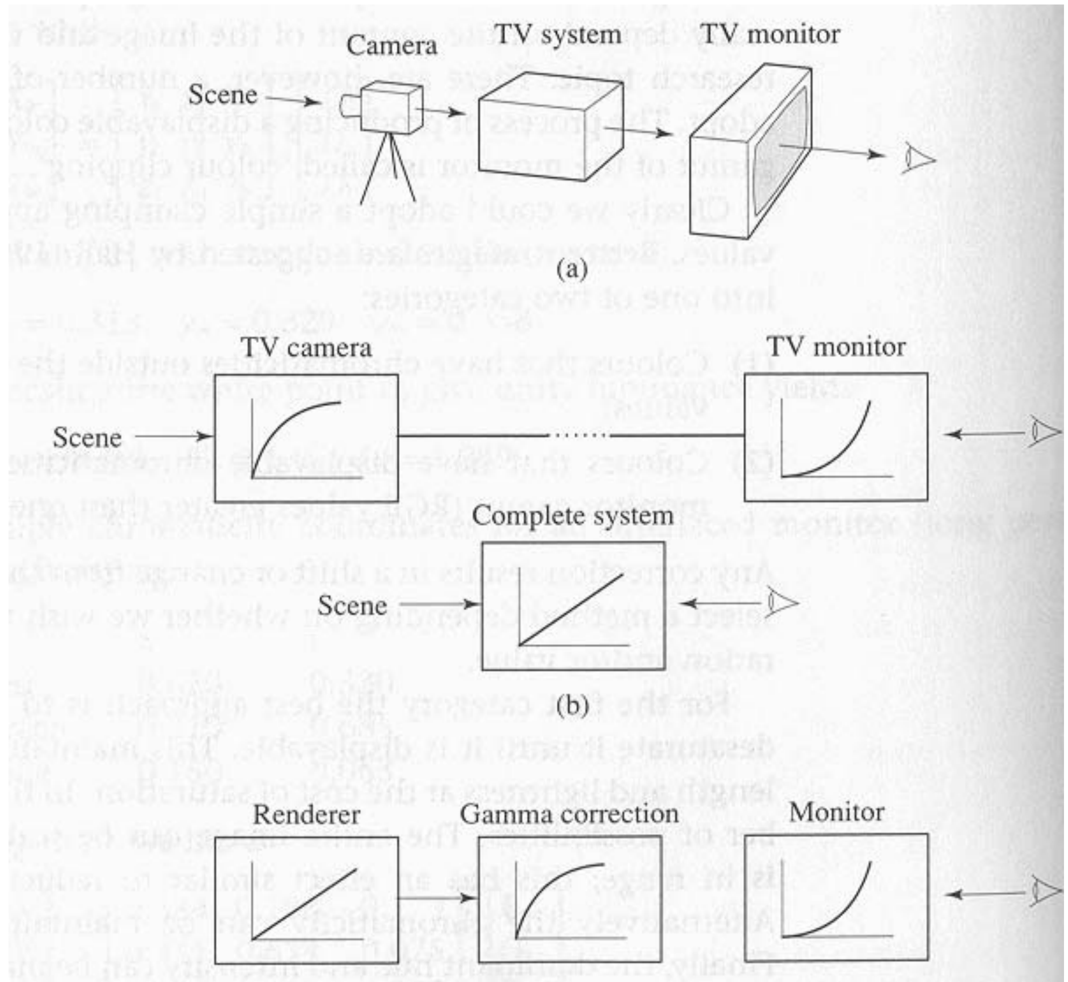
- cd : candela, unit for measuring intensity of flux of light

Gamma Correction

- The phosphor dots are not a linear system (voltage vs. intensity)

$$R_m = K(R'_i)^{\gamma_T}$$

$$R'_i = k(R_i)^{1/\gamma_T}$$



Gamma correction

- Without gamma correction, how will (0,255,127) look like?
- Normally gamma is within 1.7 and 2.8
- Who is responsible for Gamma correction?
- SGI does it for you
- PC/Mac etc, you should do it yourself

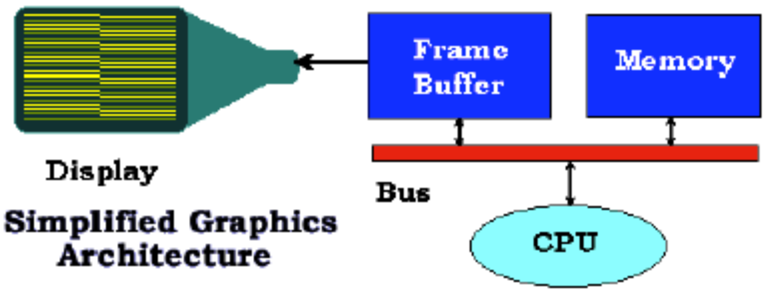
No gamma correction

Gamma corrected to 1.7

Residual Gamma or System Gamma

- Systems such as SGI monitor has a gamma of 2.4, but they only gamma correct for 1.7.
- The residue gamma is 2.4/1.7 = 1.4, why?
- Depends on how you see it? Bright screen, dark room causes changes in your eye transfer function too.
- What about web pages? Which screen do you intend for?

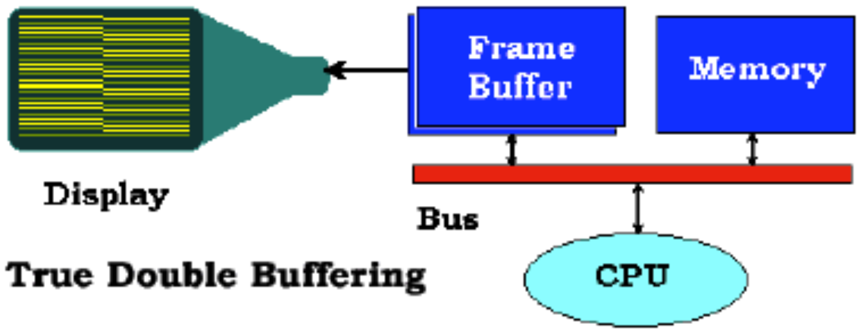
Raster Displays



Simplified Graphics Architecture

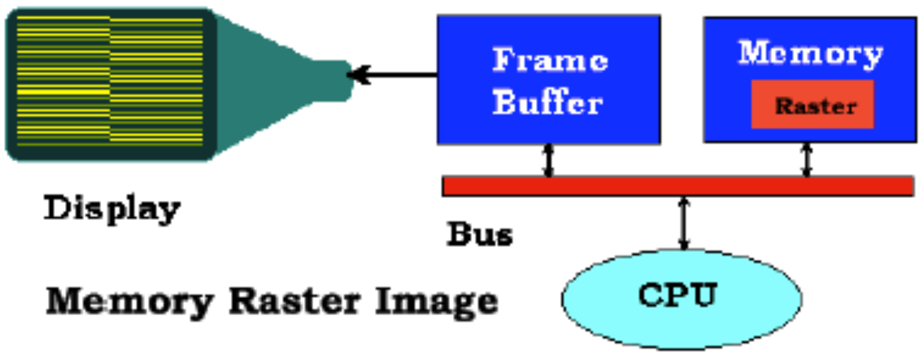
- Display synchronized with CRT sweep
- Special memory for screen update
- Pixels are the discrete elements displayed
- Generally, updates are visible

Double Buffer



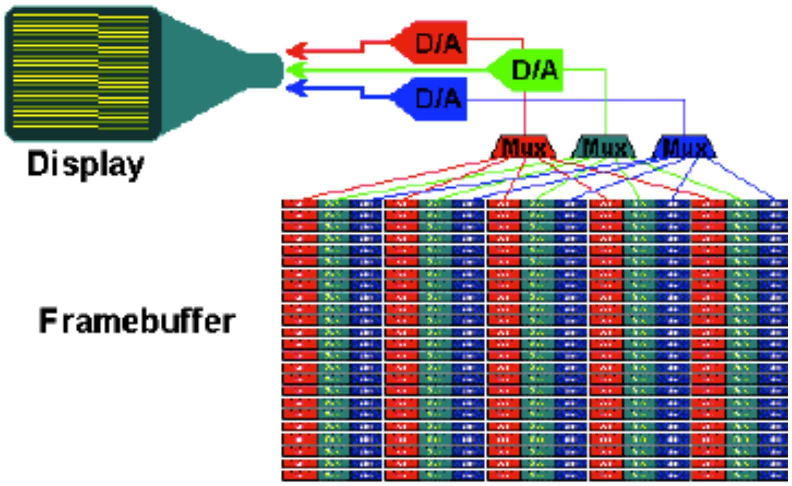
- Adds a second frame buffer
- Swaps during vertical blanking
- Updates are invisible
- Costly

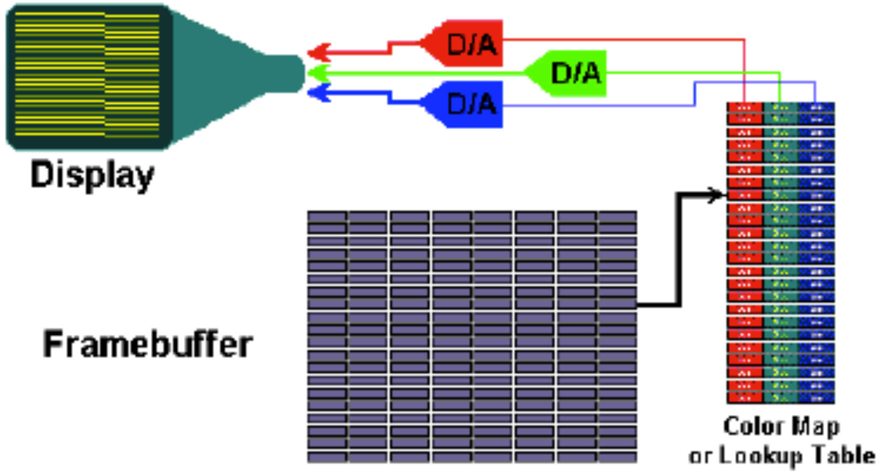
Memory Rasterizer



- Maintains a copy of the screen (or some part of it) in memory
- Relies on a fast copy
- Updates are *nearly* invisible

True Color and Indexed Color FB





High Color FB

Pixels are packed in a short.
Each primary uses 5 bits.

- Popular *PC/(SVGA)* standard (popular with Gamers)
- Each pixel can be one of 2^ 15 colors
- Can exhibit worse quantization (banding) effects than indexed- color