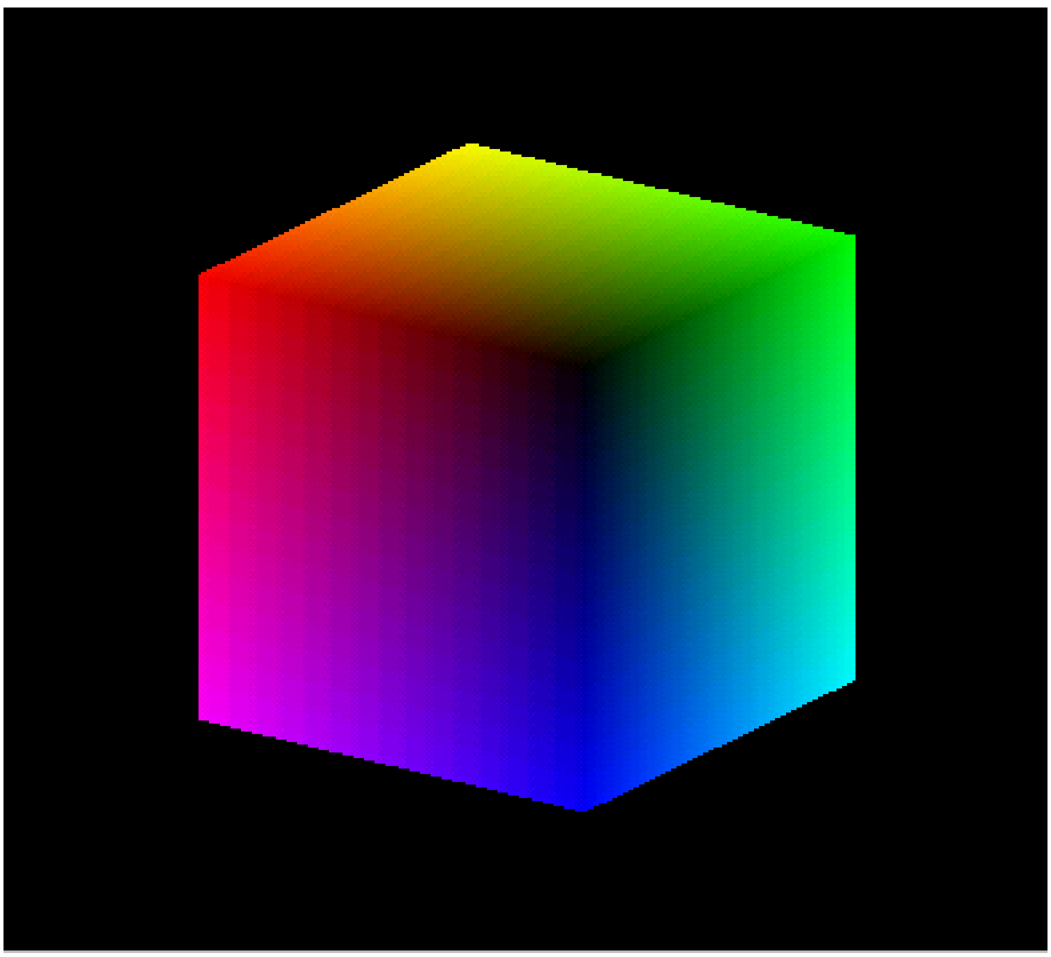
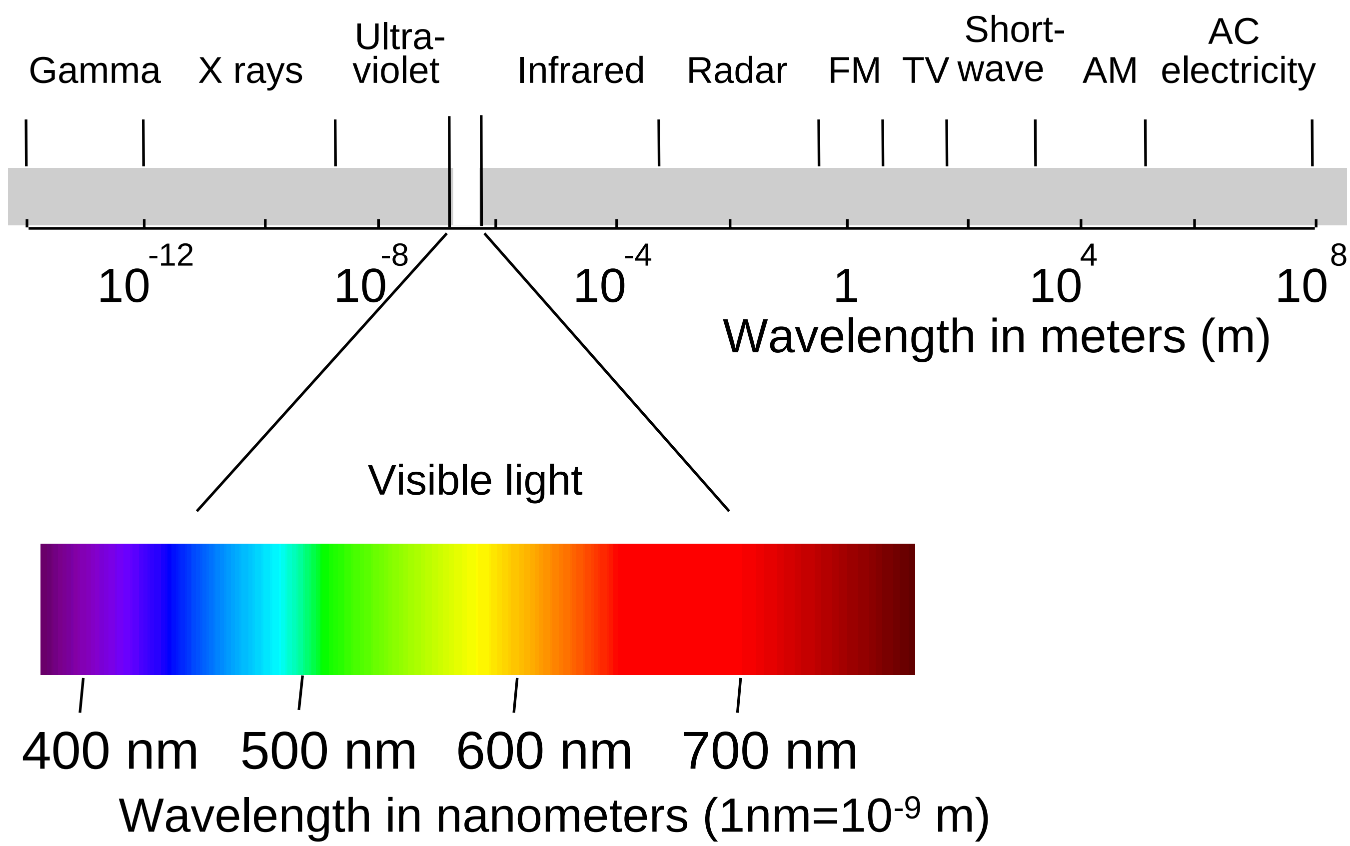
Color Representation

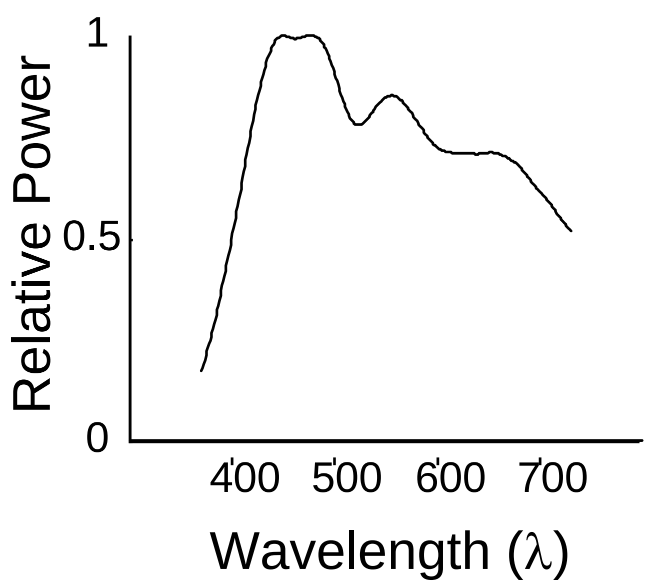


Electromagnetic Radiation - Spectrum

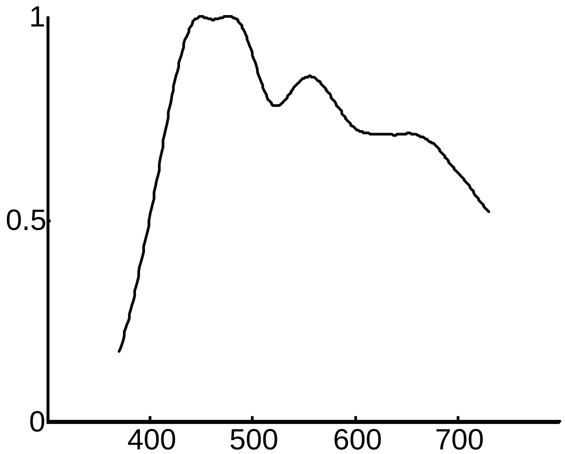


Spectral Power Distribution

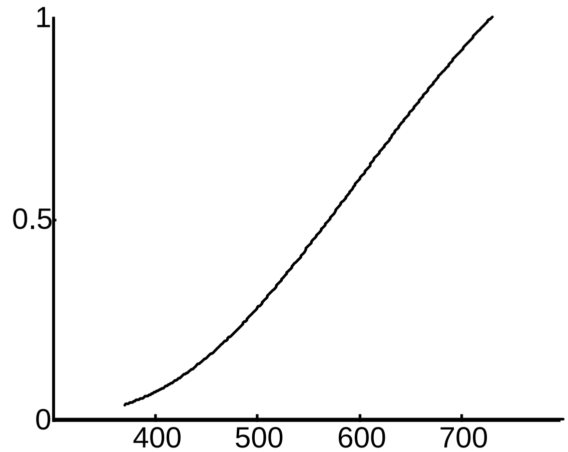
The **Spectral Power Distribution** (SPD) of a light is a function f(λ) which defines the energy at each wavelength.



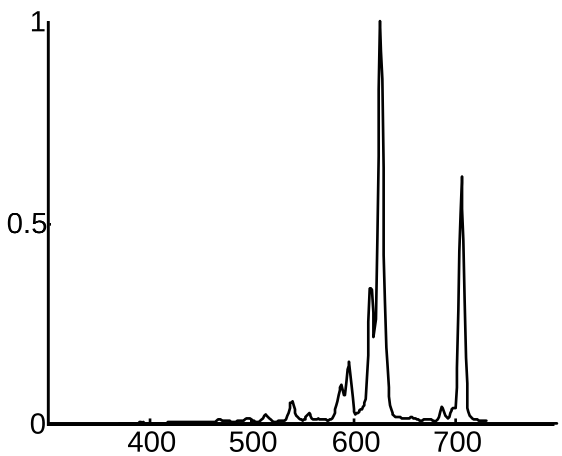
Examples of Spectral power Distributions



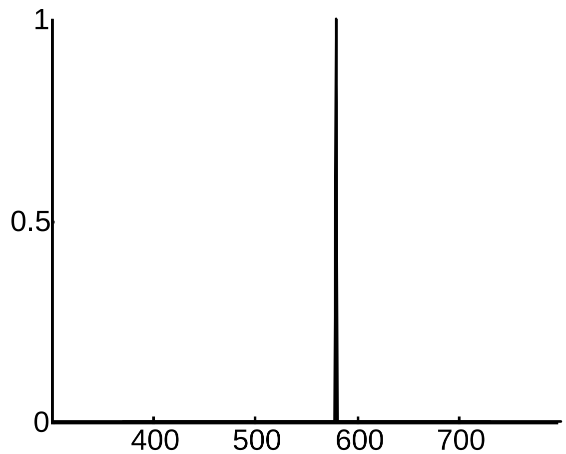
Blue Skylight



Tungsten bulb



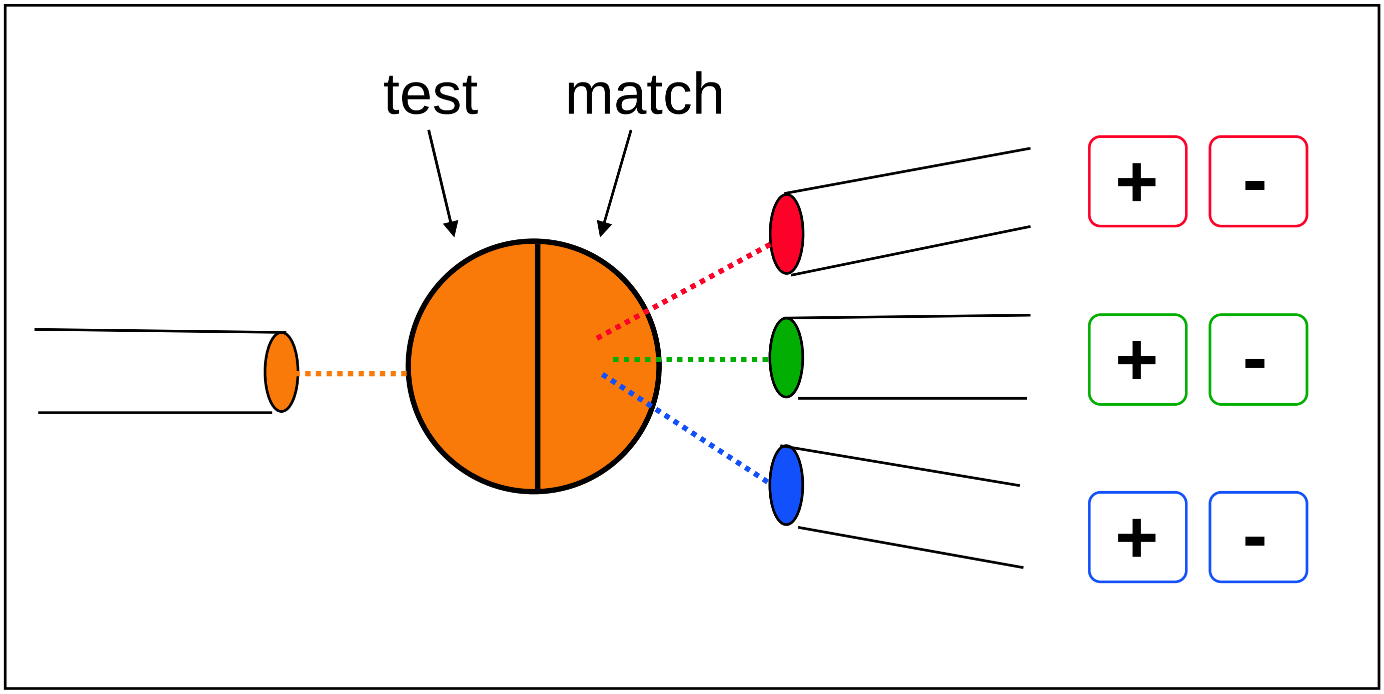
Red monitor phosphor

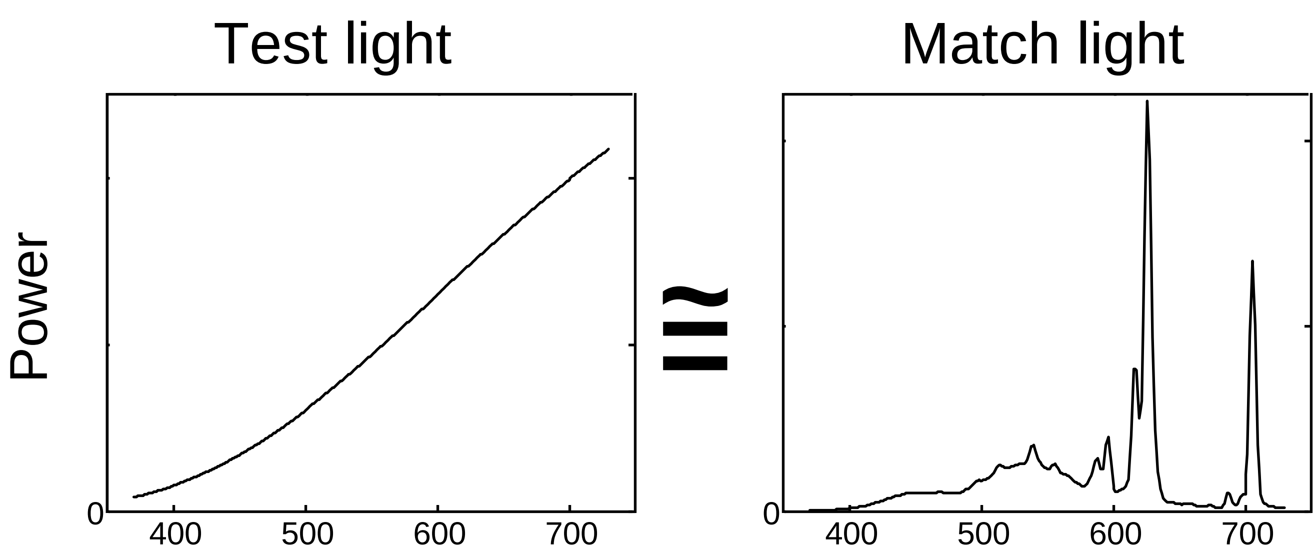


Monochromatic light

Color Matching Experiment

Three primary lights are set to match a test light.





Metamer - two lights that appear the same visually. They might have different SPDs (spectral power distributions).

Trichromatic Color Theory

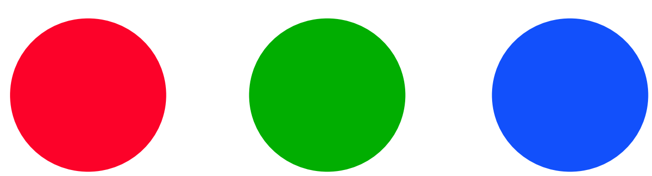
"tri"=three "chroma"=color
color vision is based on three primaries
(i.e., it is 3 dimensional).

Thomas Young (1773-1829) -

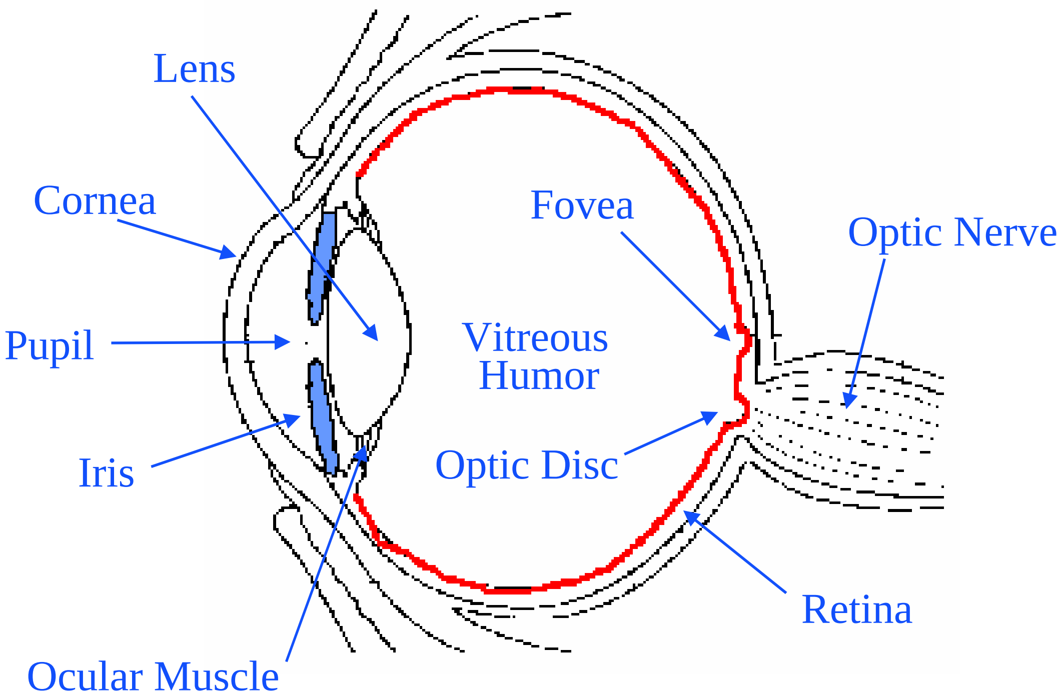
A few different retinal receptors operating with different wavelength sensitivities will allow humans to perceive the number of colors that they do.
Suggested 3 receptors.

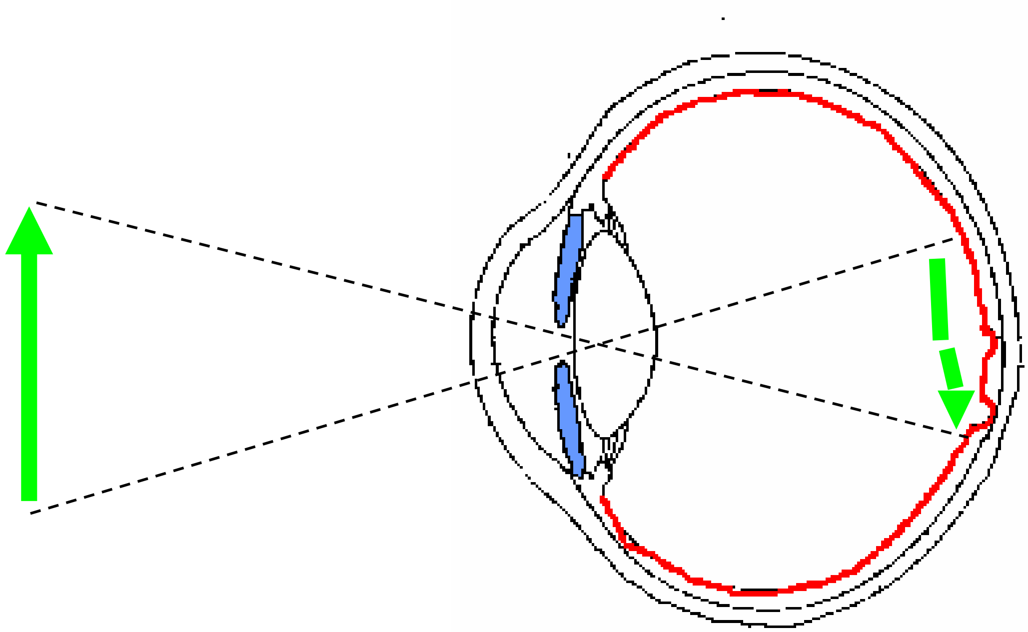
Helmholtz & Maxwell (1850) -

Color matching with 3 primaries.

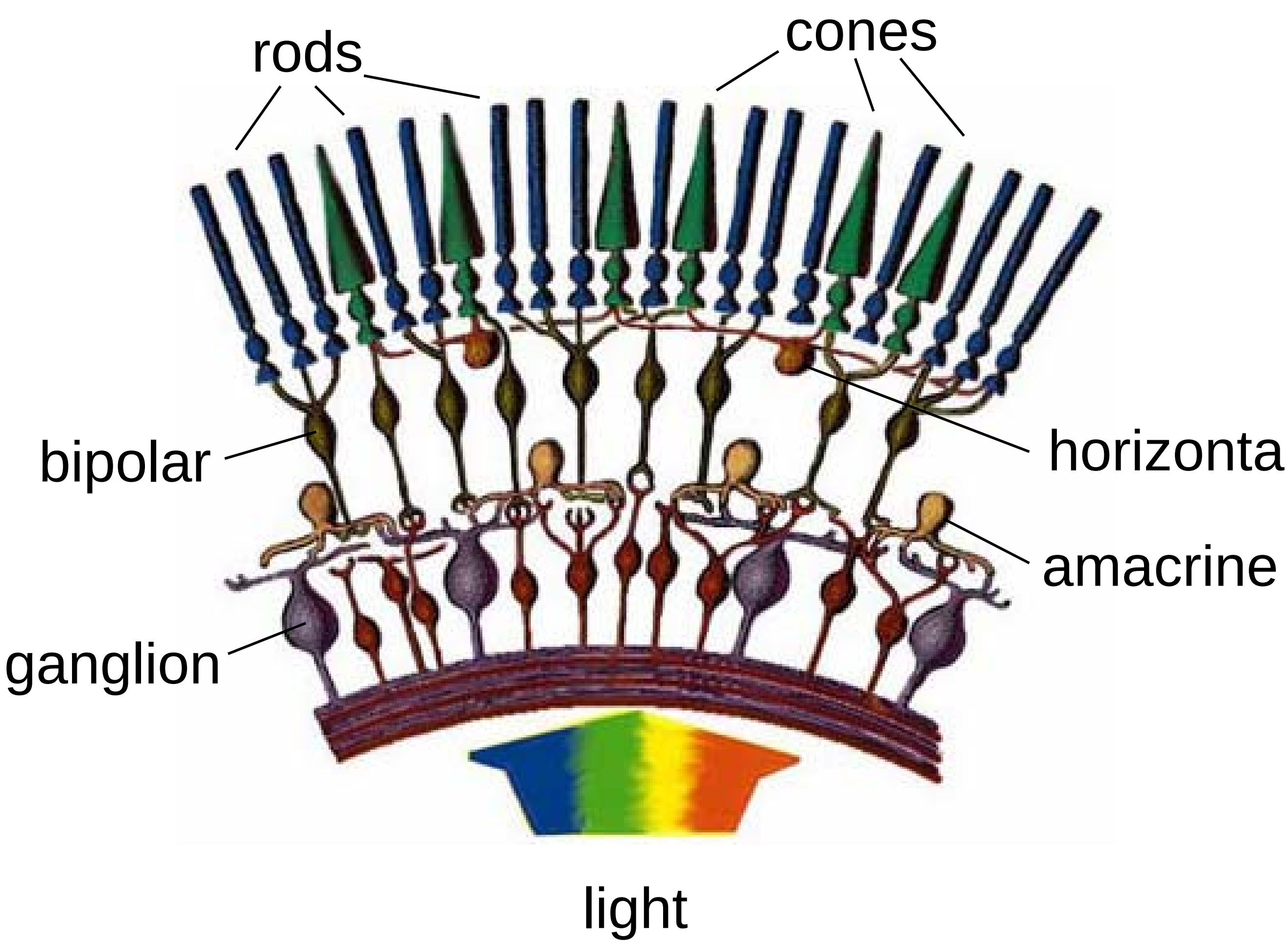


The Human Eye





The Human Retina

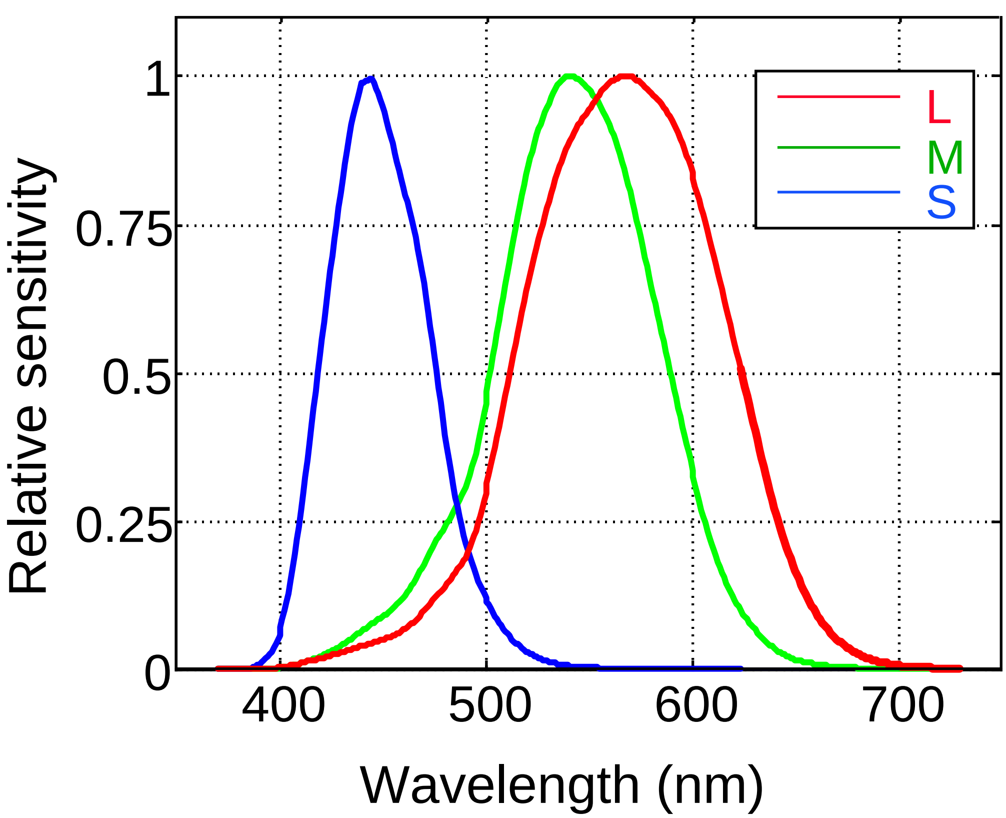


Retinal Photoreceptors

Cones -

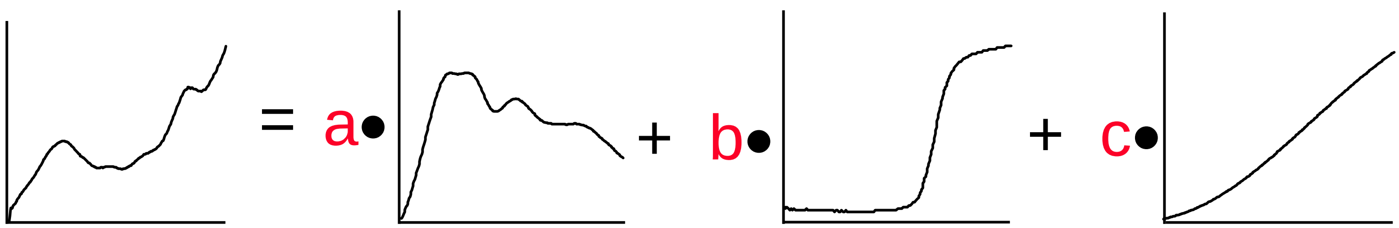
- High illumination levels (Photopic vision)
- Less sensitive than rods.
- 5 million cones in each eye.
- Only cones in fovea (aprox. 50,000).
- Density decreases with distance from fovea.
- 3 cone types differing in their spectral sensitivity: L , M, and S cones.

Cone Spectral Sensitivity



Linear Color Spaces

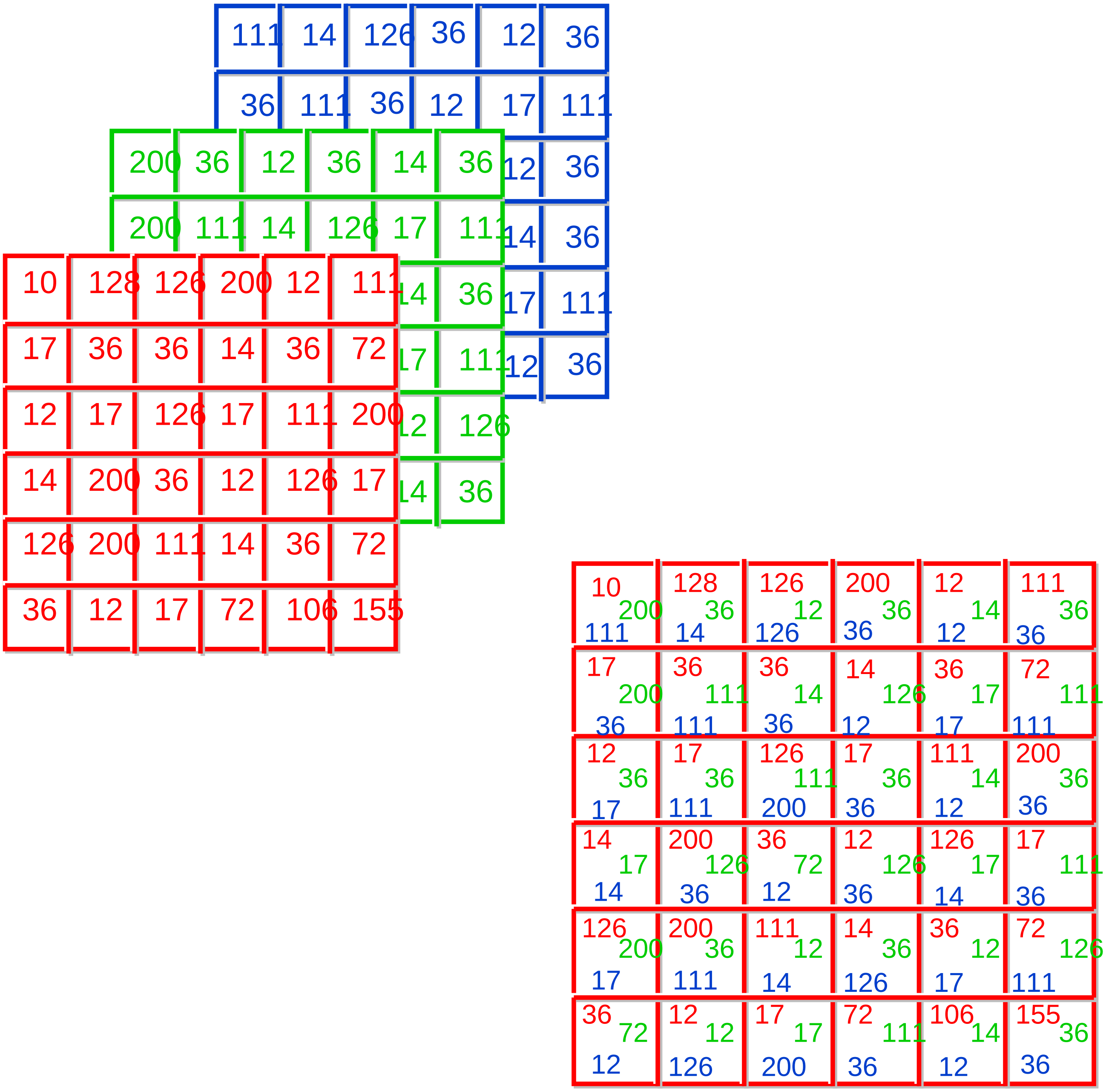
Colors in 3D color space can be described as linear combinations of 3 basis colors: primaries



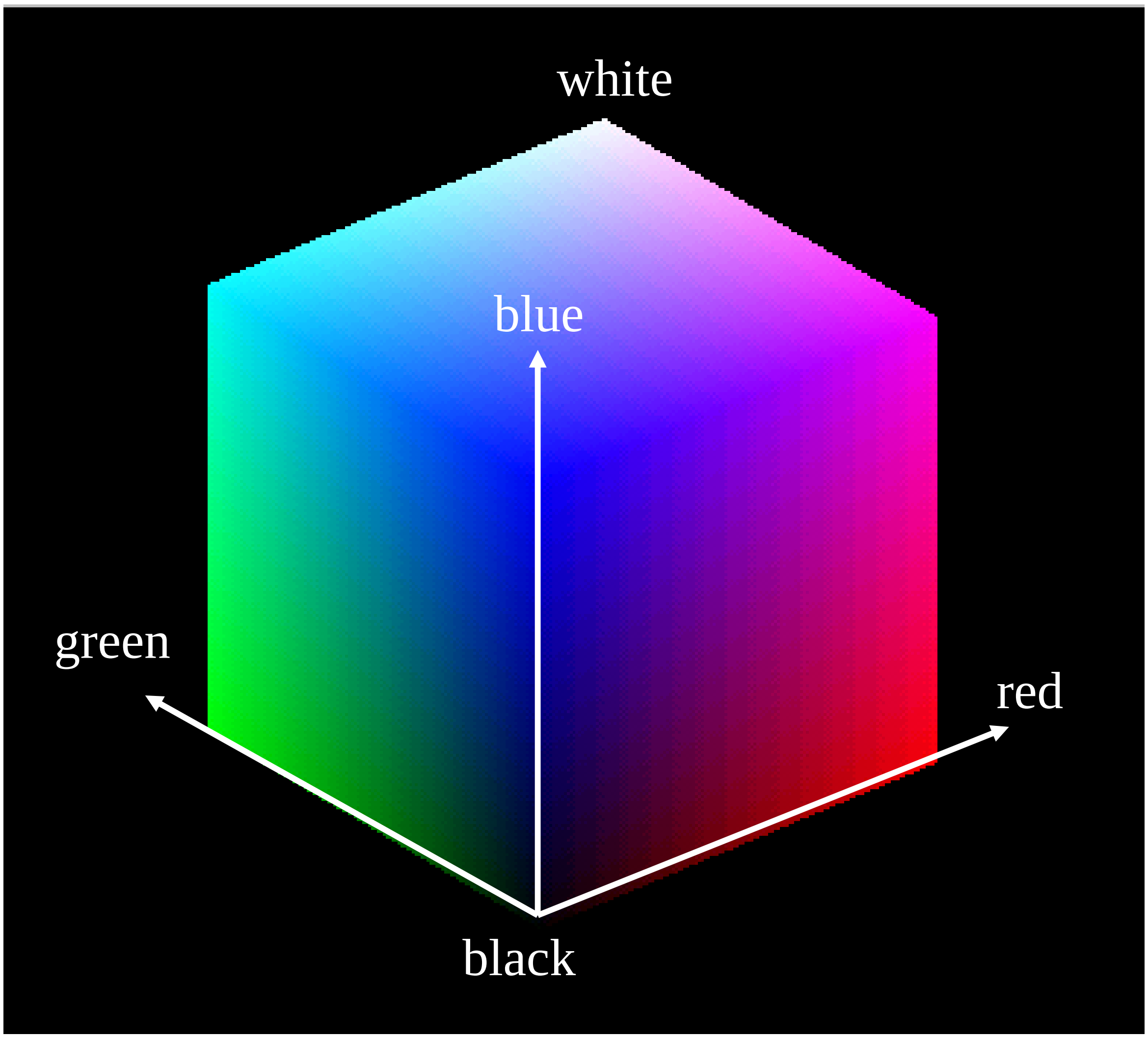
The representation of :

is then given by: (a, b, c)

Rgb Image


10 128 126 200 12 111
17 36 36 14 36 72
12 17 126 17 111 200
14 200 36 12 126 17
126 200 111 14 36 72
36 12 17 72 106 155

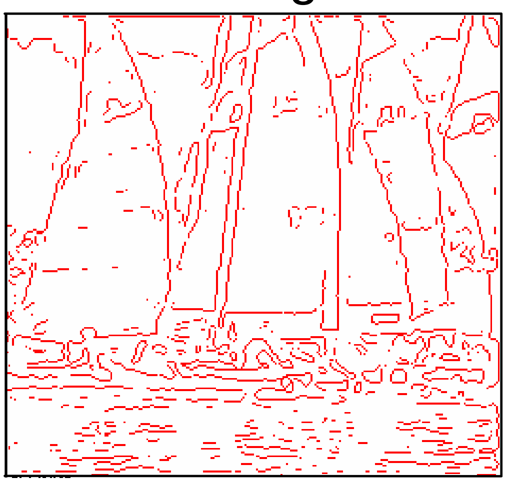
The RGB Cube



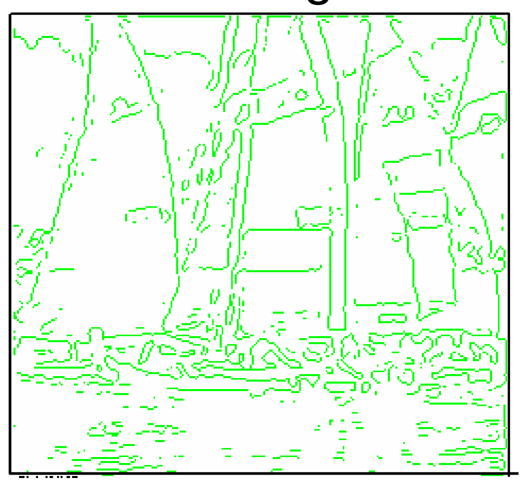
Color Edge Detection

Original

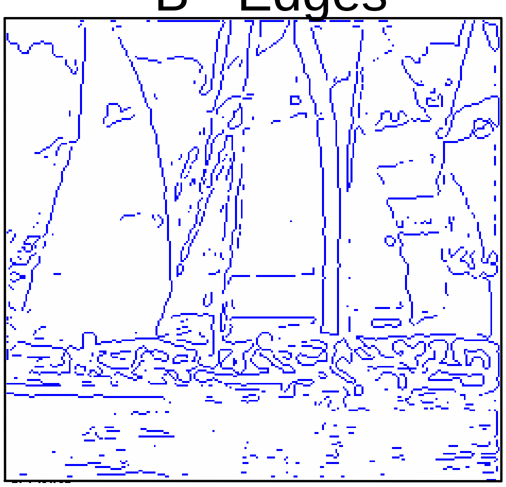
R - Edges



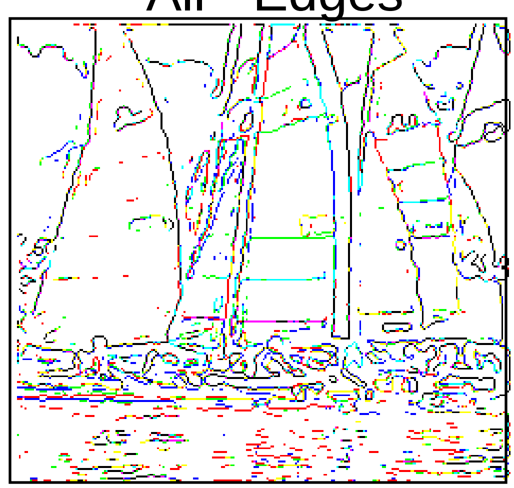
G - Edges



B - Edges



All - Edges



Color Edge Detection

Original

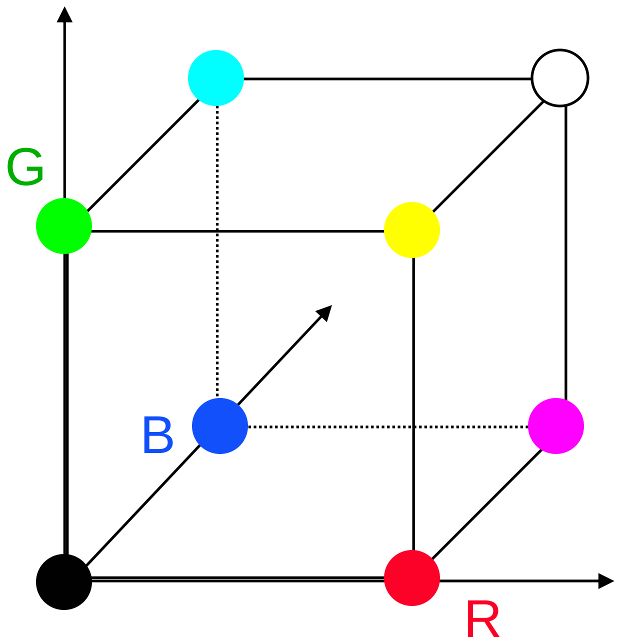
R - Edges

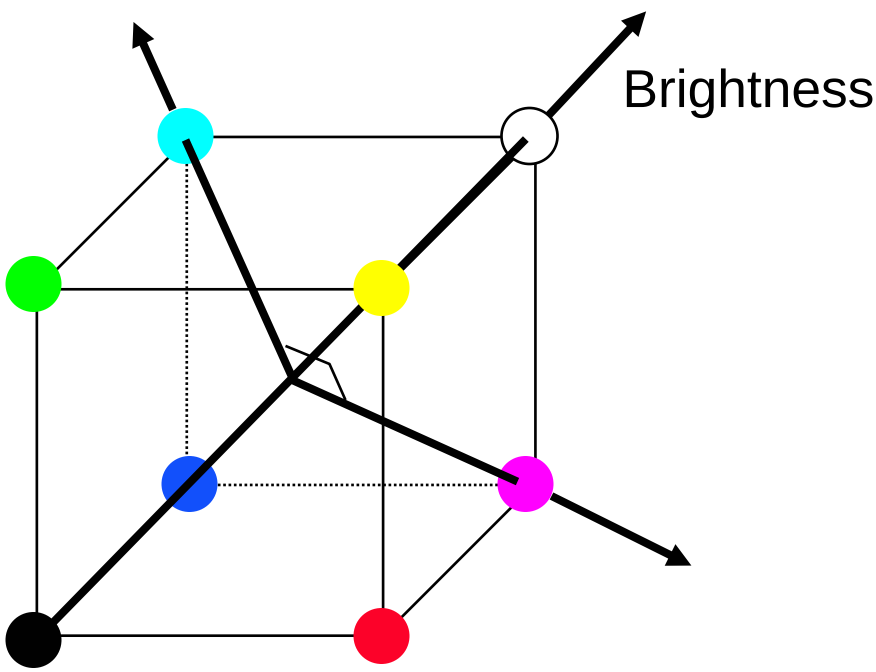
G - Edges

B - Edges

All - Edges

RGB Color Cube

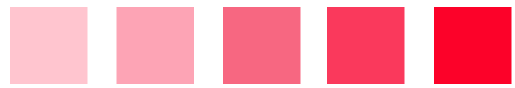




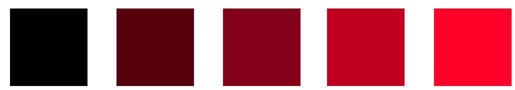
Color Description

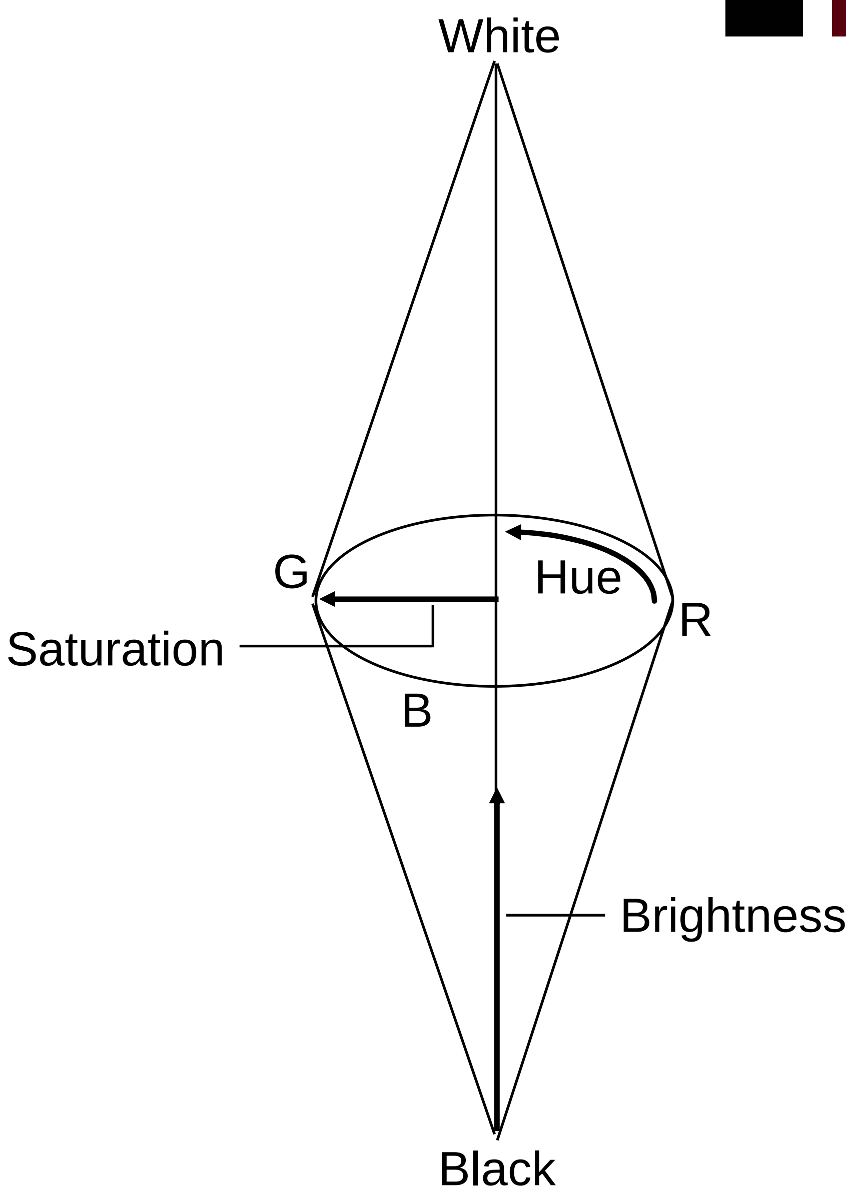
Hue (red, green, yelow, blue ...)

Saturation (pink,bright red, ...)

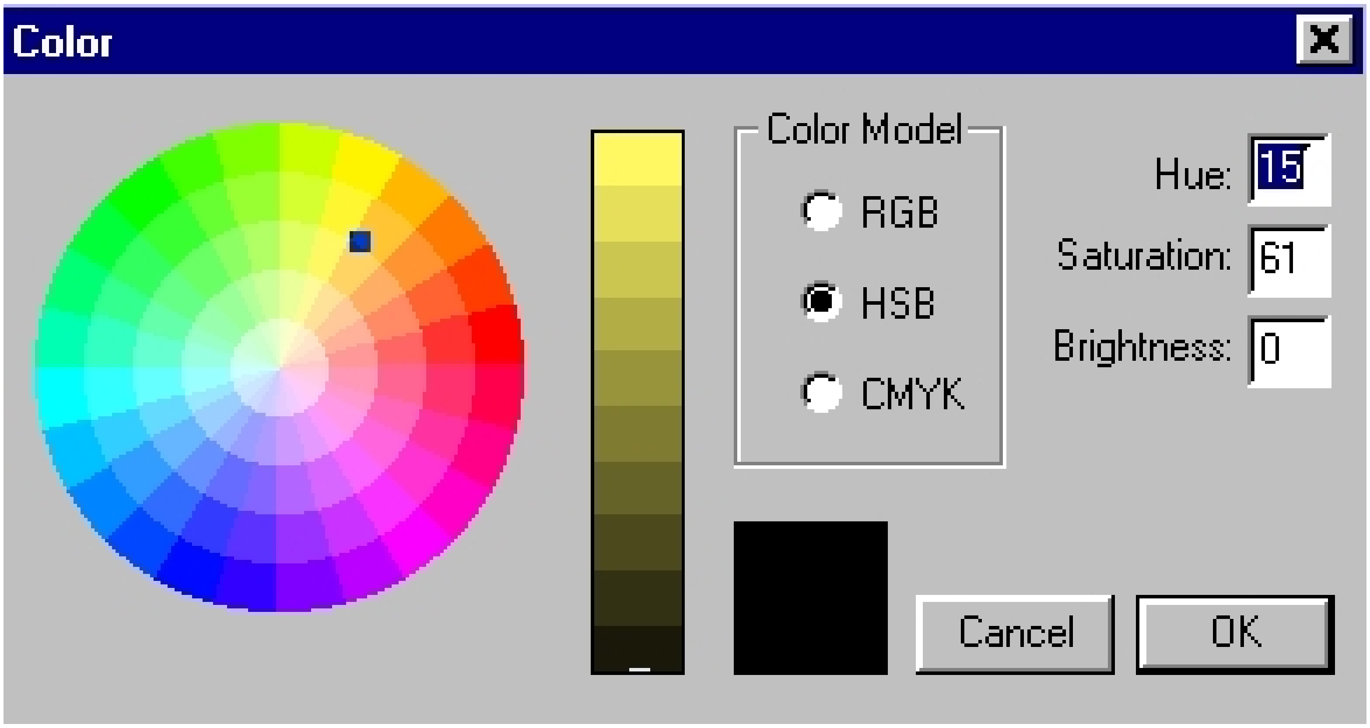


Lightness (black, grey, white ....)



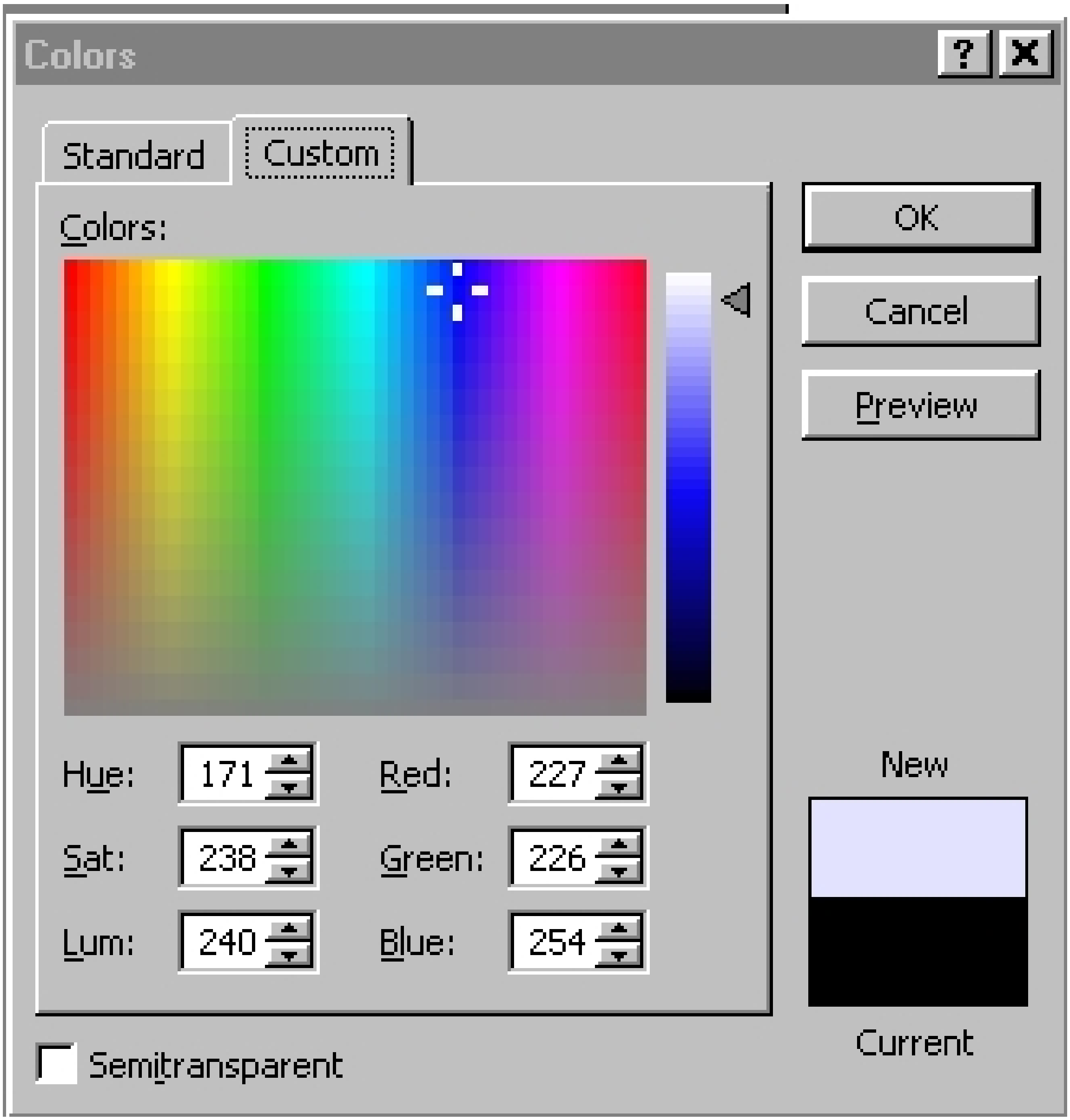


MayuraDraw

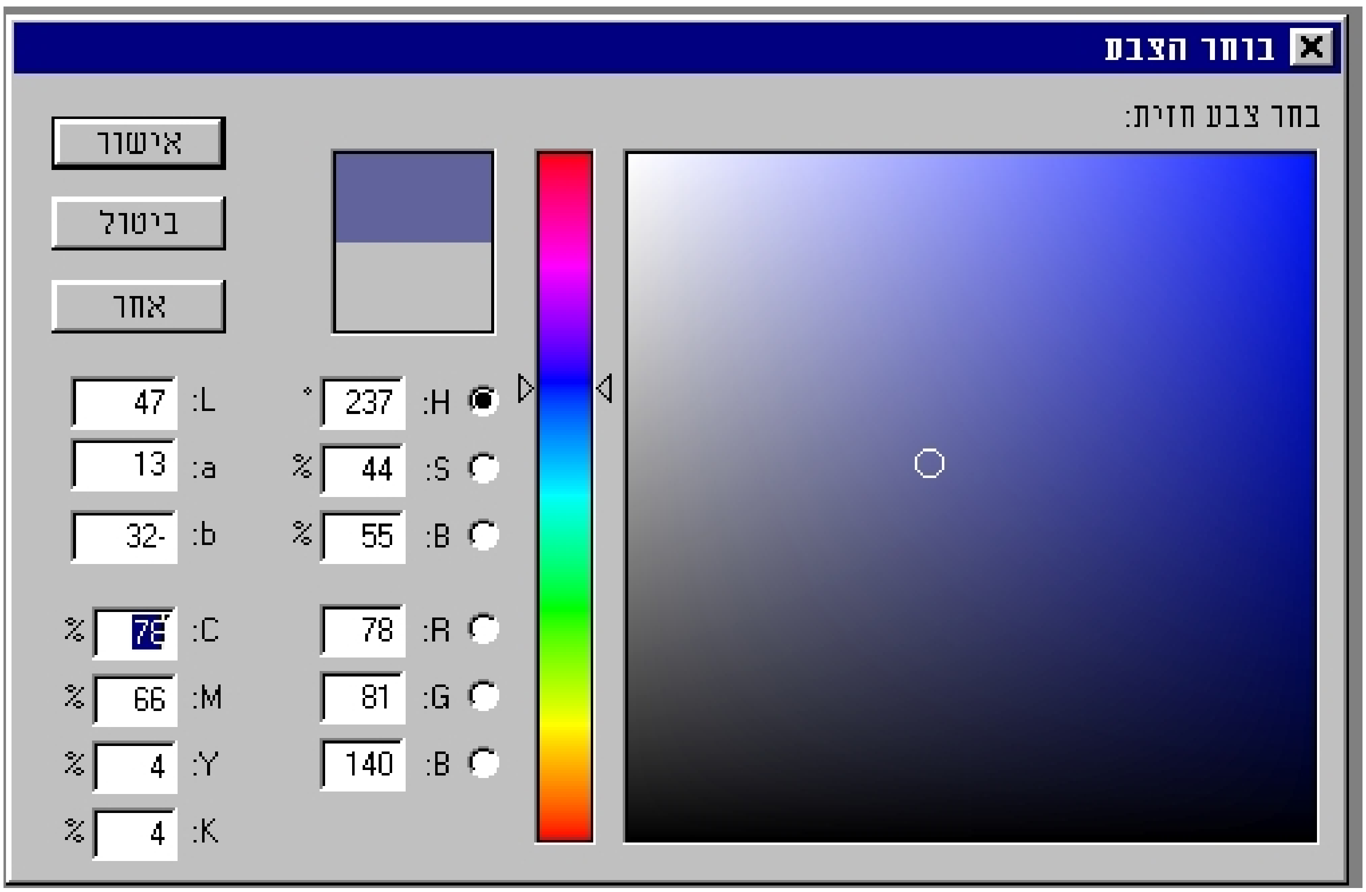


Color
Color Model
RGB
HSB
CMYK
Hue:
15
Saturation:
61
Brightness:
0
Cancel
OK

PowerPoint


Colors
?
Standard
Custom
Colors:
OK
Cancel
Preview
Hue:
171
Red:
227
Sat:
238
Green:
226
Lum:
240
Blue:
254
New
Current
Semitransparent

PhotoShop



בוחר הצבע
בחר צבע חזית:
אישור
ביטול
אחר
L: 47
a: 13
b: 32-
C: 78 %
M: 66 %
Y: 4 %
K: 4 %
H: 237 °
S: 44 %
B: 55 %
R: 78
G: 81
B: 140

YIQ - Color Space

NTSC = National Television Systems Committee

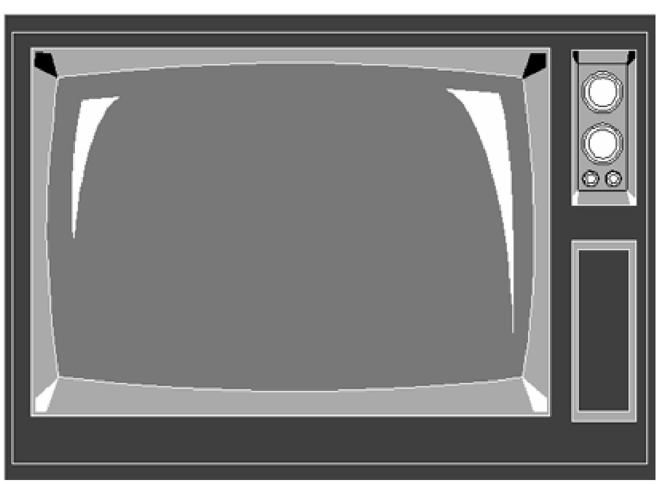
Y = luminance

I = red-green

Q = blue-yellow

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.177 & 0.813 & 0.011 \\ 0.540 & -0.263 & -0.174 \\ 0.246 & -0.675 & 0.404 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

R G B are the CIE-RGB



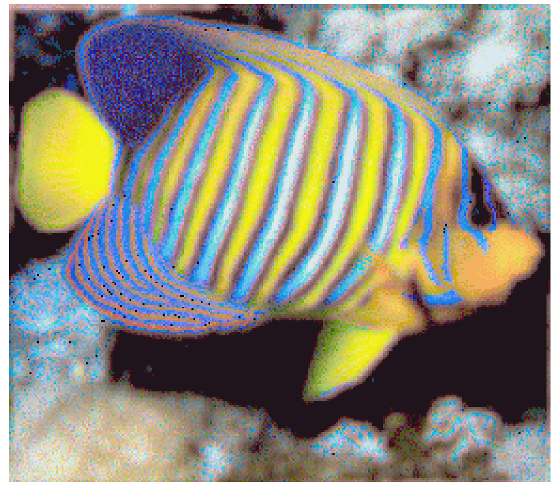
RGB To Monochrome

RGB

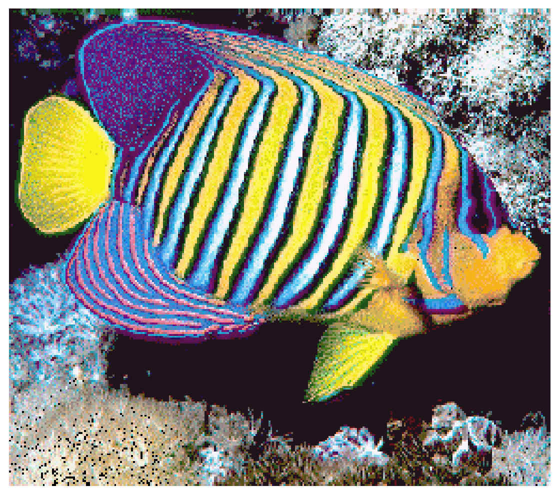
Y

Original

Y - Blur



I - Blur

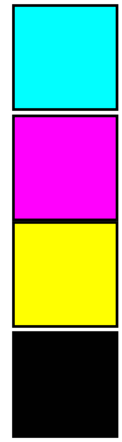


Q - Blur

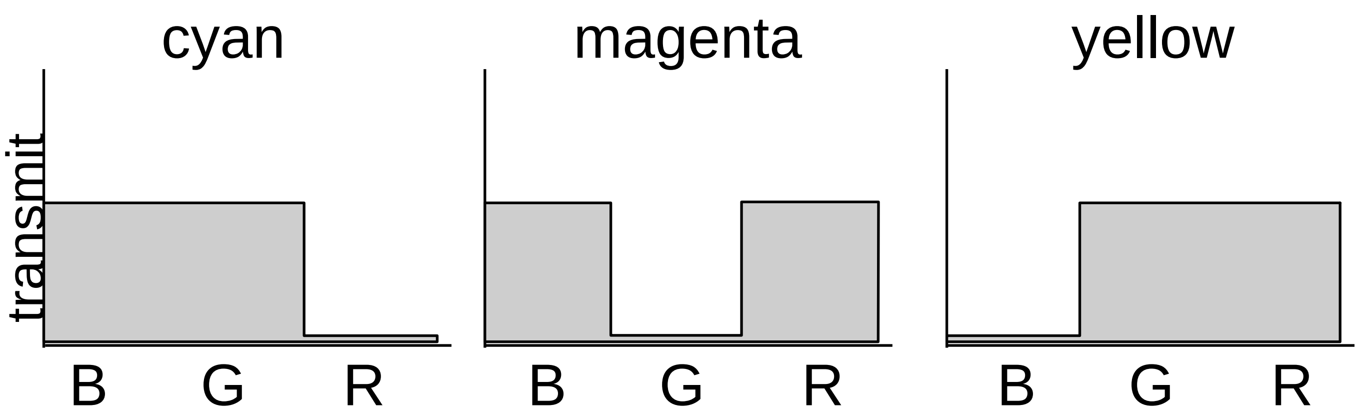
Subtractive Color System - CMYK

Printer Dyes:

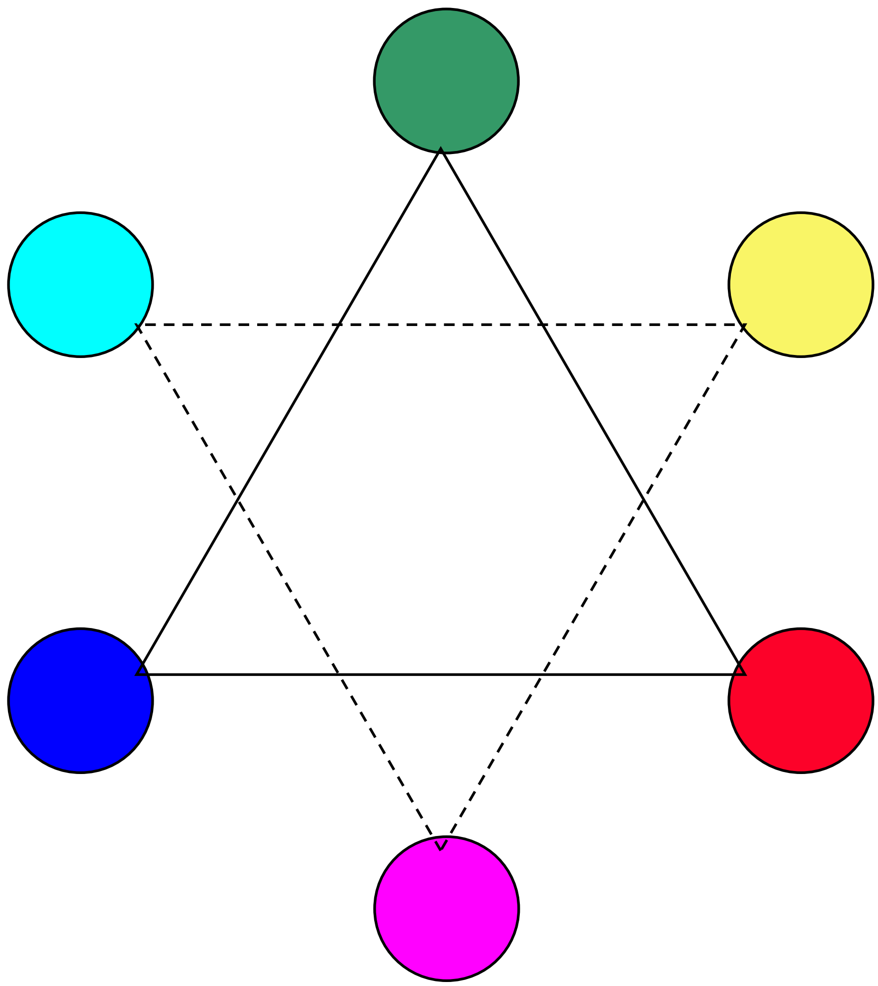
Cyan	= removes red
Magenta	= removes green
Yellow	= removes blue
blacK	= removes all



Ideal block dyes:



Opponent Color Wheel

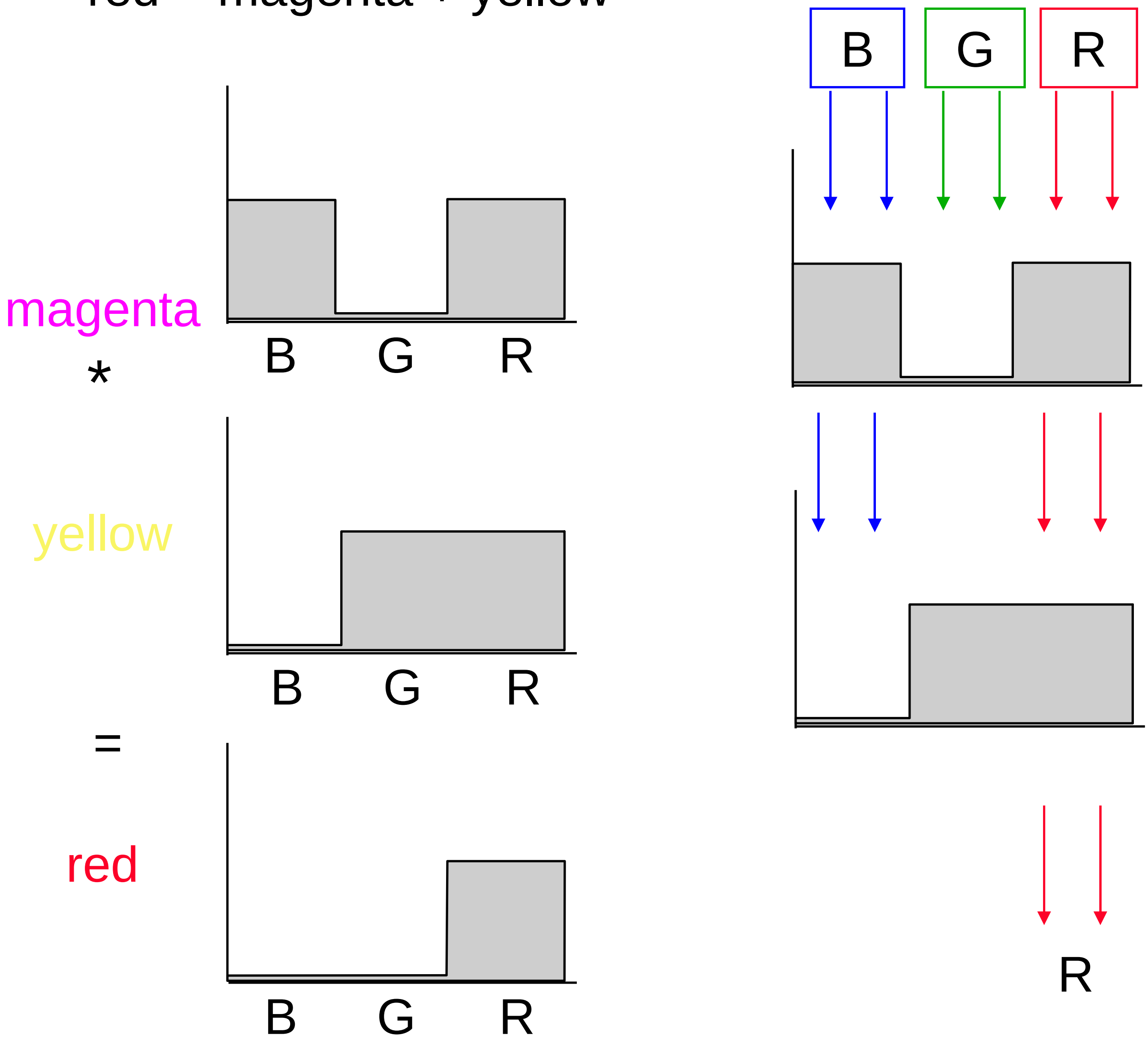


Additive primaries

Subtractive Primaries

Multiplicative (Subtractive) Color System

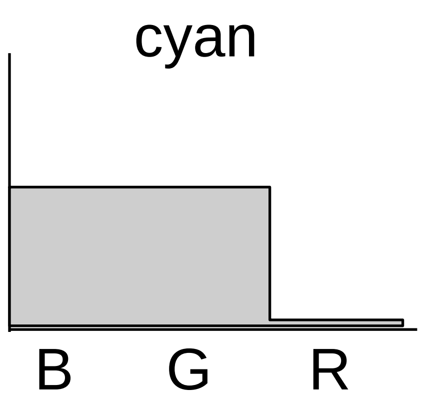
red = magenta + yellow

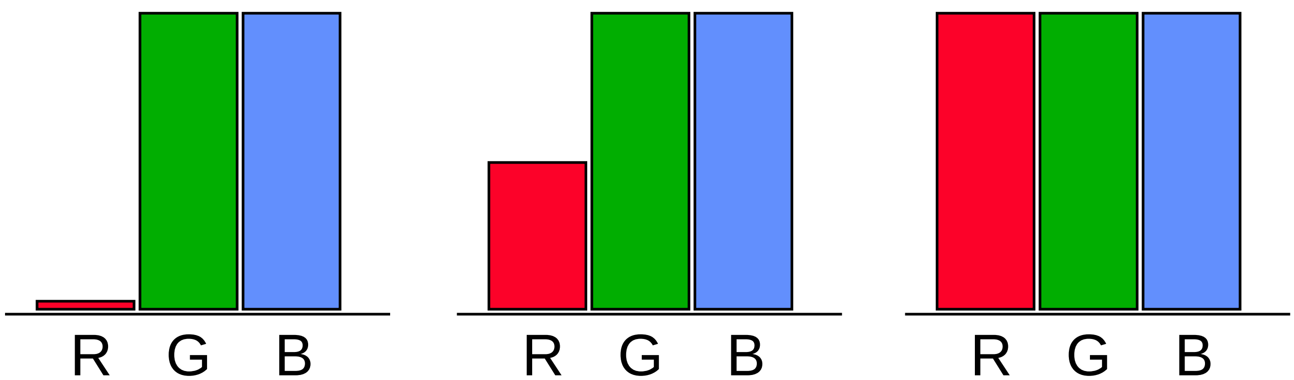


red = magenta + yellow
green = cyan + yellow
blue = magenta + cyan

Cyan - controls amount of red in print:

low C = high R (also high G and B)
high C = low R (high G and B)

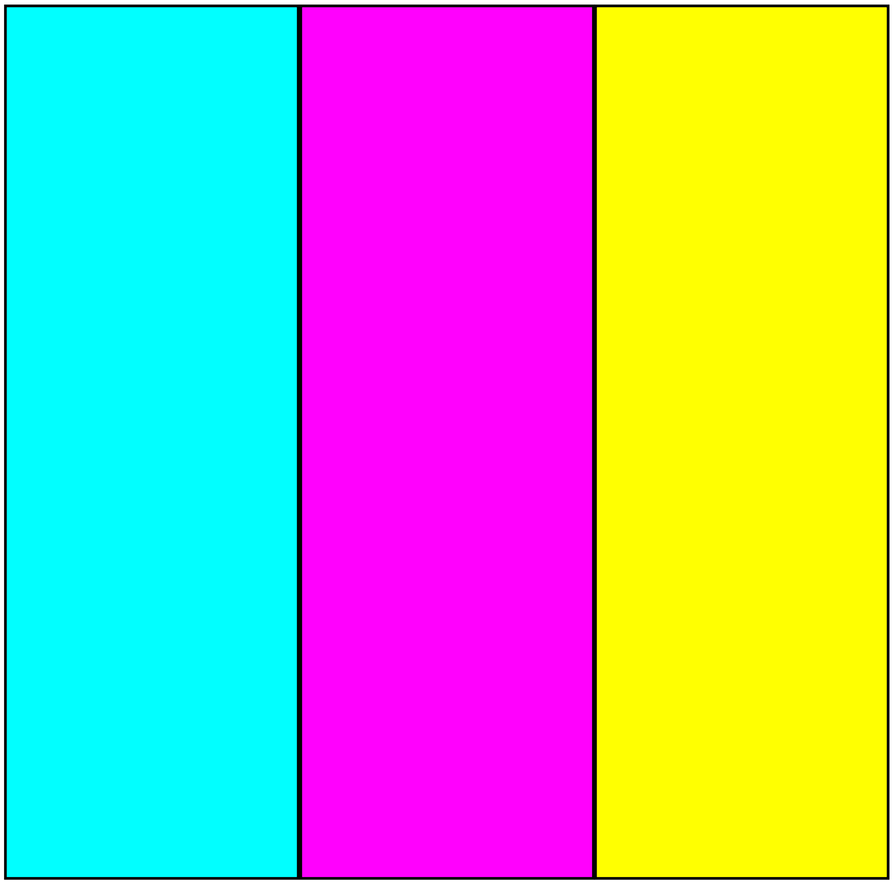


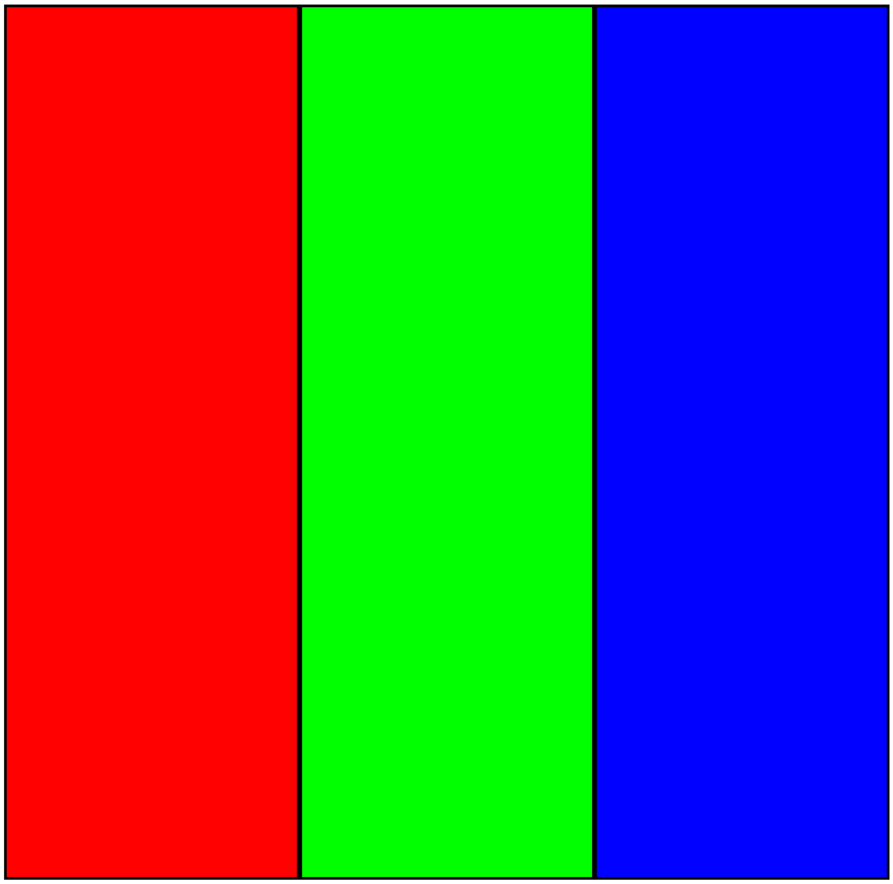


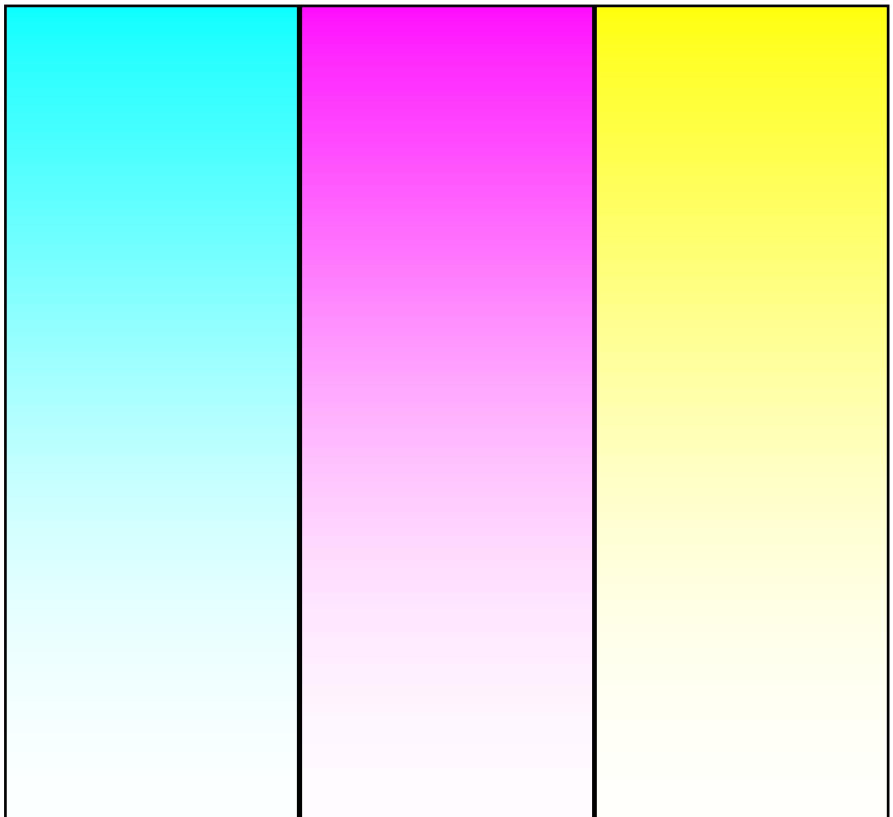
High density cyan

Medium density cyan

Low density cyan





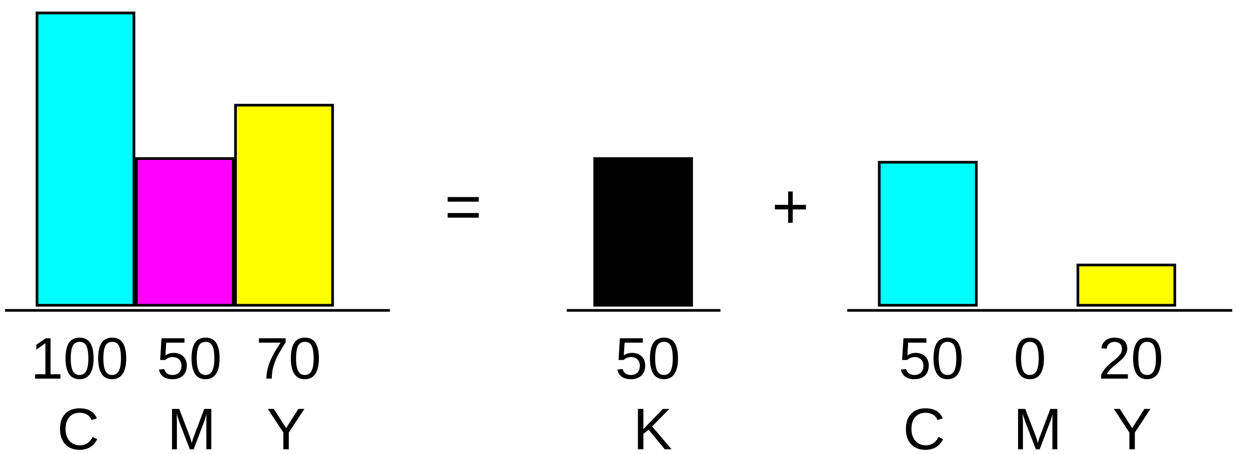


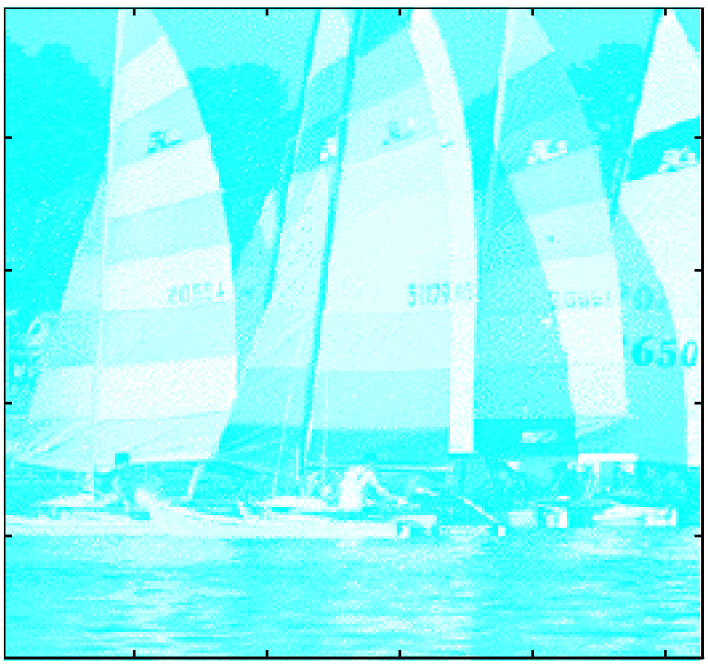
CMY + Black

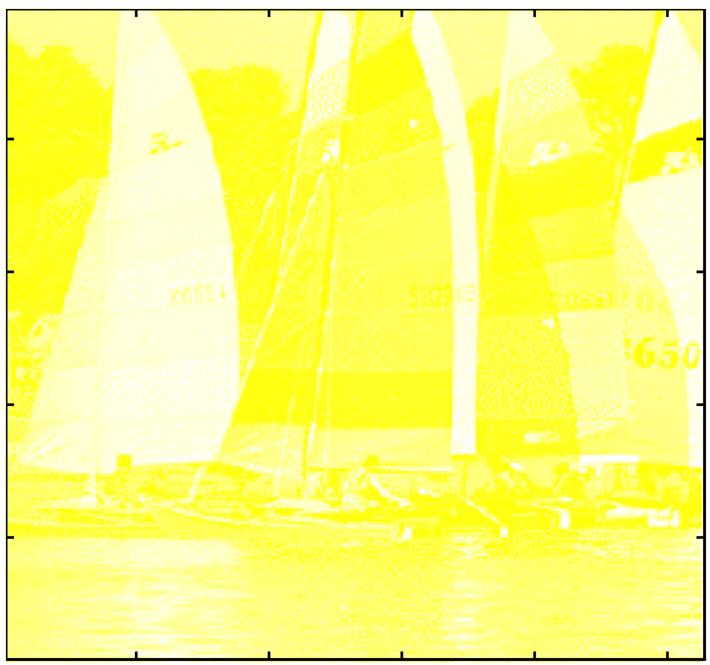
C + M + Y = K (black)

- Using three inks for black is expensive
- C+M+Y = dark brown not black
- Black instead of C+M+Y is crisper with more contrast.

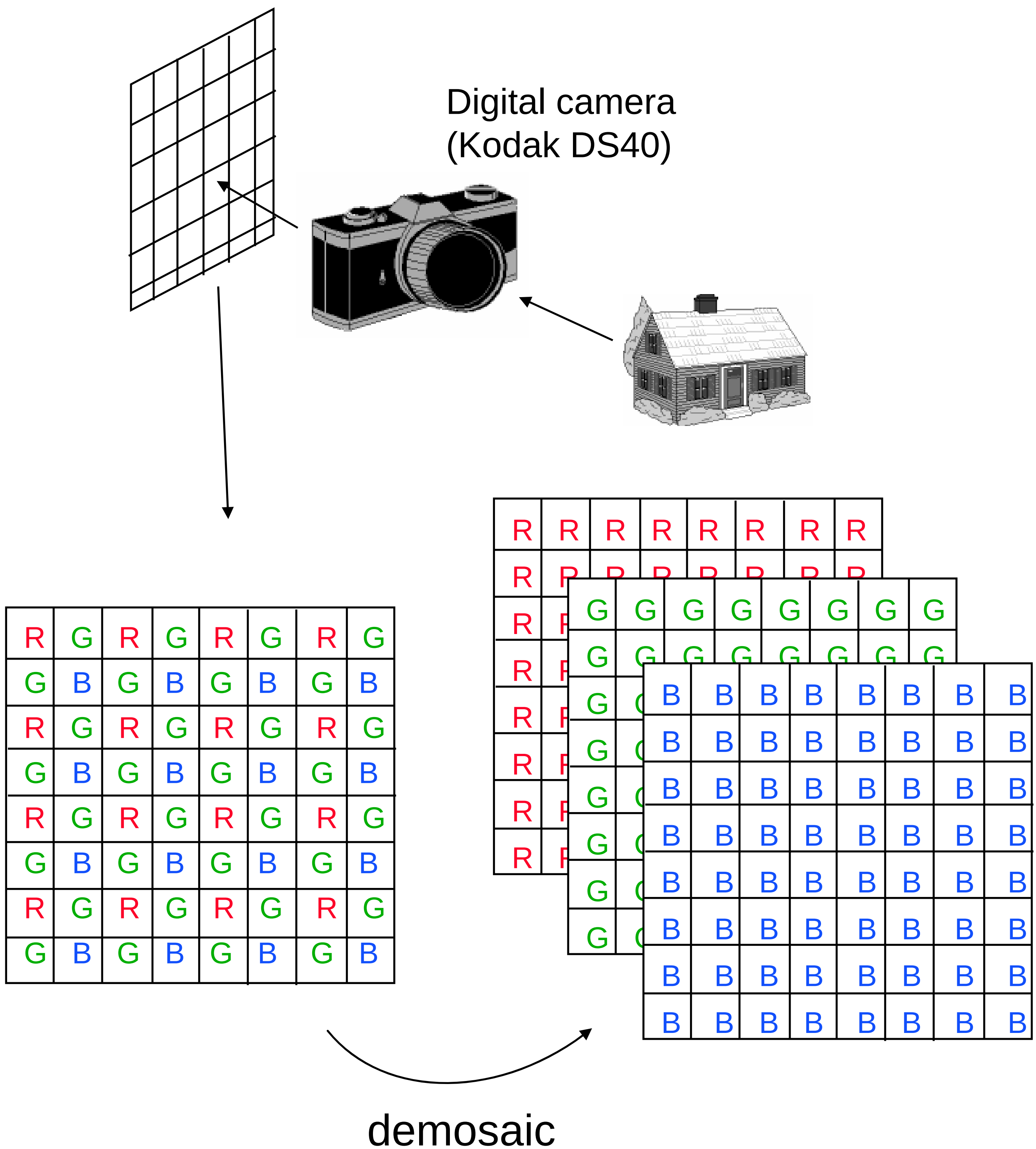
Undercolor removal -
(gray component replacement)



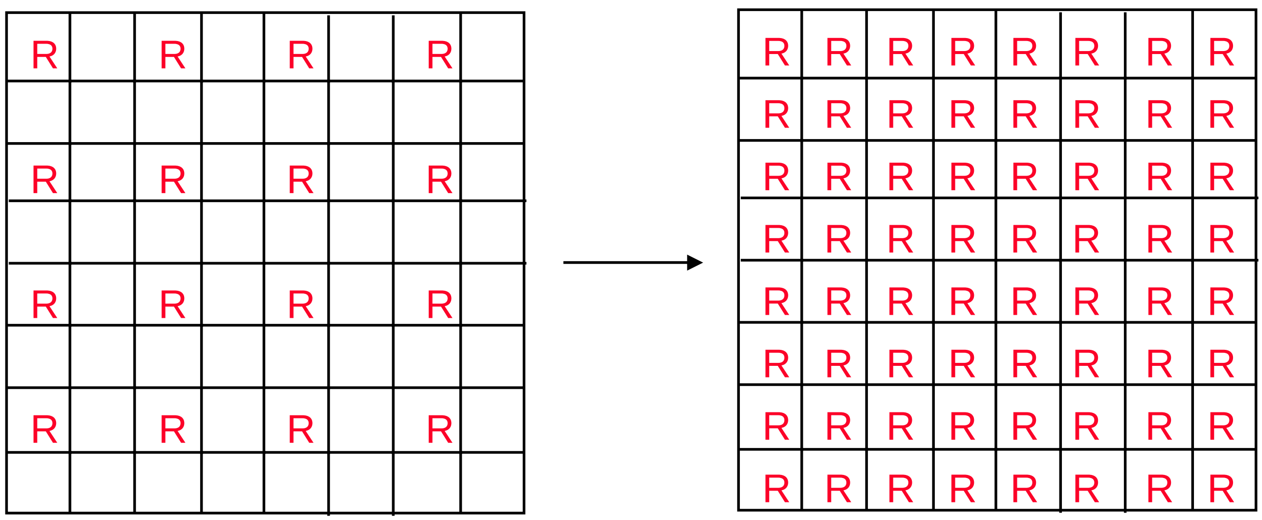

650



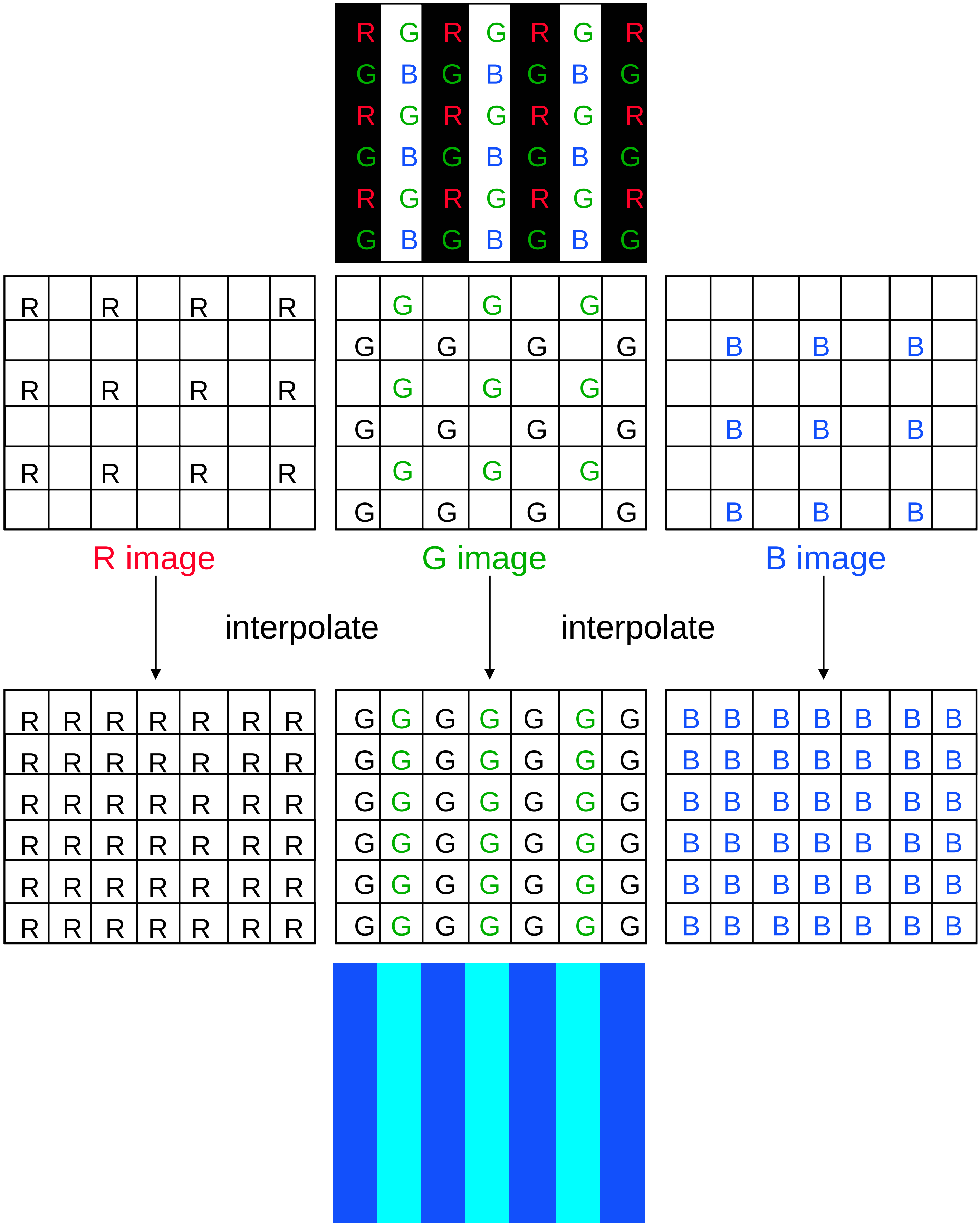
Demosaicing



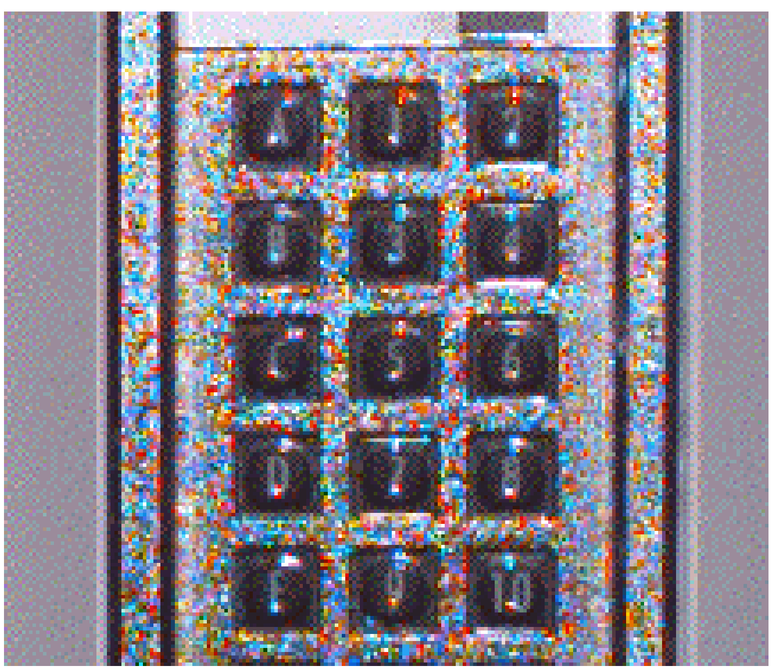
Demosaicing - Linear interpolation



Demosaic Aliasing



Demosaicing - Example (Kodak)



Demosaicing - Various Approaches

Regularization

Minimize over a functional with a data fit term and an inter-channel color correlation term.

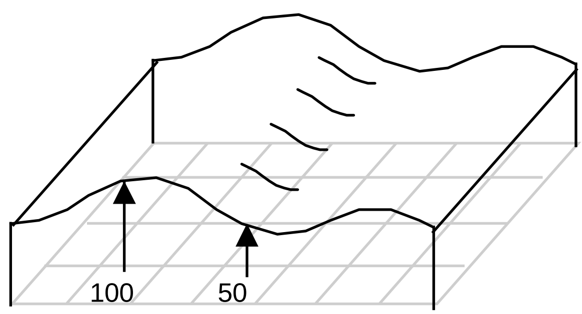
(Gamer & Keren)

Minimal Surface

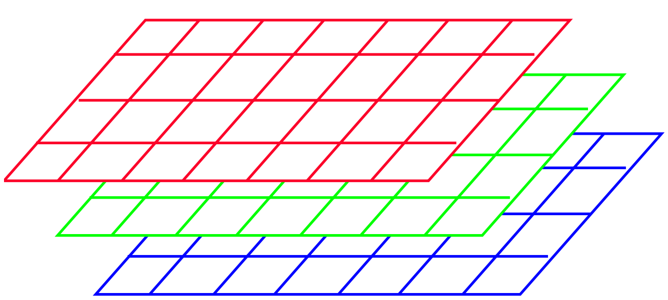
Minimize over a functional with a data fit term and a 5D surface area term. (Beltrami Flow)

(Kimmel)

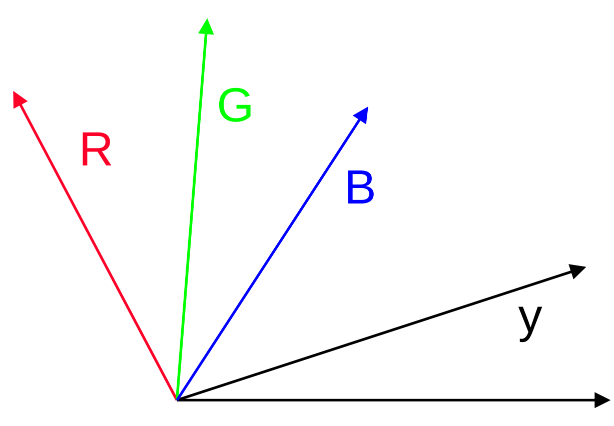
Grayscale Image



3D



RGB Image



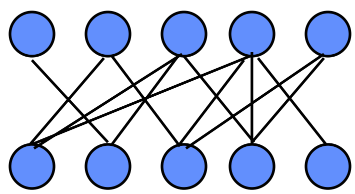
5D

Demosaicing - Various Approaches

Learning Schemes

Learn linear and non linear optimal filters
for classes of images (ANN).

(Kapah & Hel-Or)



Demosaicing - Learning Schemes

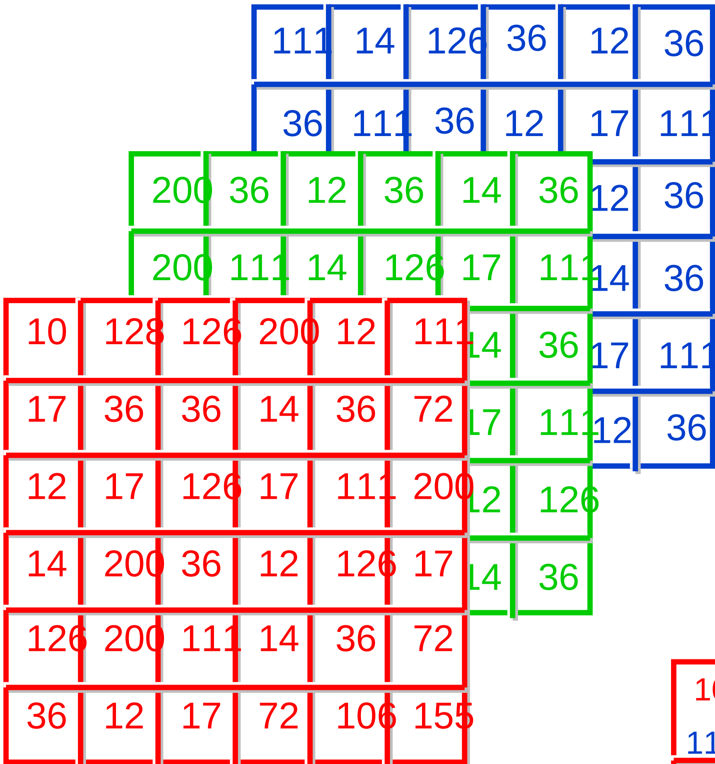
Channel independent

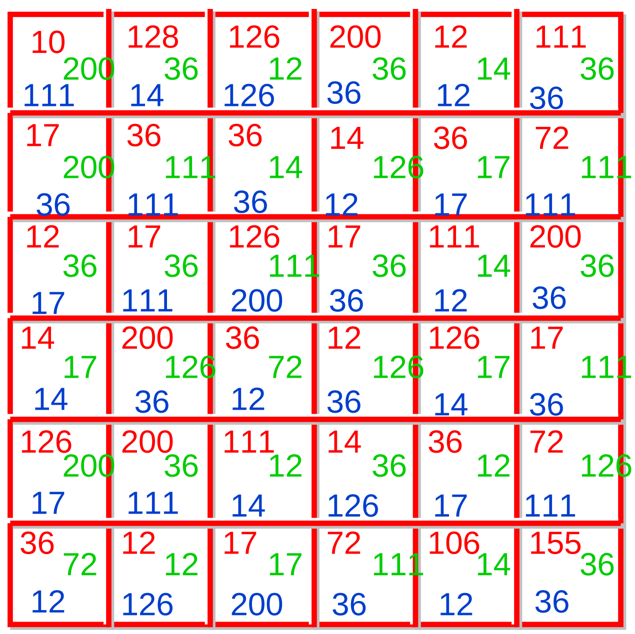
Perceptron (Linear)

Quadratic - Learned on Image

Quadratic - Learned on Class

Color Quantization





Indexed Image

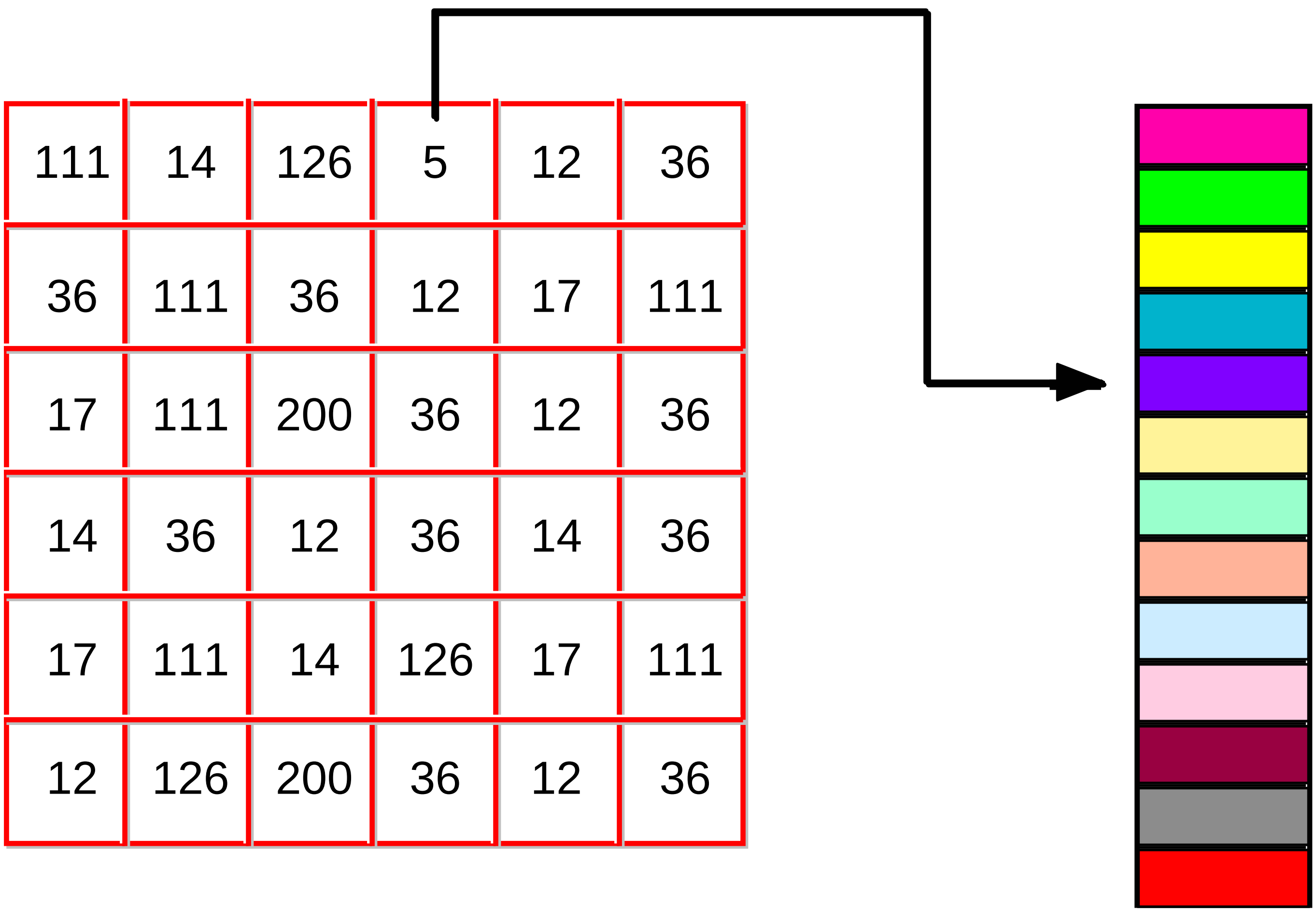
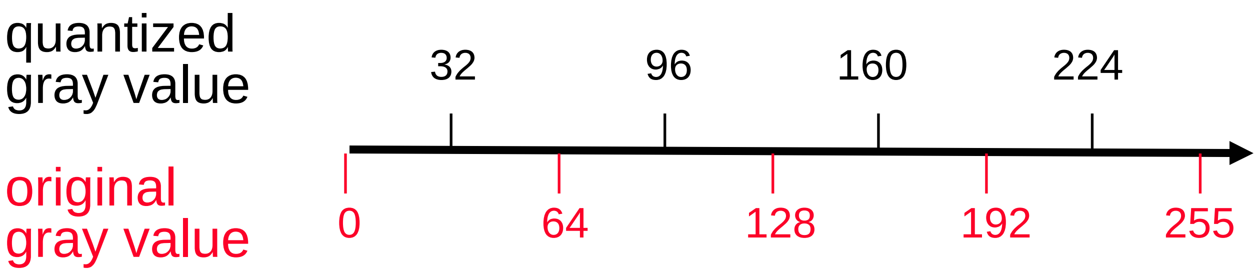
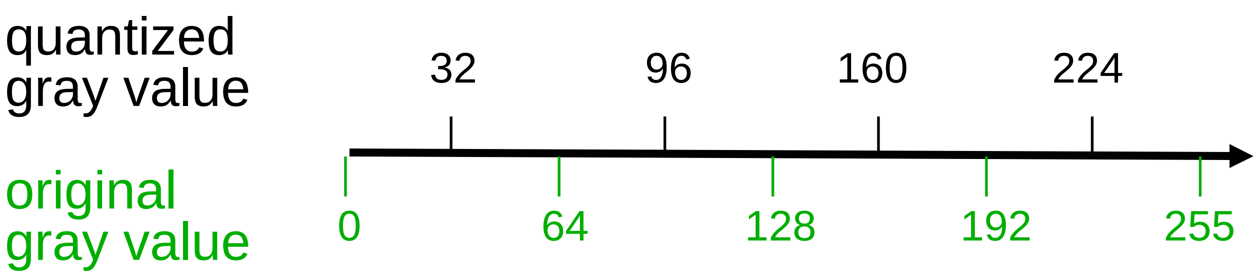


Image Independent Quantization





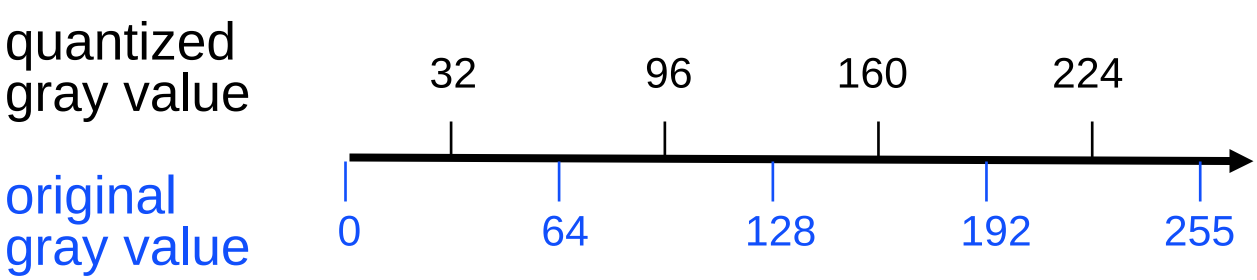


Image Independent Quantization

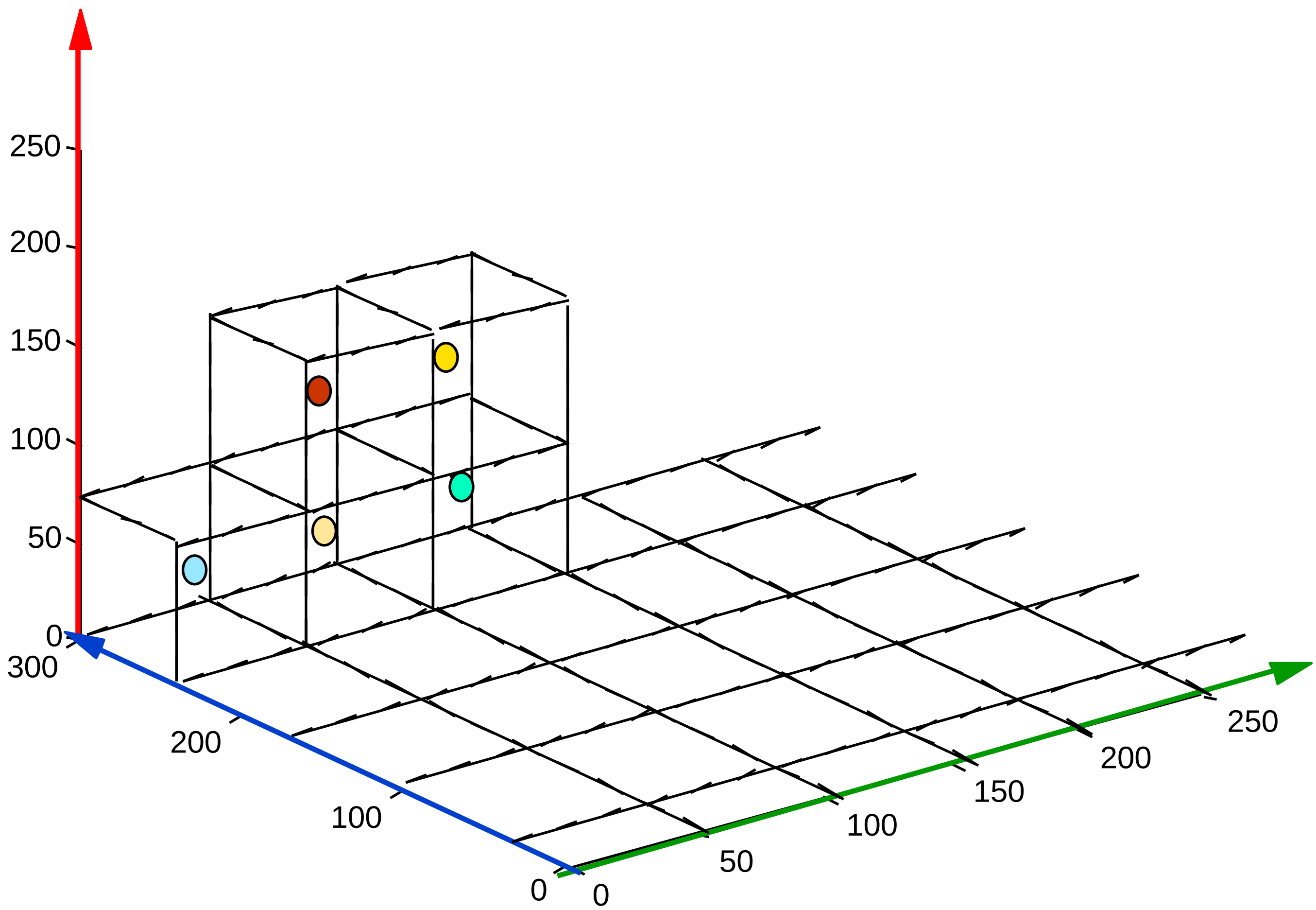
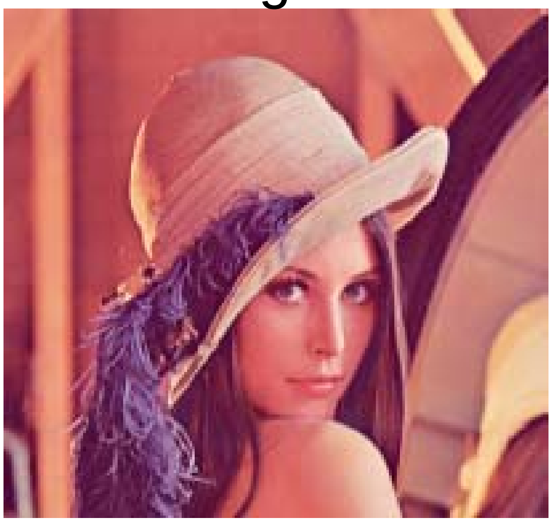


Image Independent Quantization

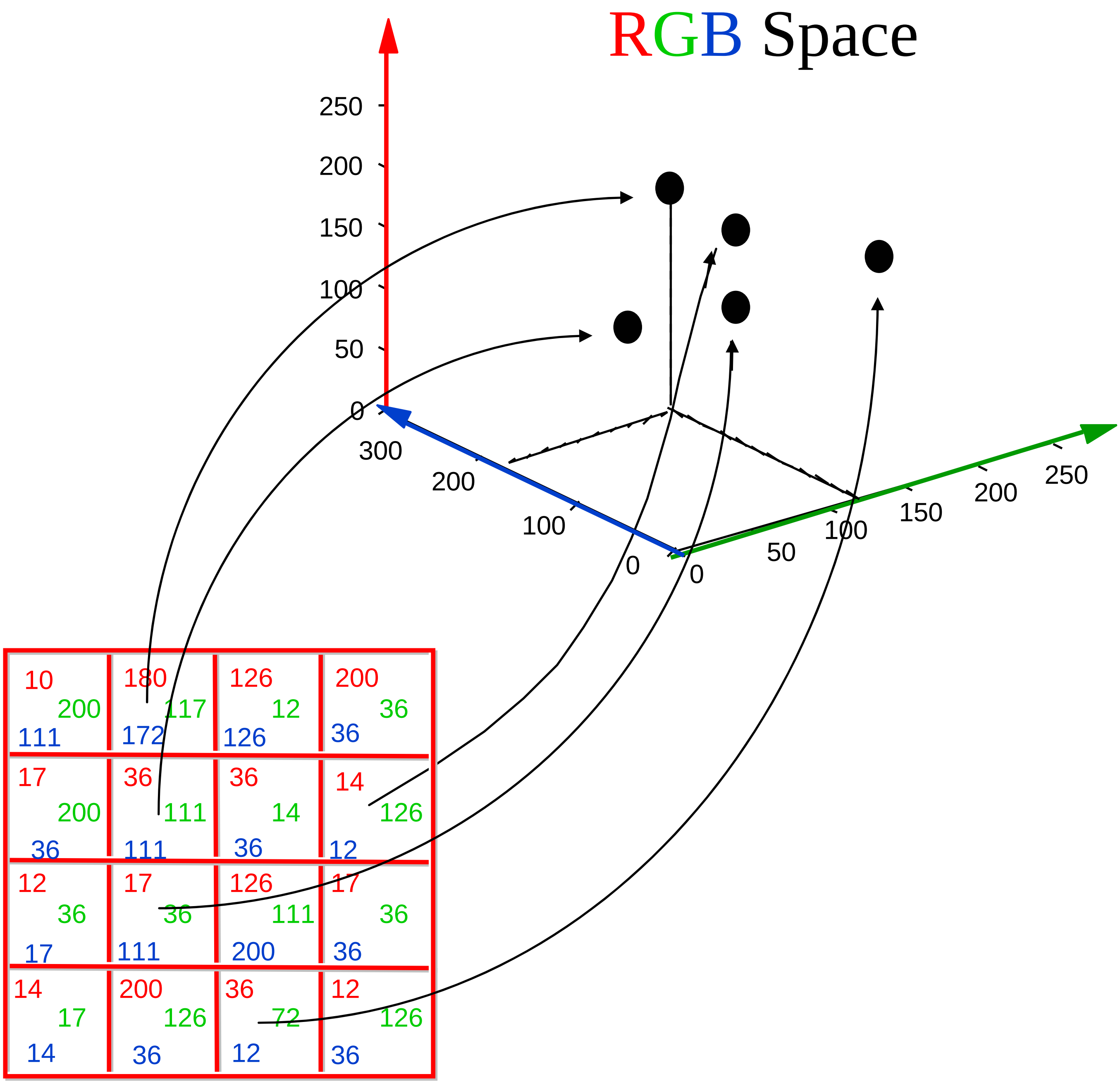
Original



125 Colors

64 Colors

27 Colors


RGB Space
250
200
150
100
50
0
300
200
100
0
0
50
100
150
200
250
10 200 111
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126 12 126
200 36 36
17 200 36
36 111 111
36 14 36
14 126 12
12 36 17
17 36 111
126 111 200
17 36 36
14 17 14
200 126 36
36 72 12
12 126 36

RGB Image

RGB Space

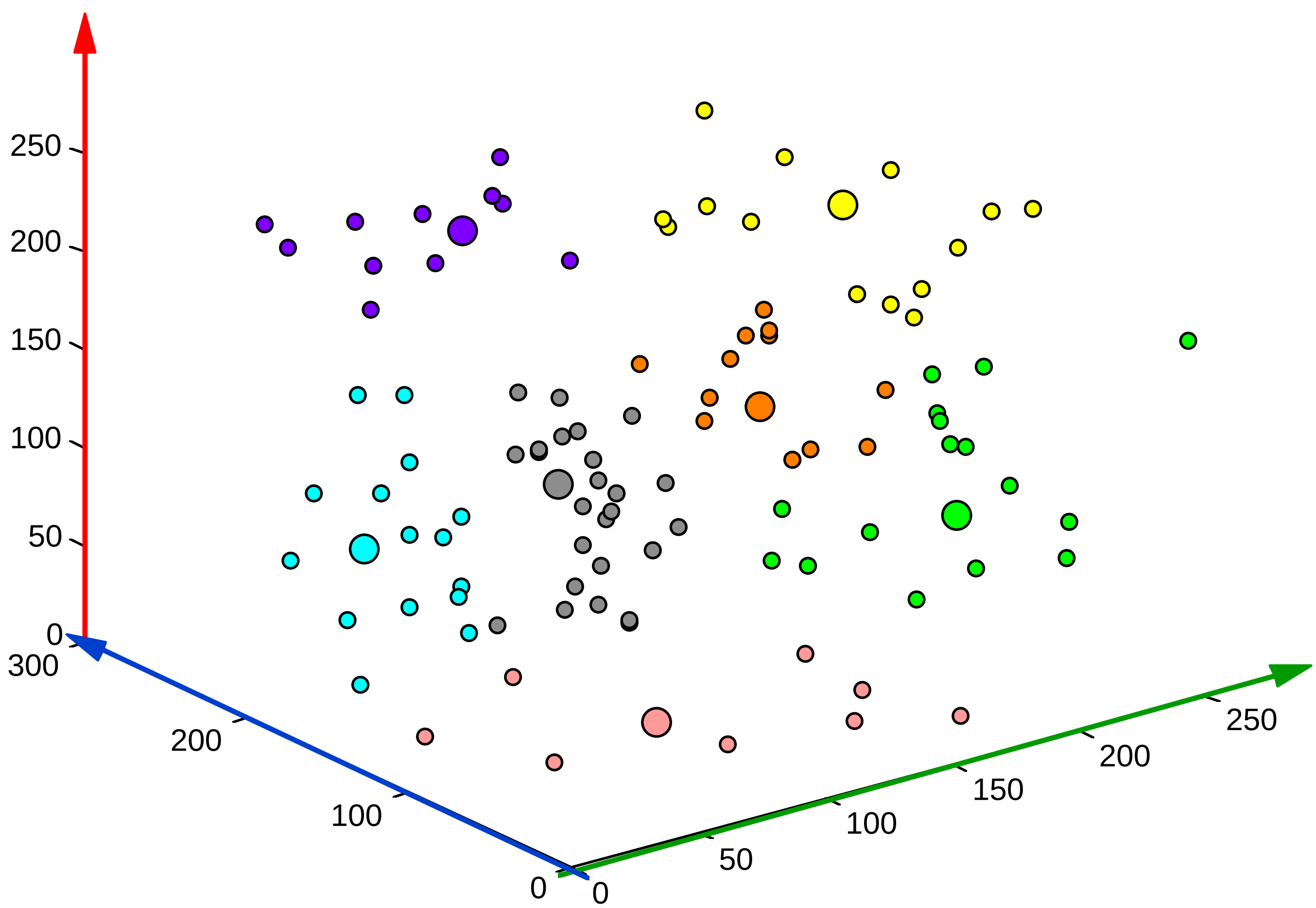
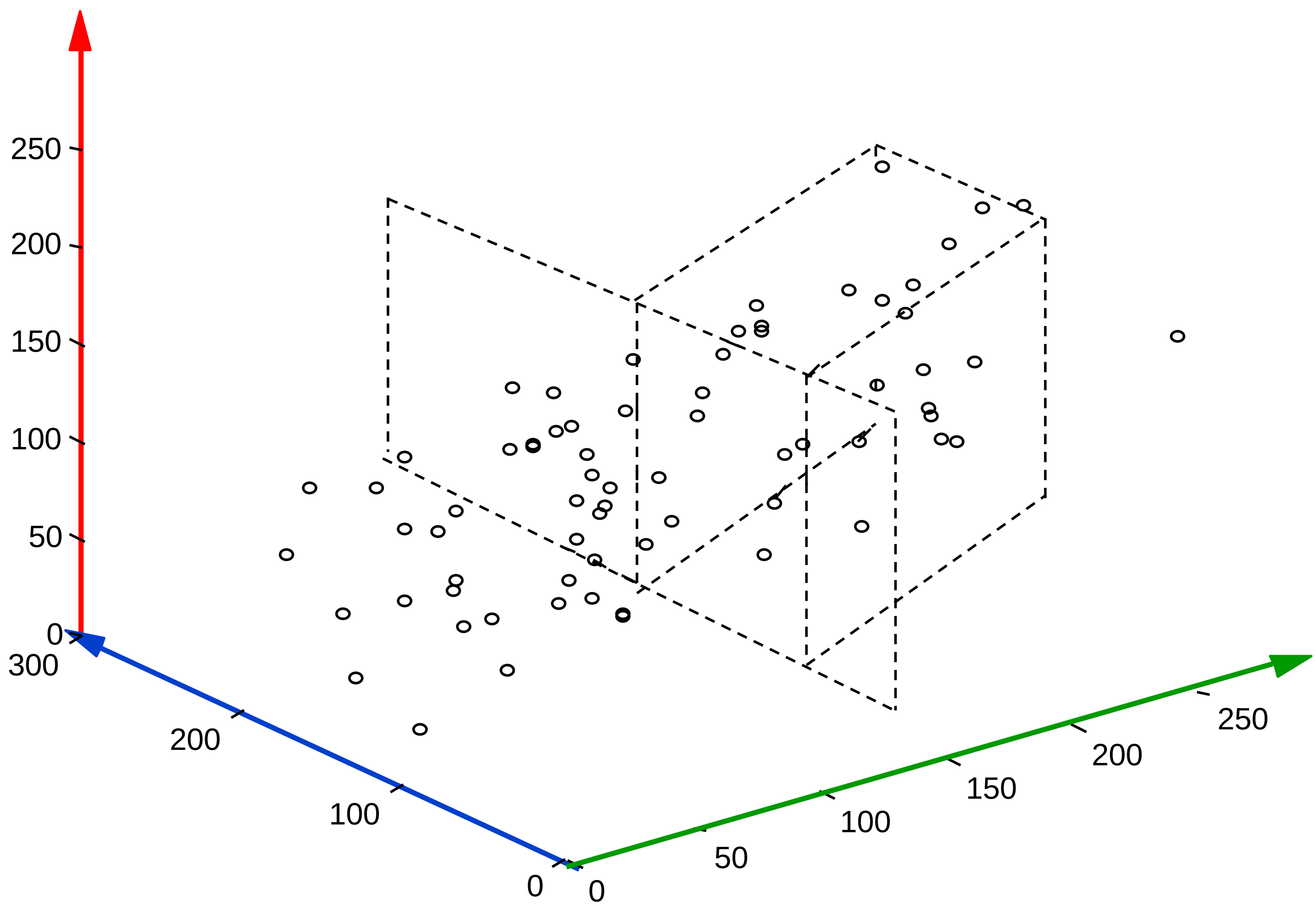


Image Dependent Quantization



Clustering using Iso Data

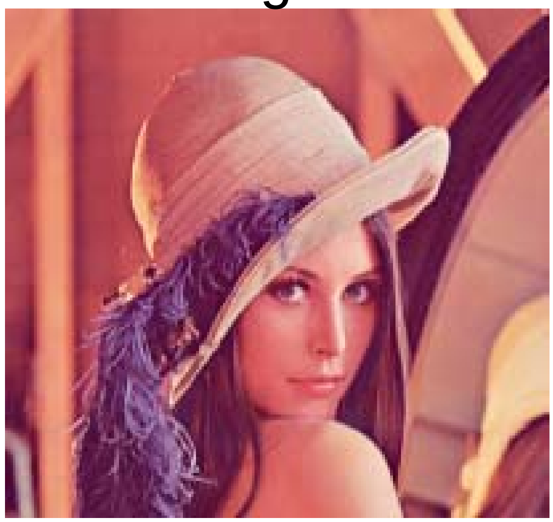
Input: $C=\{c_i\}$, $i=1..n$ - color points.

Output: $S=\{s_j\}$, $j=1..k$ - color indices.

- Distribute s_j, $j=1..k$, uniformly in color space.
- Divide C into k classes based of distances to S.
- For each class j, calculate the mean M_j.
- Set $S_j=M_j$.
- Iterate until convergence.

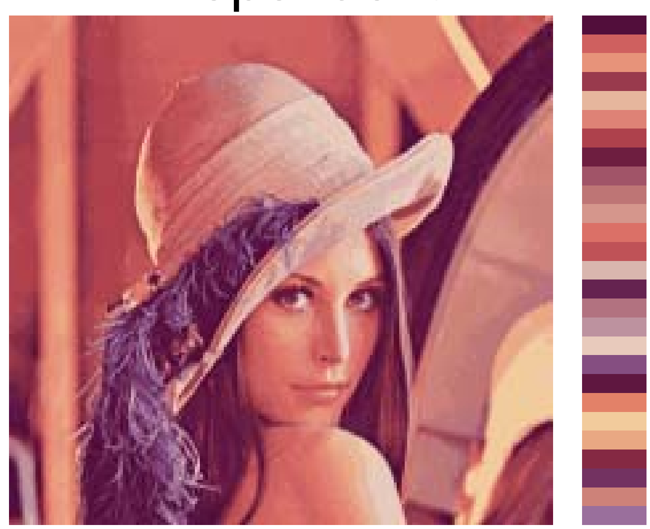
Image Dependent Quantization

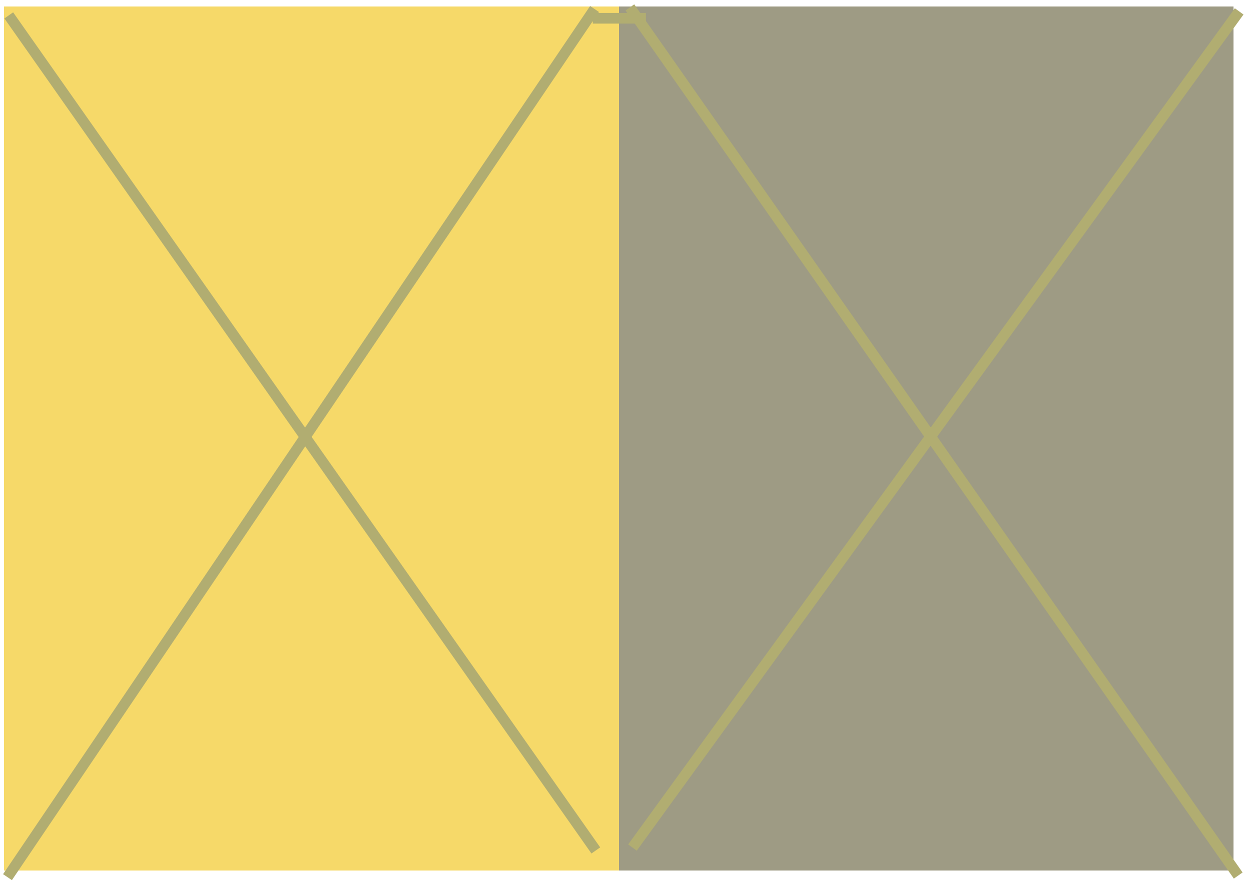
Original



Independent

Dependent





Albers (1975)