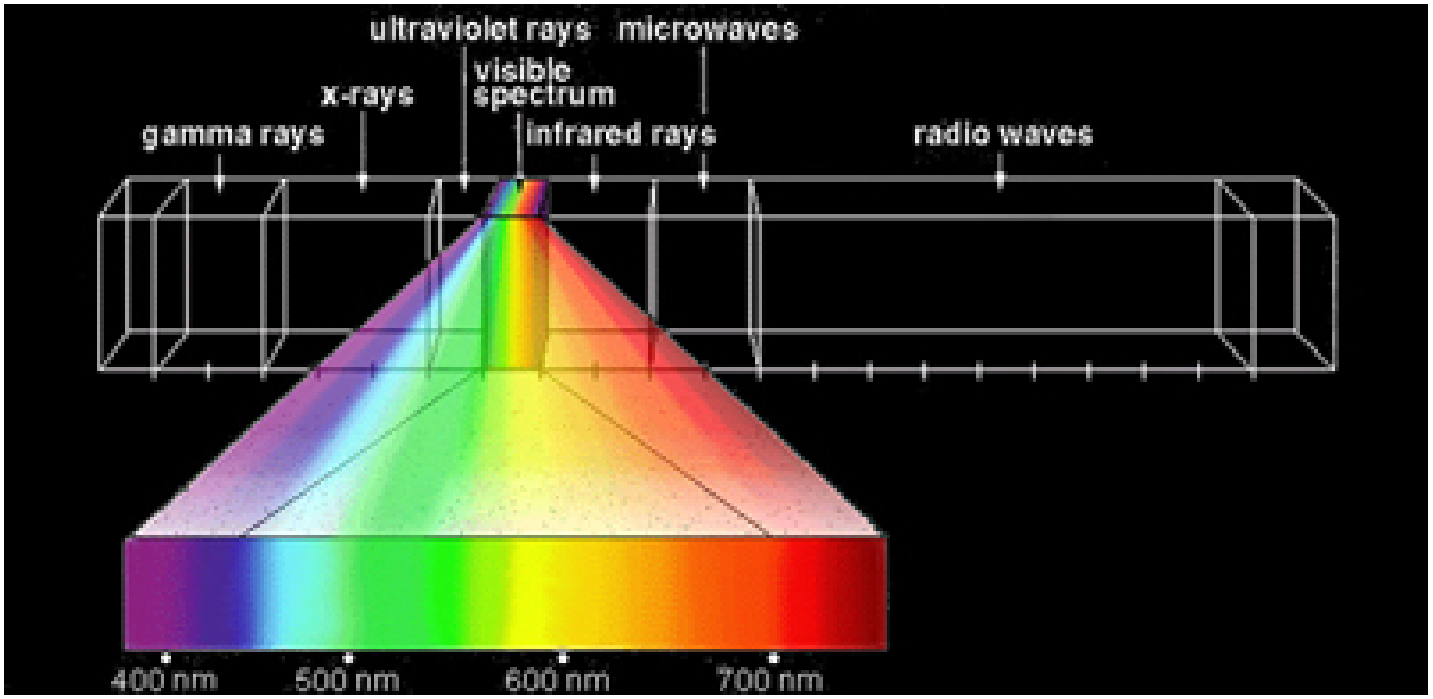
Computer Graphics

Color

Farhad Kamangar

Everything should be made as simple as possible, but not simpler. “Albert Einstein”

Visible Spectrum

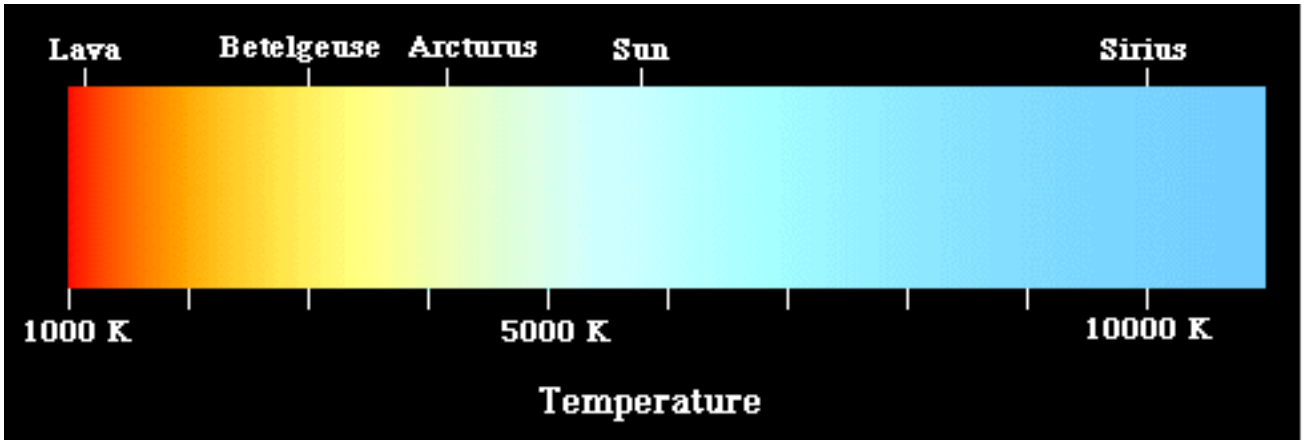
- 

Visible Spectrum

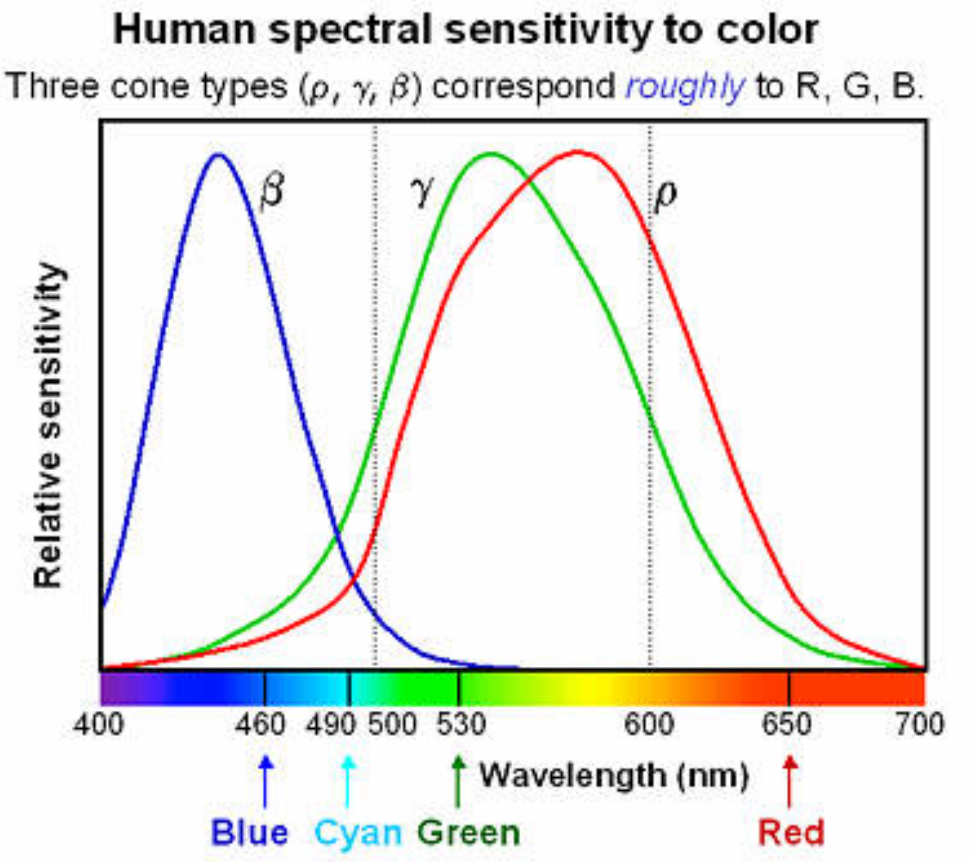
380 nm

780 nm

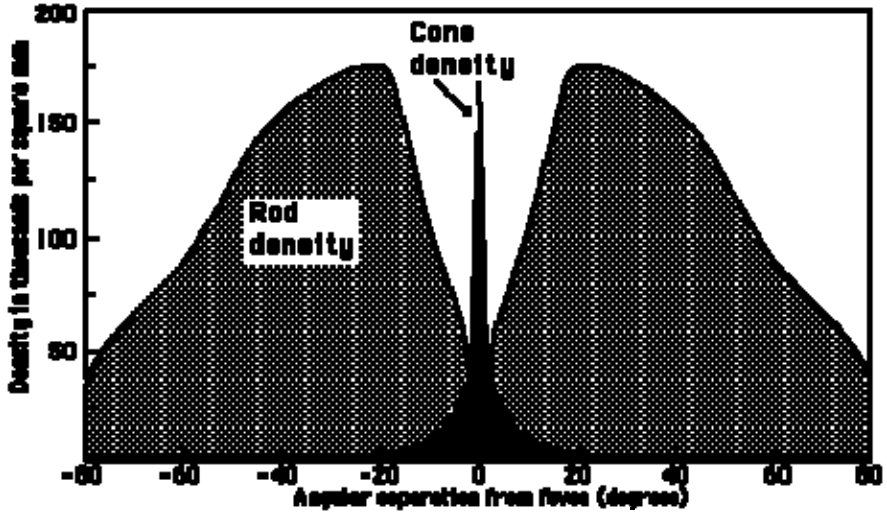
BLACKBODY RADIATION



Human Spectral Sensitivity

- 

Rod and Cone density

- 

Cone Details

- Current understanding is that the 6 to 7 million cones can be divided into "red" cones (64%), "green" cones (32%), and "blue" cones (2%) based on measured response curves. They provide the eye's color sensitivity. The green and red cones are concentrated in the fovea centralis . The "blue" cones have the highest sensitivity and are mostly found outside the fovea, leading to some distinctions in the eye's blue perception.
- The cones are less sensitive to light than the rods, as shown a typical day-night comparison. The daylight vision (cone vision) adapts much more rapidly to changing light levels, adjusting to a change like coming indoors out of sunlight in a few seconds. Like all neurons, the cones fire to produce an electrical impulse on the nerve fiber and then must reset to fire again. The light adaption is thought to occur by adjusting this reset time.
- The cones are responsible for all high resolution vision. The eye moves continually to keep the light from the object of interest falling on the fovea centralis where the bulk of the cones reside.

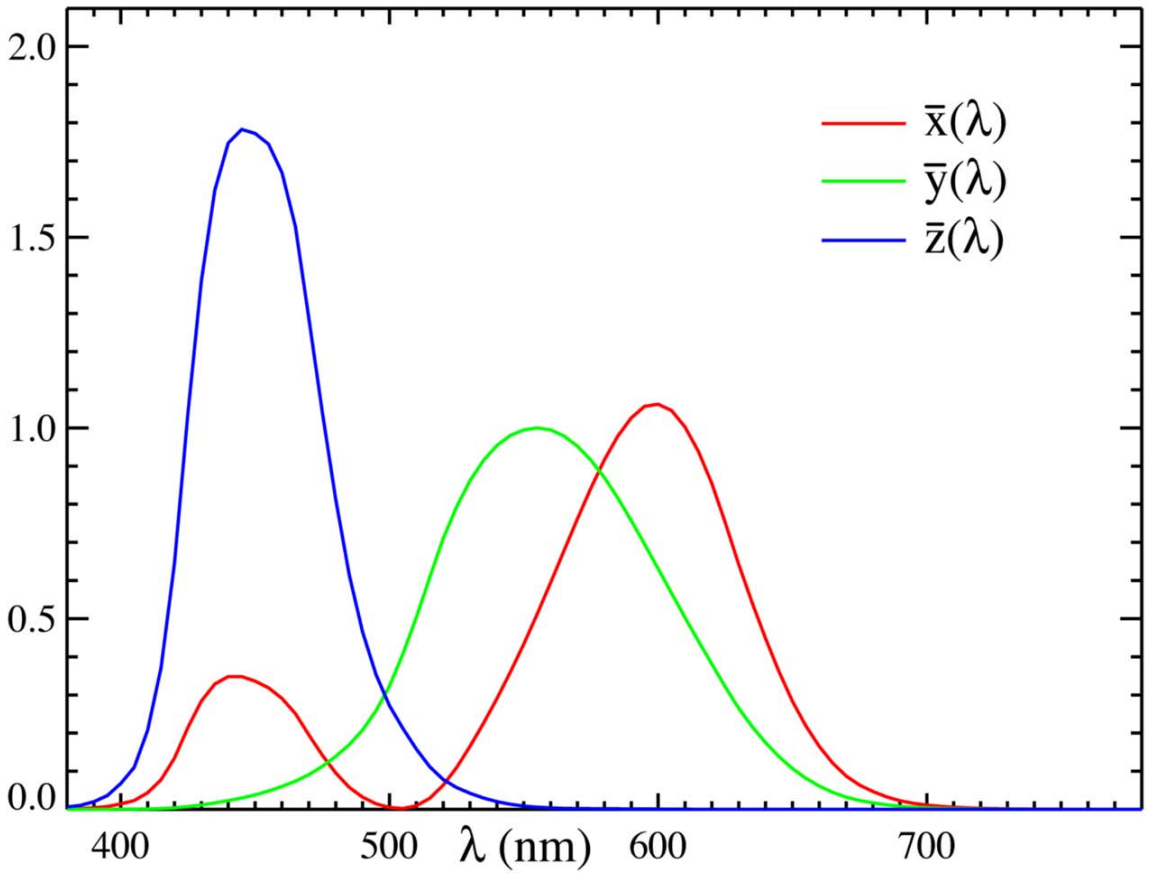
The CIE standard observer color-matching functions

Tristimulus values

$$X = \int_0^\infty I(\lambda)\,\overline{x}(\lambda)\,d\lambda$$

$$Y = \int_0^\infty I(\lambda)\,\overline{y}(\lambda)\,d\lambda$$

$$Z = \int_0^\infty I(\lambda)\,\overline{z}(\lambda)\,d\lambda$$

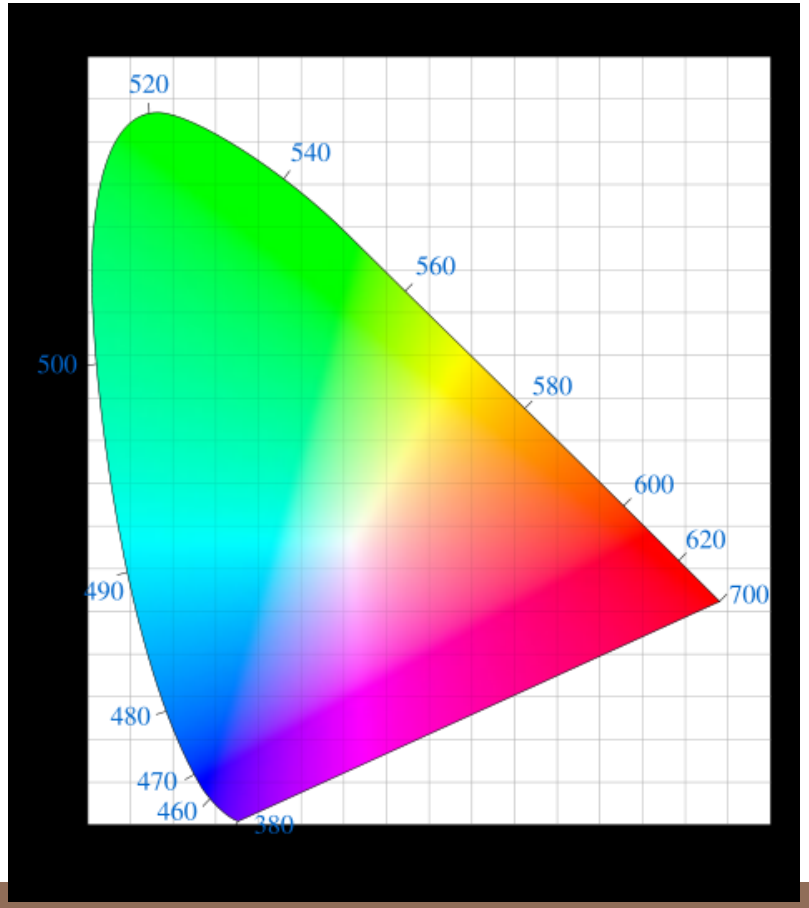


Other observers, such as for the CIERGB space or other RGB color spaces, are defined by other sets of three color-matching functions, and lead to tristimulus values in those other spaces

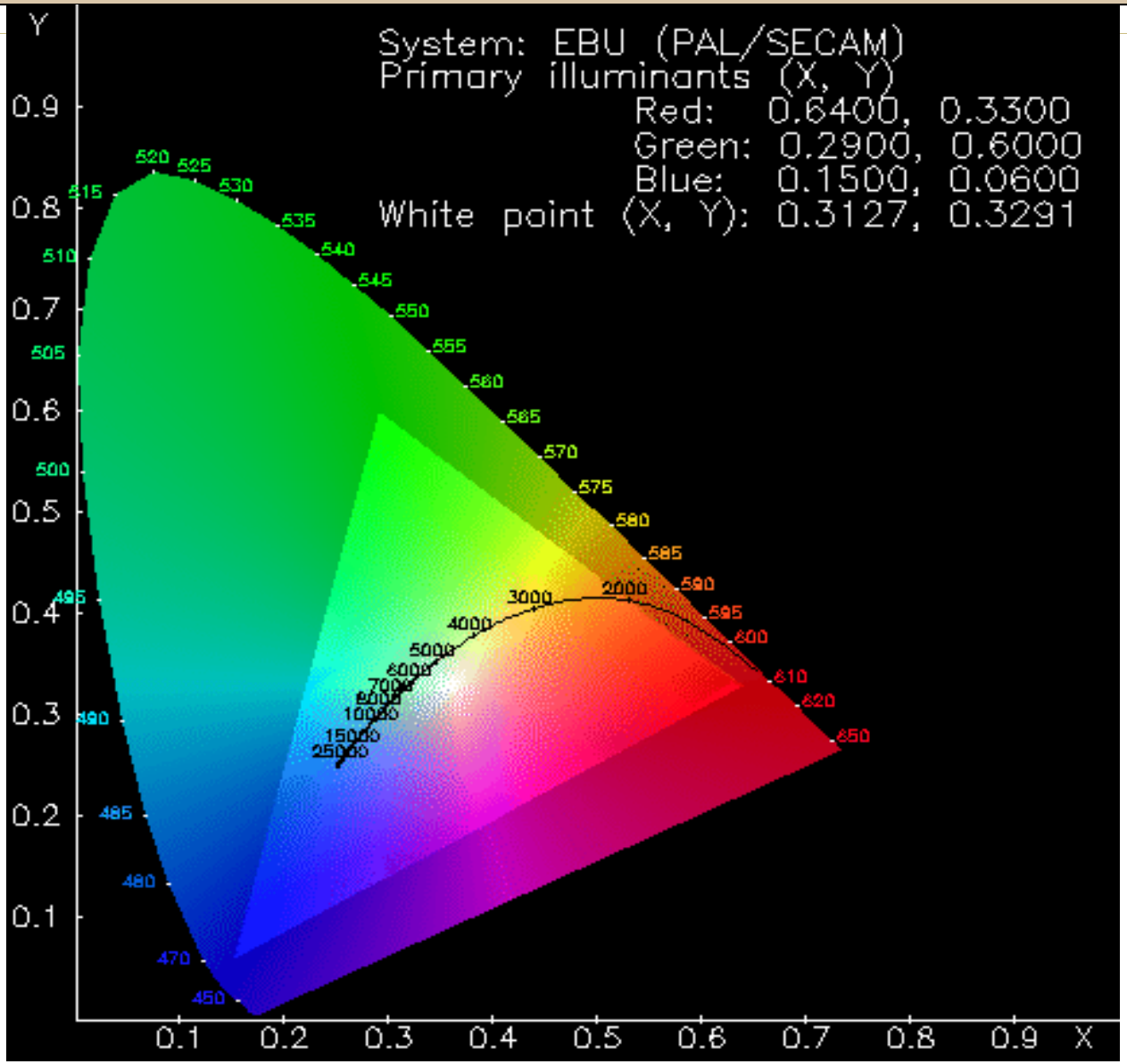
The CIE *xy* chromaticity diagram

- The CIE XYZ color space was deliberately designed so that the *Y* parameter was a measure of the brightness or luminance of a color. The chromaticity of a color was then specified by the two derived parameters *x* and *y*, two of the three normalized values which are functions of all three tristimulus values *X*, *Y*, and *Z*:

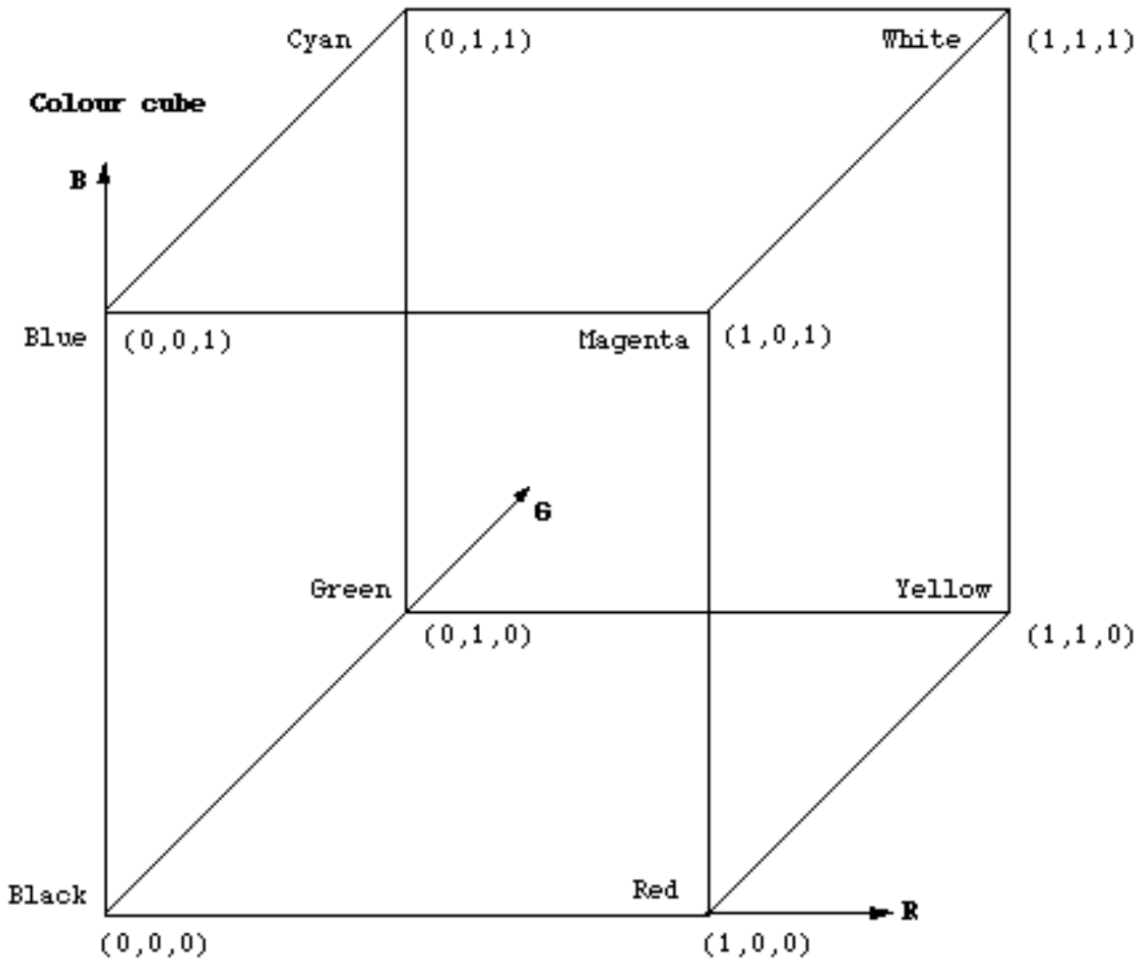
$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$



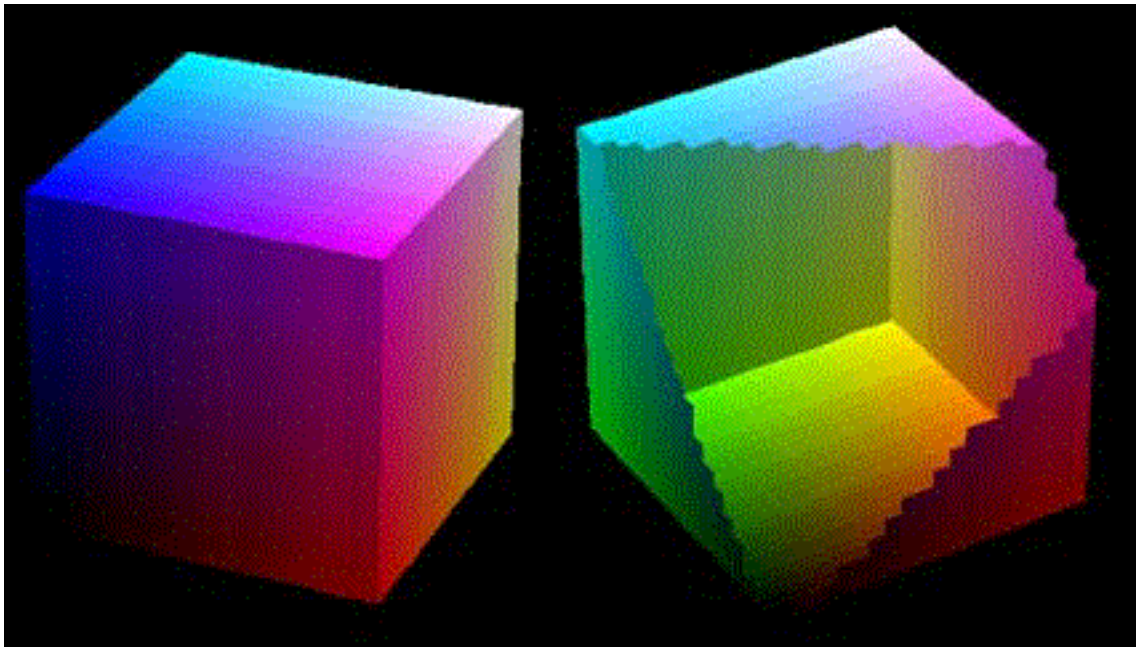
CHROMATICITY DIAGRAM



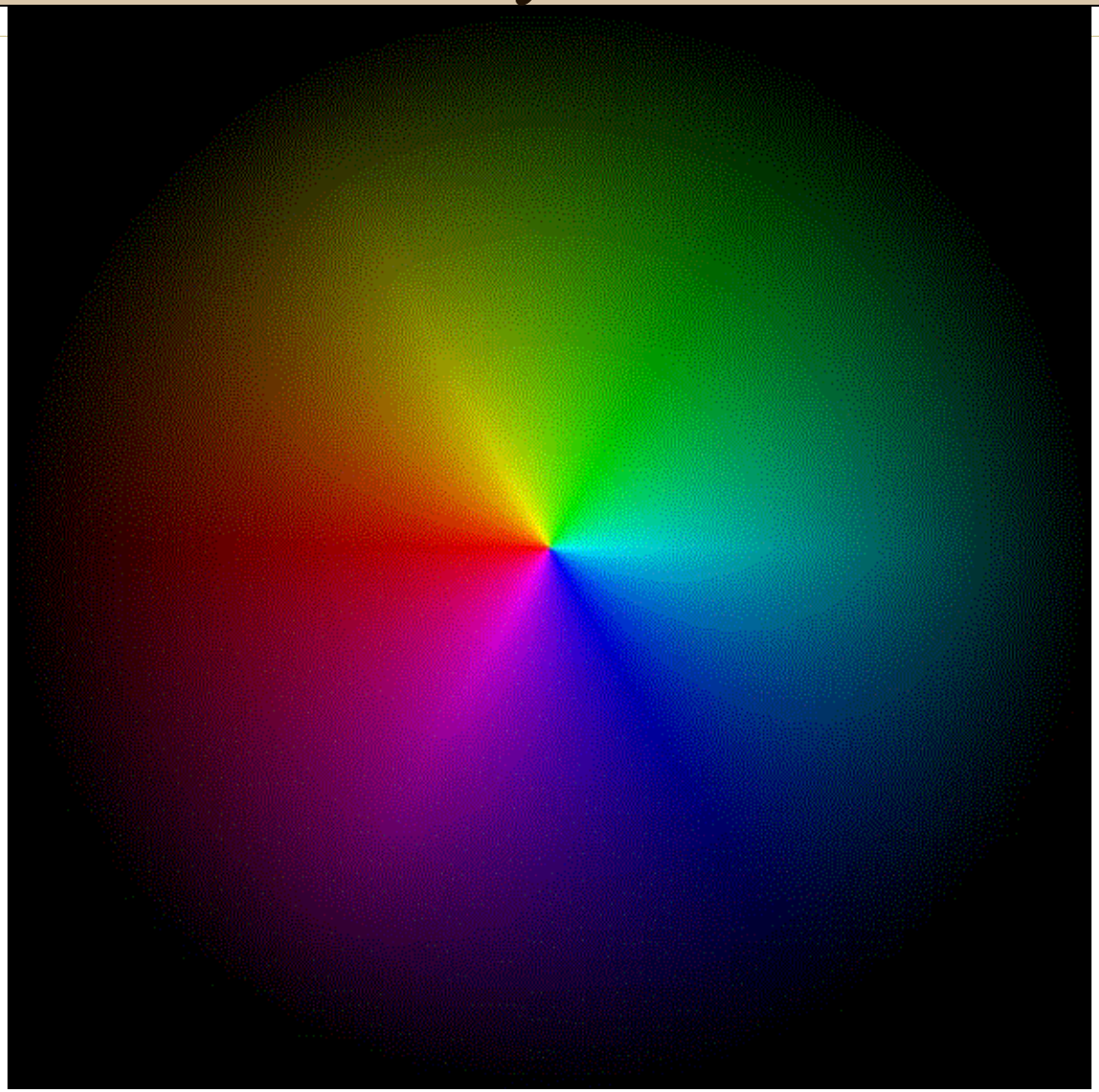
RGB Space


Colour cube
B
G
R
Cyan
(0,1,1)
White
(1,1,1)
Blue
(0,0,1)
Magenta
(1,0,1)
Green
(0,1,0)
Yellow
(1,1,0)
Black
(0,0,0)
Red
(1,0,0)

RGB Space



Hue Intensity Color Circle



Additive and Subtractive Colors

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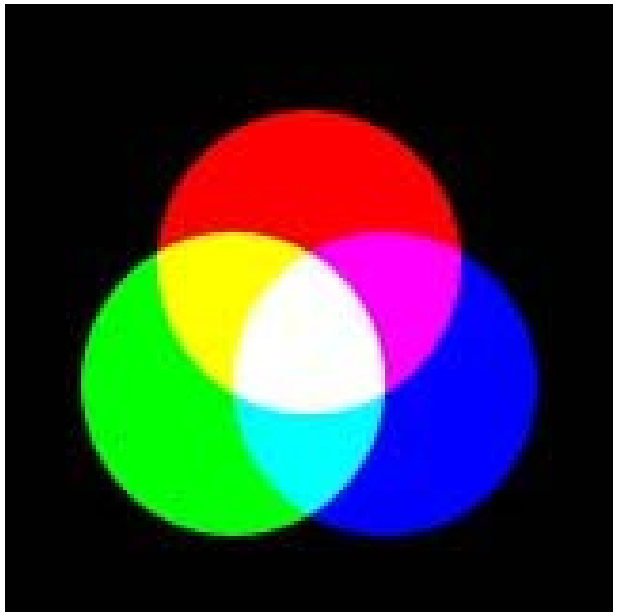
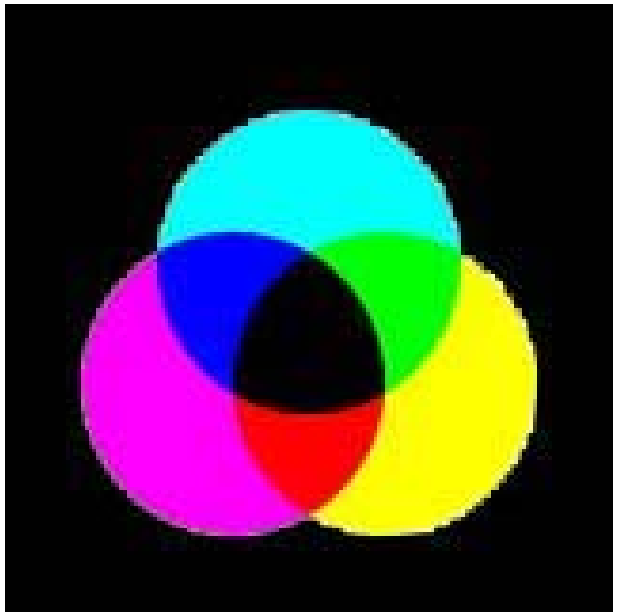




Color Space – YCbCr

- YCbCr
  - Used for: digital video encoding, digital camera
  - Y: luminacance
  - Cb: blue chroma
  - Cr: red chroma

Color Space – YCbCr

- Conversion from RGB:
  - Y=0.299(R-G) + G + 0.114(B-G)
  - Cb=0.564(B-Y)
  - Cr=0.713(R-Y)
- The Matrix form:

$$\begin{pmatrix} Y \\ Cb \\ Cr \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.168636 & 0.232932 & -0.064296 \\ 0.499813 & -0.418531 & -0.081282 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

RGB to YIQ & CMY Conversion

$$\begin{pmatrix} Y \\ I \\ Q \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ 0.595716 & -0.274453 & -0.321263 \\ 0.211456 & -0.522591 & 0.311135 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

Color Space – YUV

- YUV
  - Used for: video encoding for some standard such as NTSC, PAL, SECAM
- Axes:
  - Y: luma
  - U: blue chroma
  - V: red chroma

Color Space – CMYK

- Used for printers (subtractive color mixing)
  - Cyan
  - Magenta
  - Yellow
  - K: black

$C = 1 - R$

$M = 1 - G$

$Y = 1 - B$

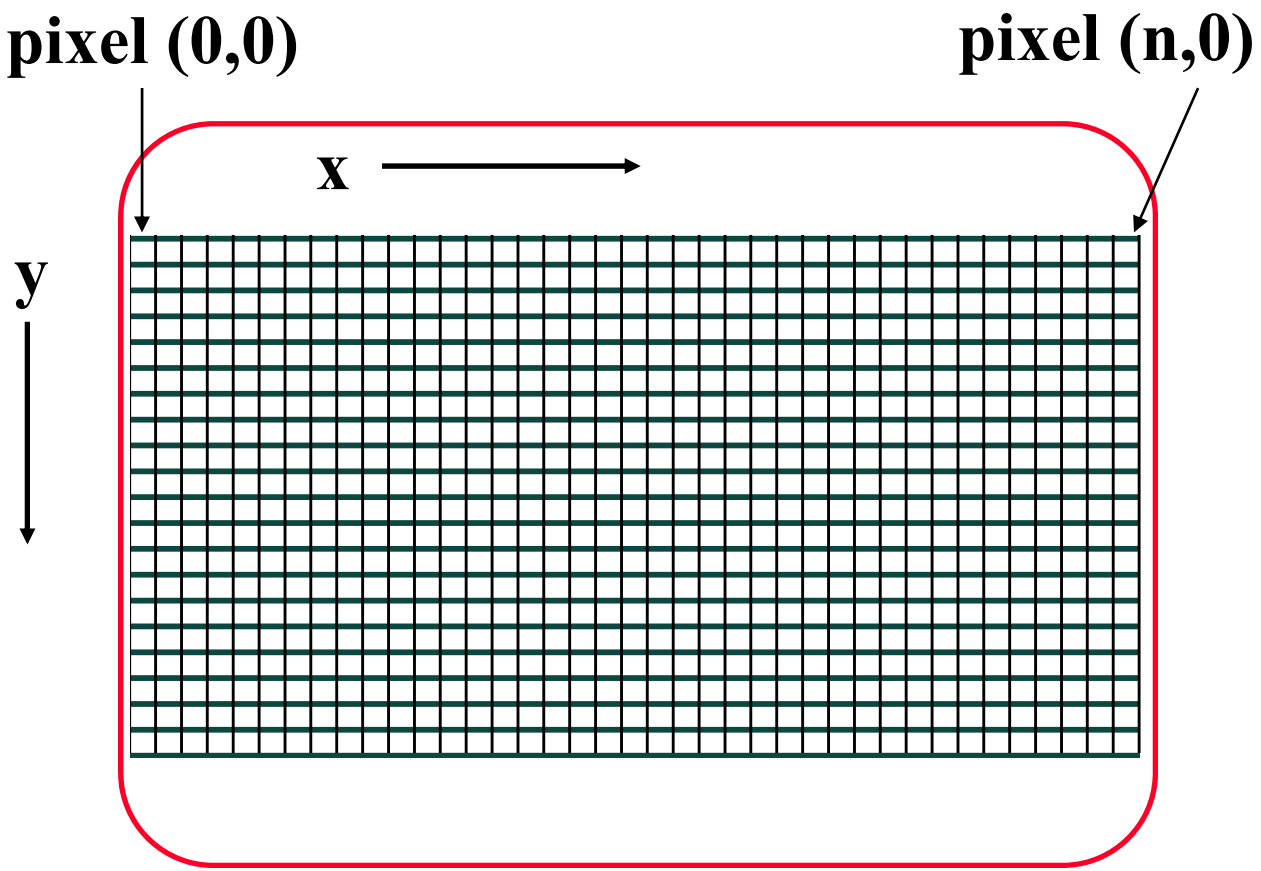
$K = \min(C, M, Y)$

Color Space – YUV

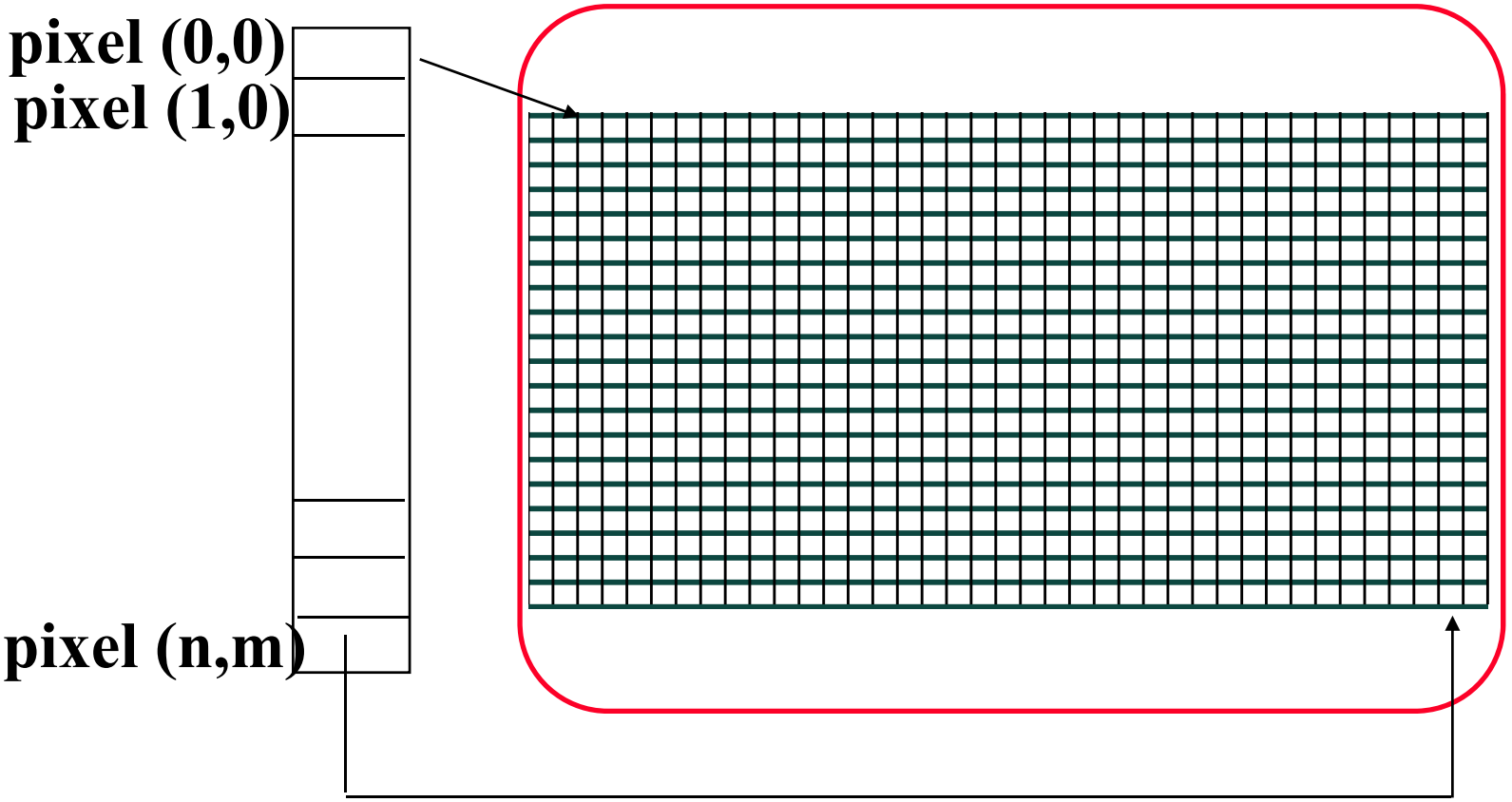
- Conversion from RGB:
  - Y=0.299R+0.587G+0.114B
  - U=0.436(B-Y)/(1-0.114)
  - V=0.615(R-Y)/(1-0.299)
- The Matrix form:

$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.14713 & -0.28886 & 0.436 \\ 0.615 & -0.51499 & -0.10001 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

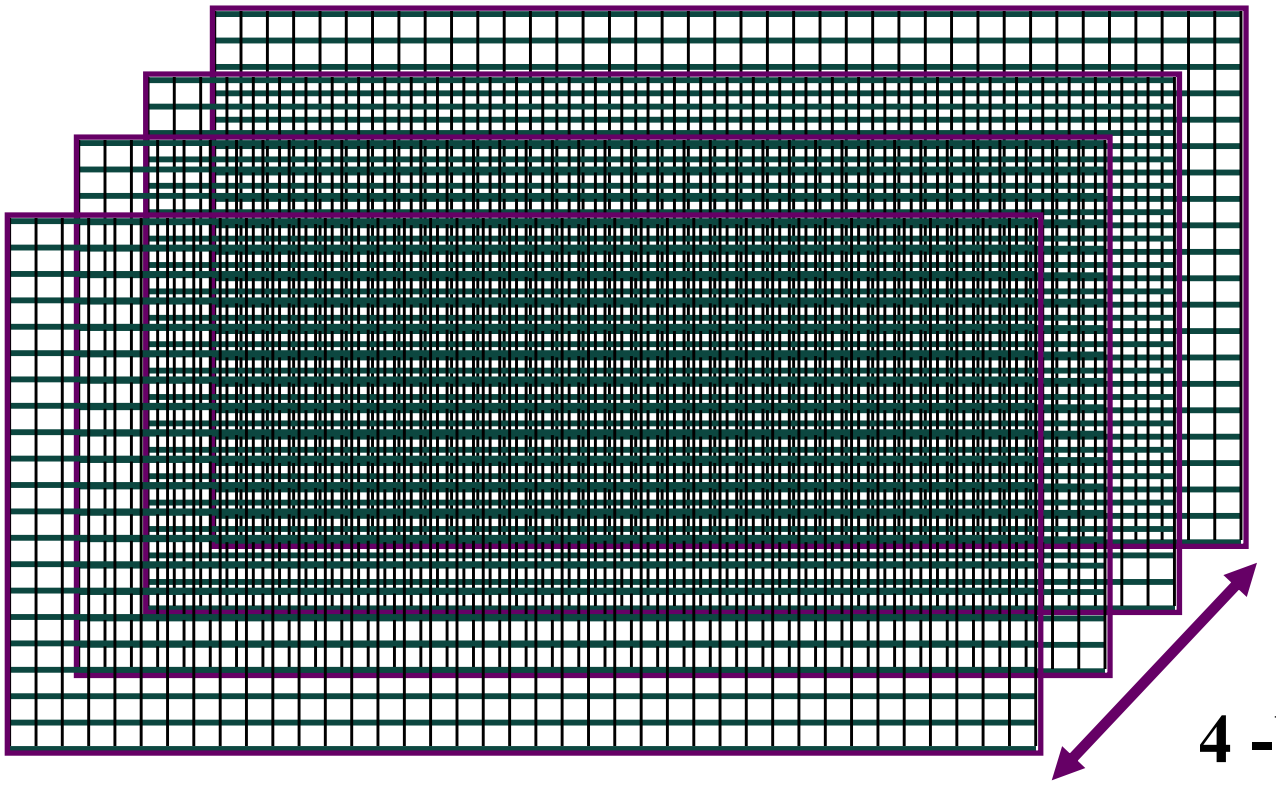
Screen



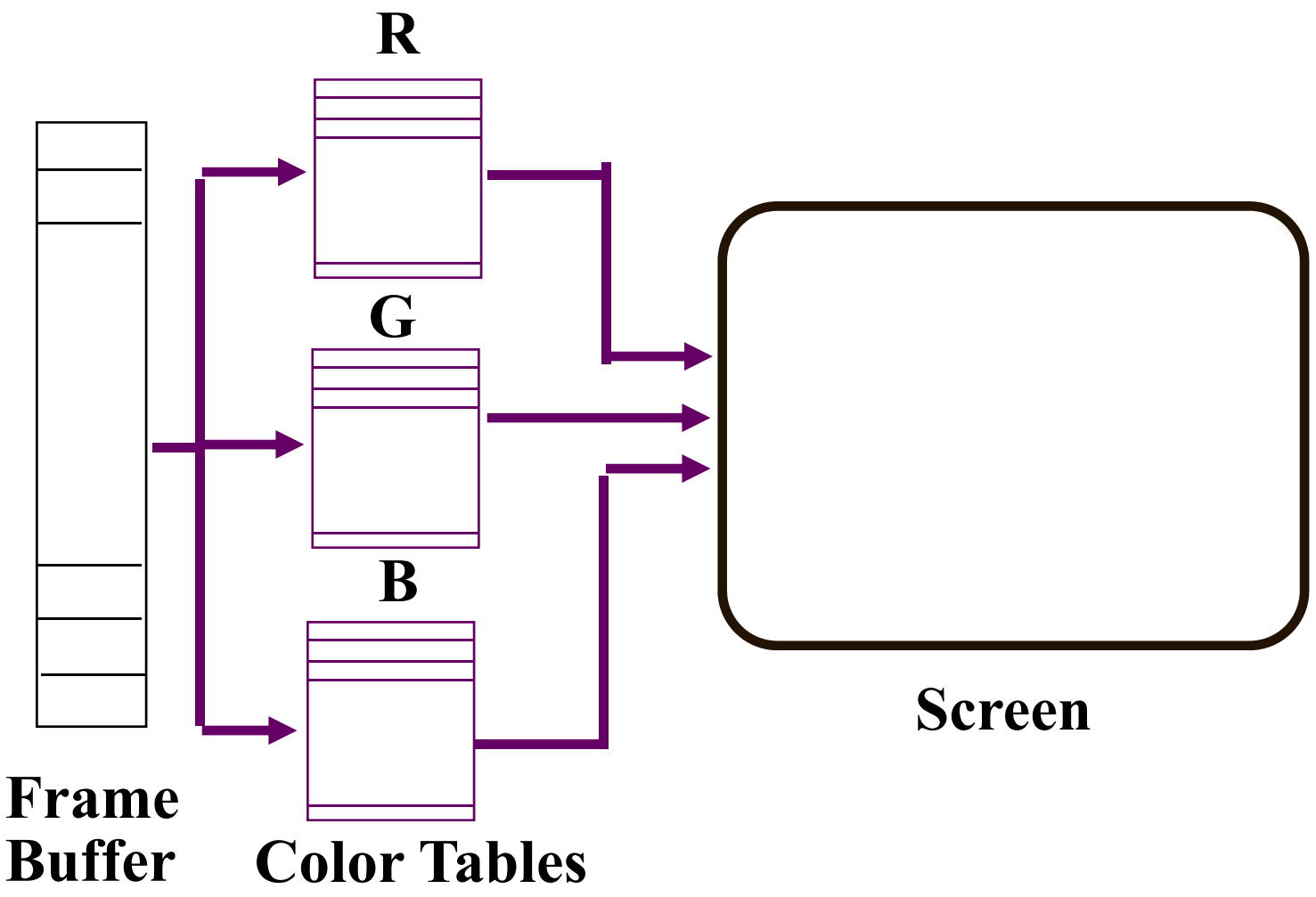
Frame Buffer



Bit Planes



Color Look-up Table



Direct Color Visual