Course Presentation

Multimedia Systems

Color Space

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March 2013

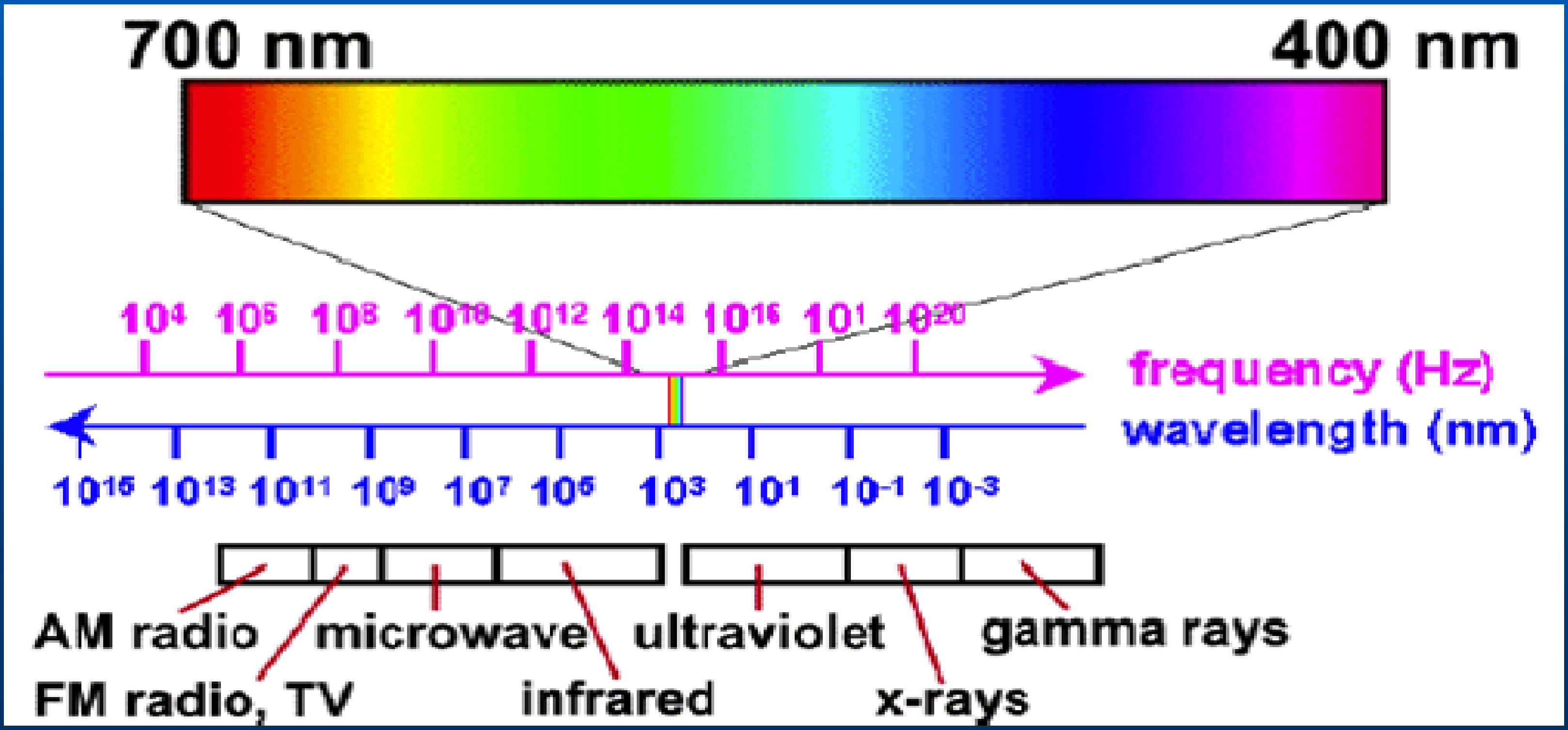
Sharif University of Technology

DML

Physics of Color

Light

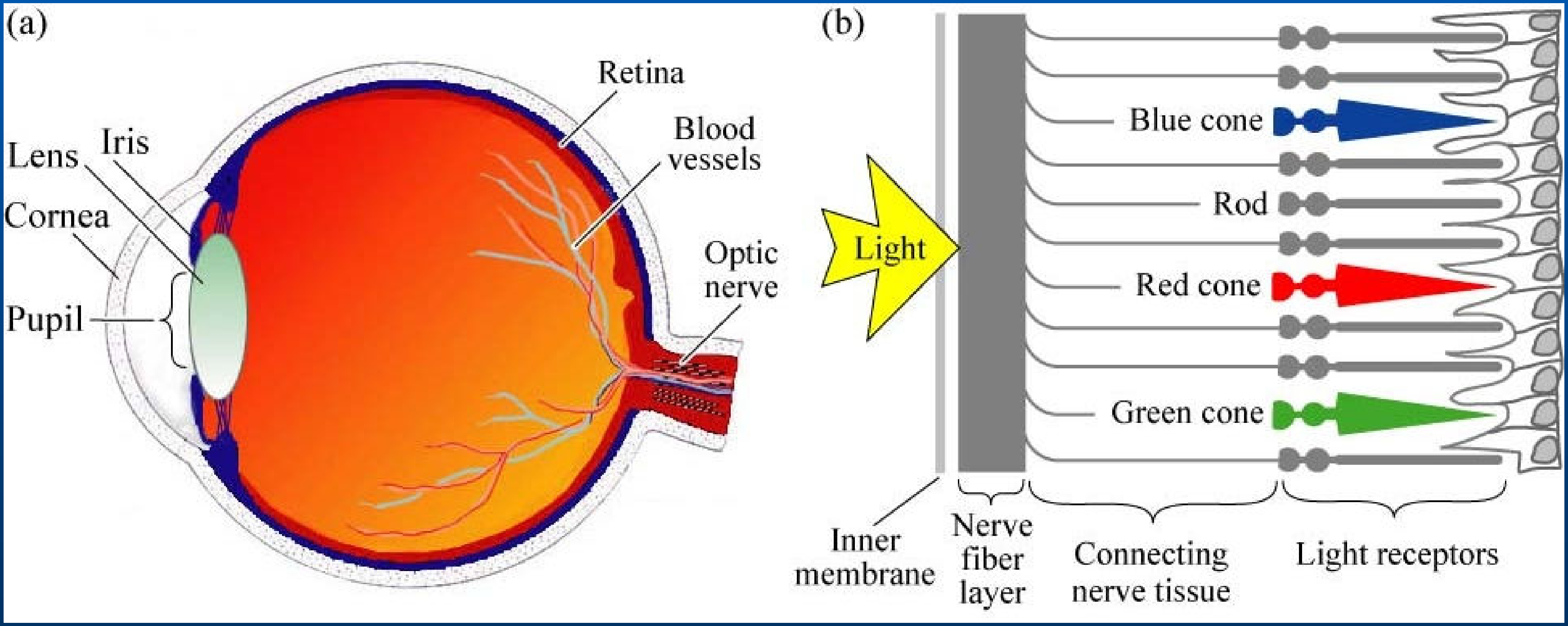
- **Light or visible light is the portion of electromagnetic radiation that is visible to the human eye.**



Color is Human Sensation

Human Eye

- Through **cone** and **rod** receptors in the retina
- Three kinds of cones: Long (**L, Red**), Medium (**M, Green**), Short (**S, Blue**)
- Rod receptor is mostly for luminance perception(useful for night vision)



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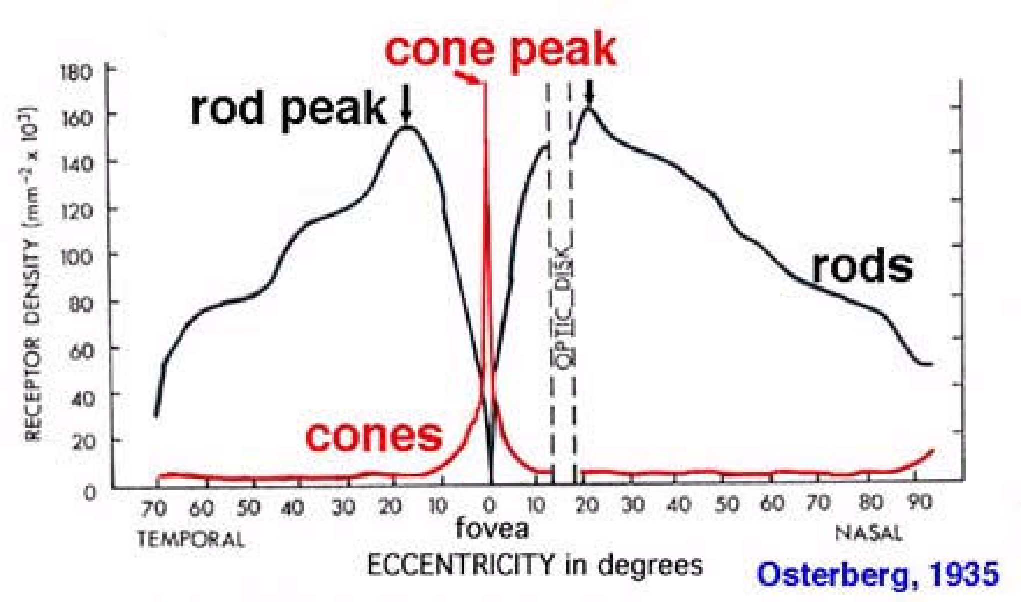
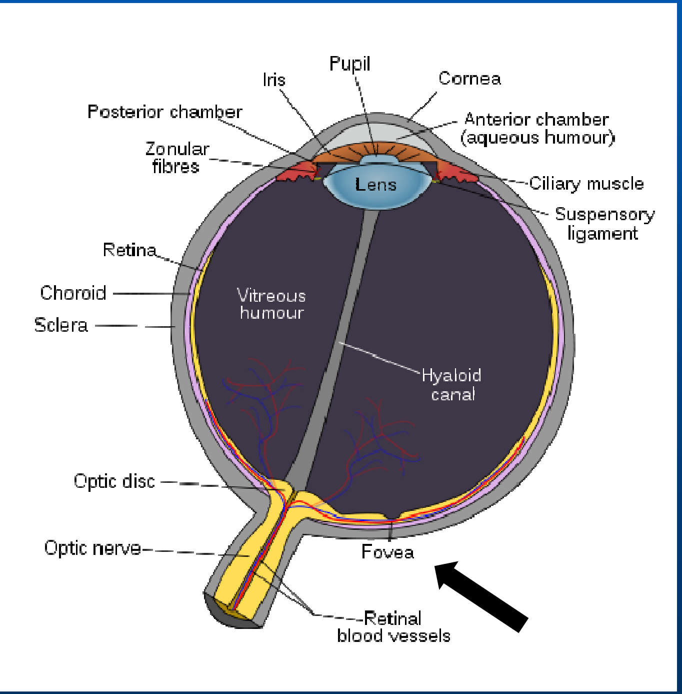
Human Eye

Fovea

- The fovea is responsible for sharp central vision
- The human fovea has a diameter of about 1.0 mm with a high concentration of cone photoreceptors.



Spatial Distribution



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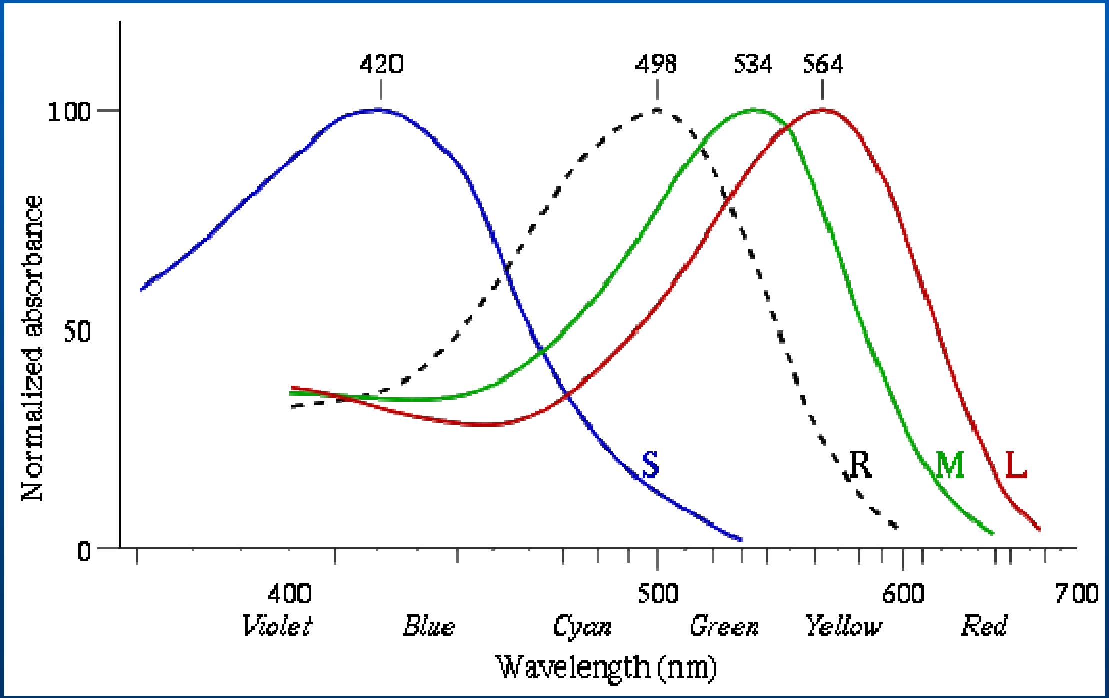
Human Eye

Photoreceptor cell

- **Normalized typical human cone (and rod) absorbances (not responses) to different wavelengths of light**



Idea
We can have different colors by mixing primary color components of "light" or "pigment"

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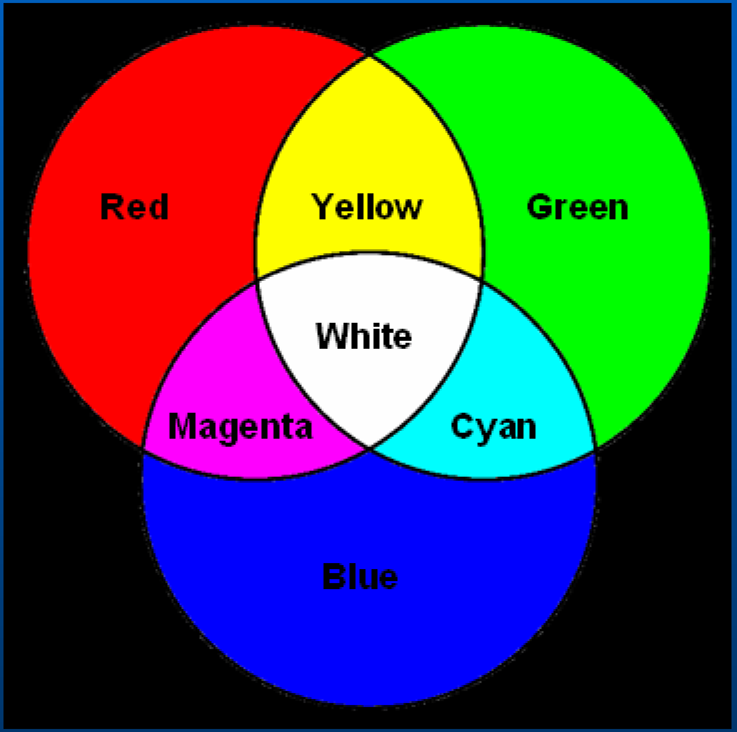
Additive Color Mixing

Mixing of Light

- **Usually red, green and blue**
  - **RGB color model**
- **Application**
  - **LCD, LED, plasma and CRT (picture tube) color video displays**

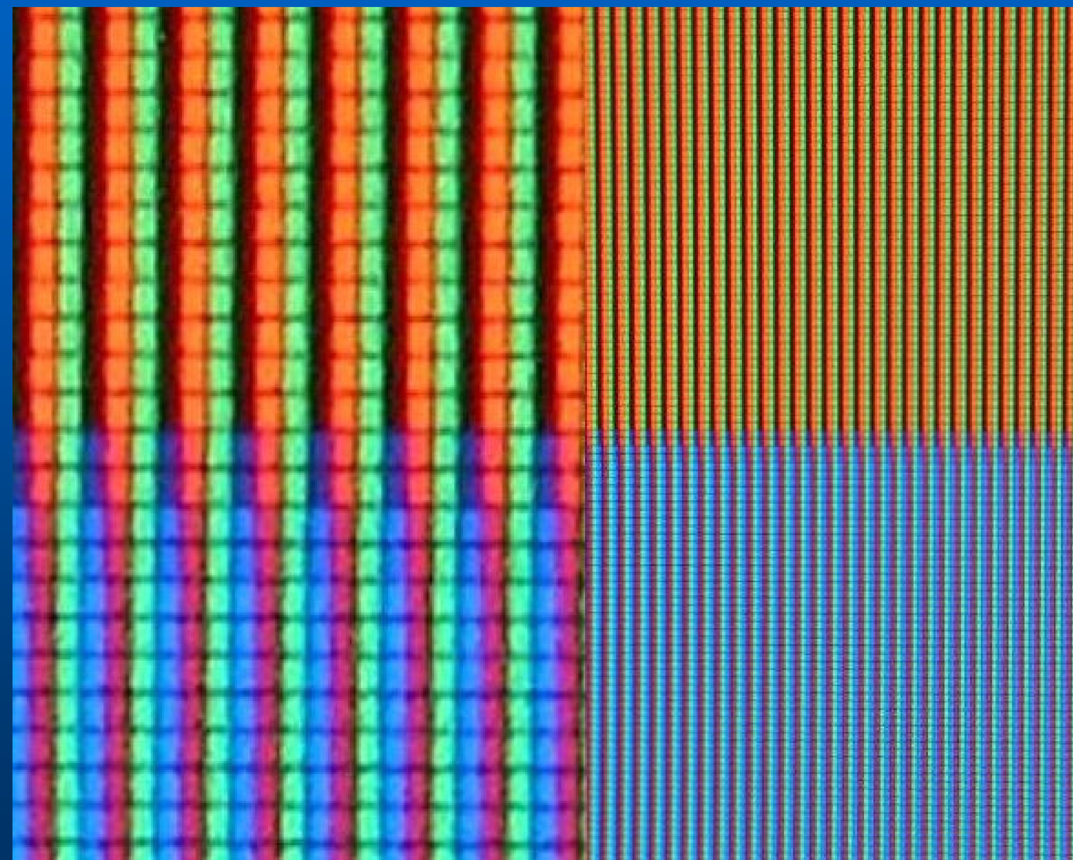
Examine TV display with a sufficiently strong magnifier

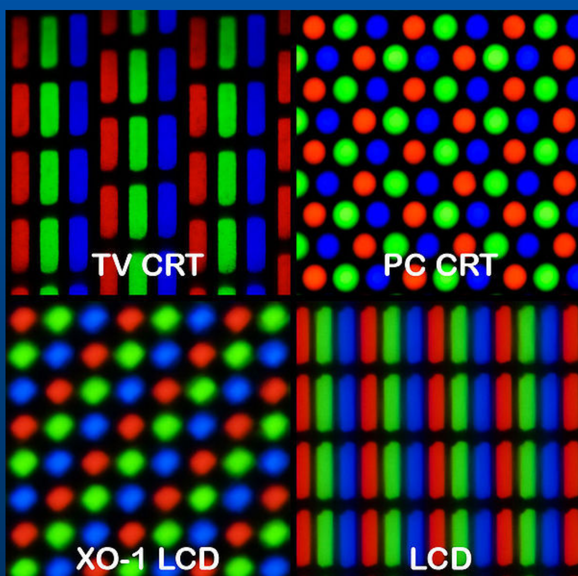


RGB

LCD TV Close-up

RGB sub-pixels in an LCD TV
(on the right: an orange
and a blue color;
on the left: a close-up)





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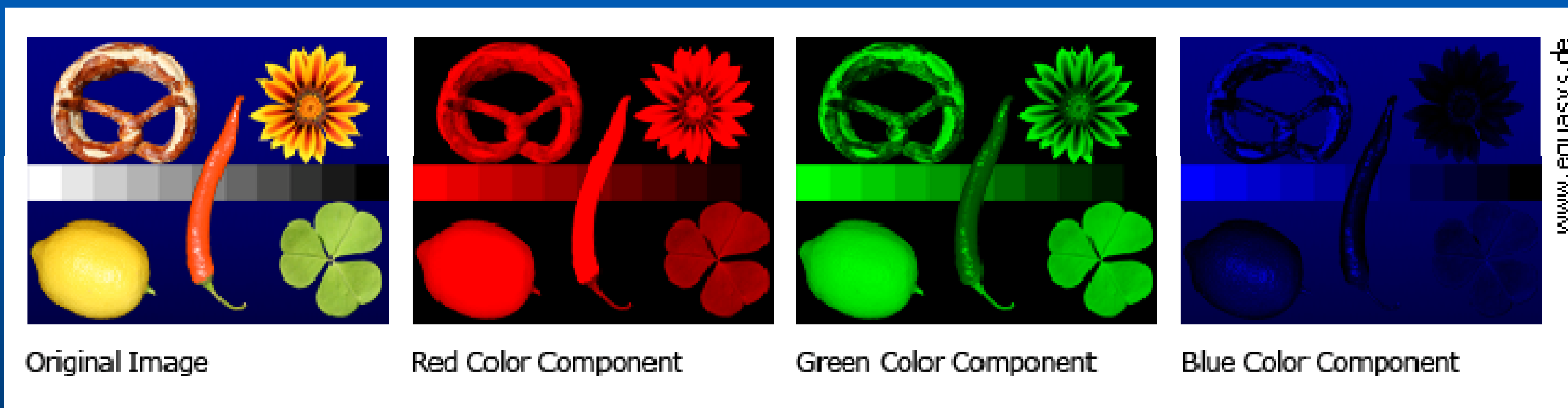
RGB

Color Components



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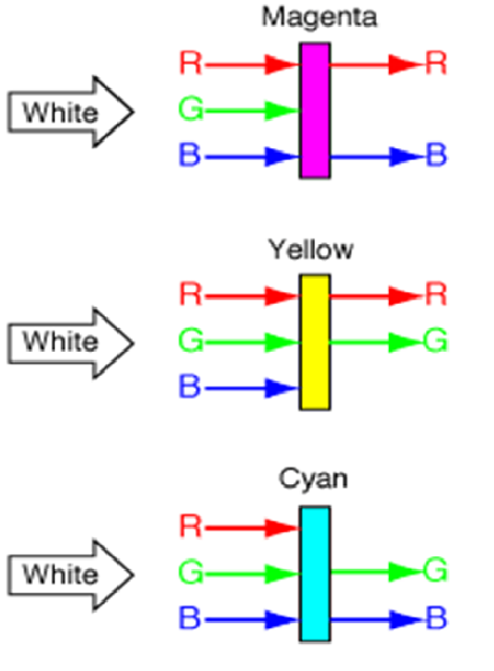
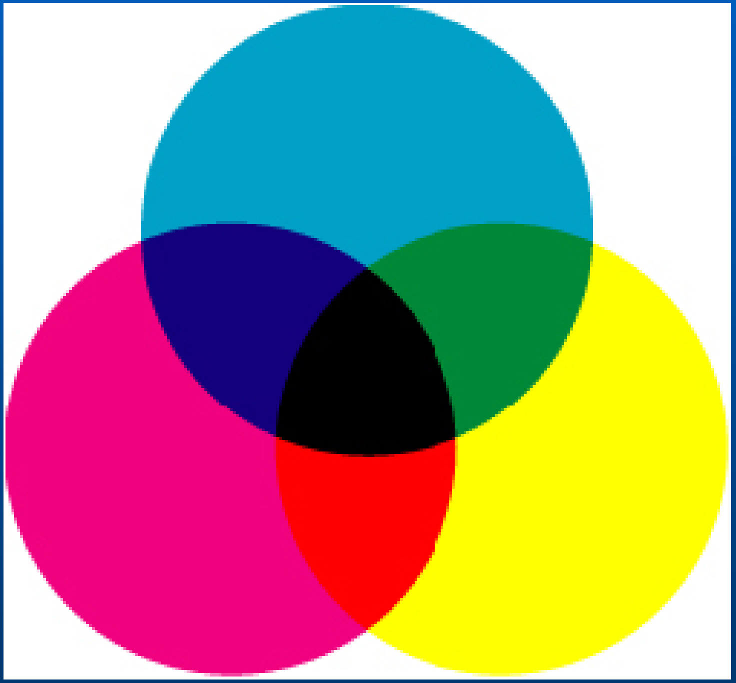
Subtractive Color Mixing

Mixing of Pigment

- **Primary: Cyan, Magenta, Yellow**
  - **CMYK color model**
- **Application**
  - **Printers**

Pigments absorb light





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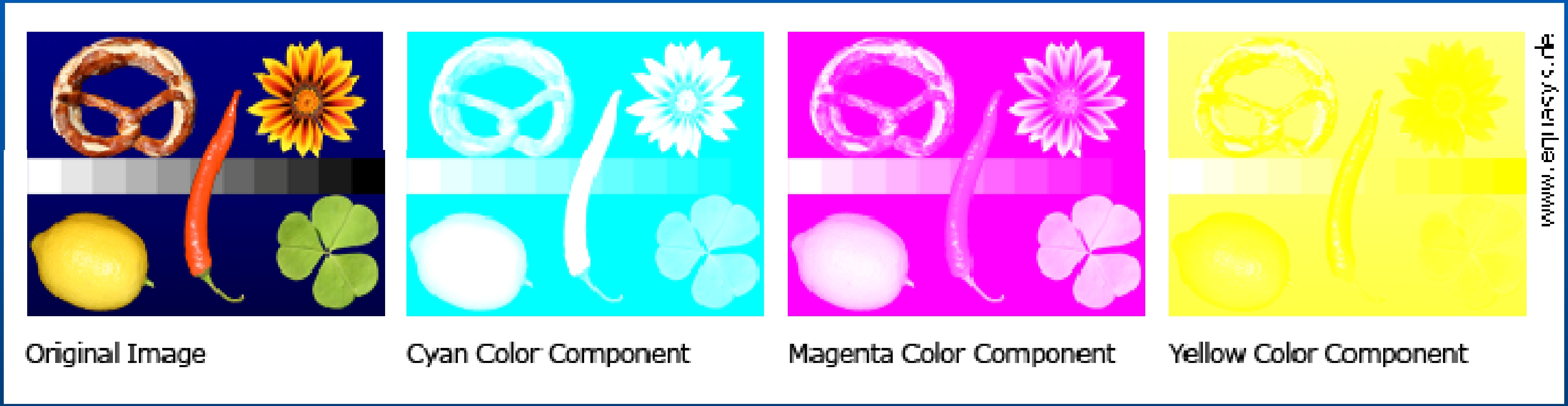
CMYK

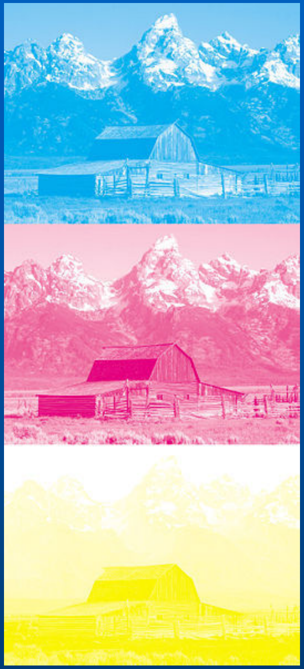
Color Components



CMYK

Why Including the Black?

A color photograph of the Teton Range.



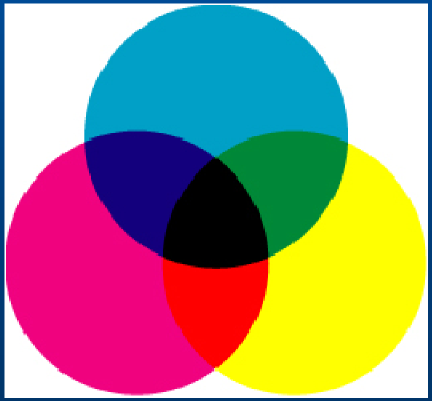
Separated for printing with process cyan, magenta, and yellow inks.

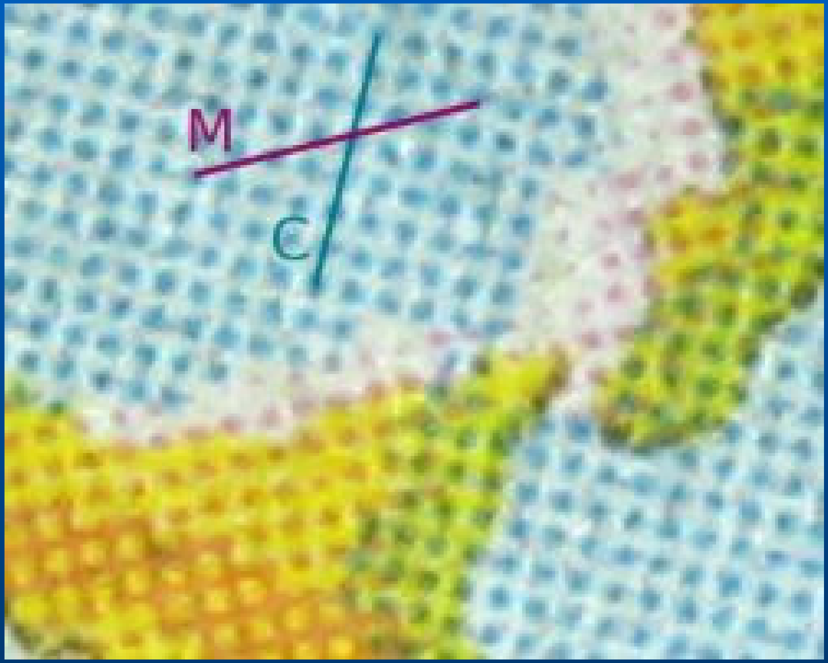
Separated with maximum black, to minimize ink use.

CMYK

Close-up of a Print

This close-up of printed halftone rasters show that magenta on top of yellow appears as orange/red, and cyan on top of yellow appears as green





Color Space Models

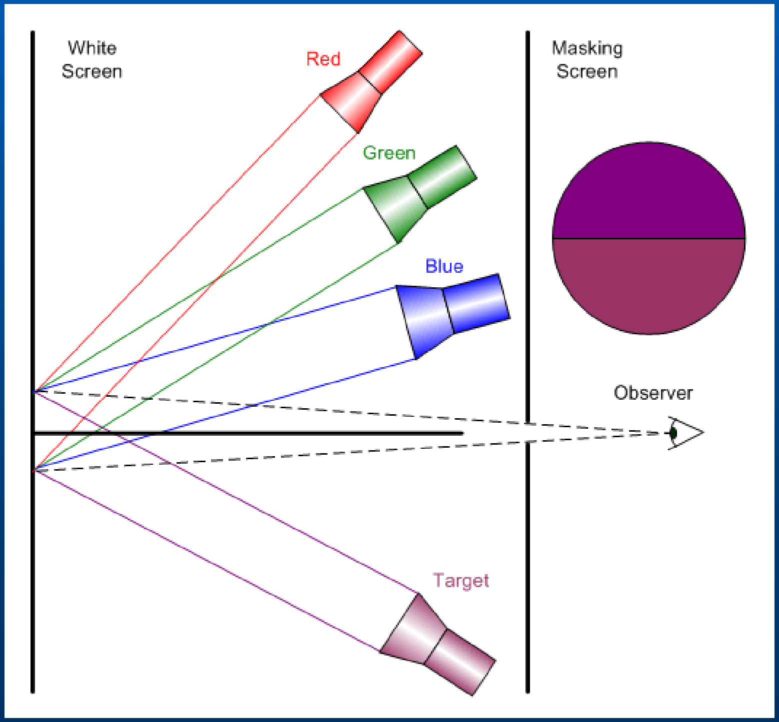
CIE 1931 XYZ color space

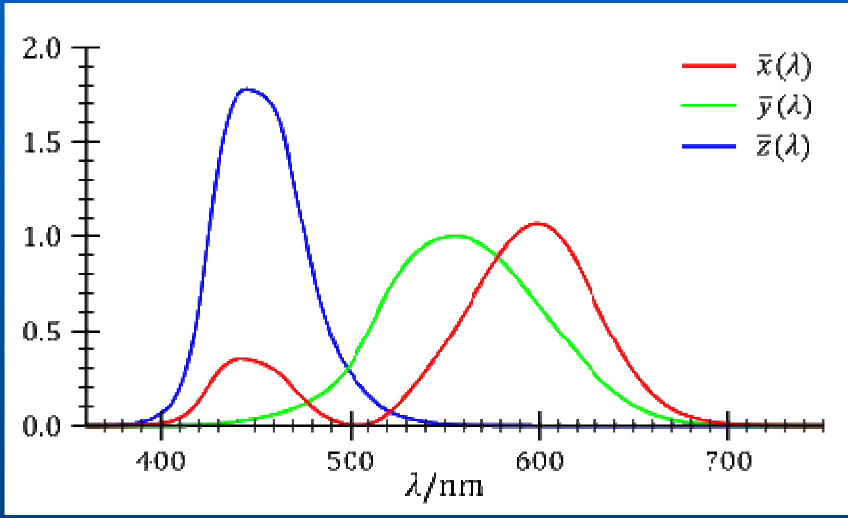
- **One of the first mathematically defined color spaces**
- **Created by the International Commission on Illumination (CIE)**
- **The CIE XYZ color space was derived from a series of experiments done in the late 1920s by W. David Wright and John Guild.**

Color Space Models

CIE Experiments

The observer would alter the brightness of each of the three primary beams until a match to the test color was observed.





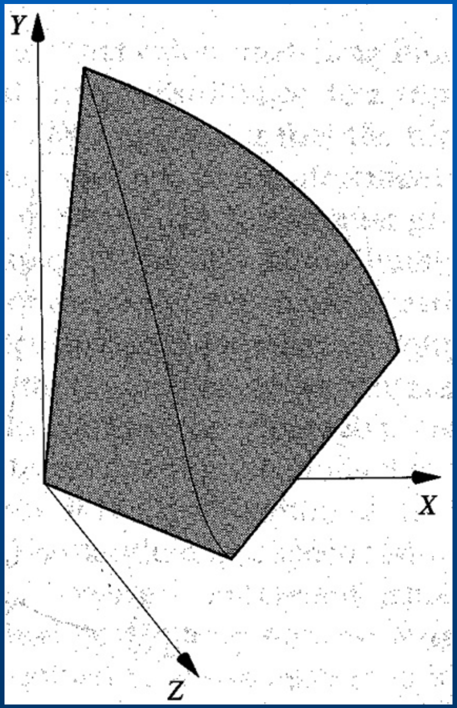
CIE XYZ primaries

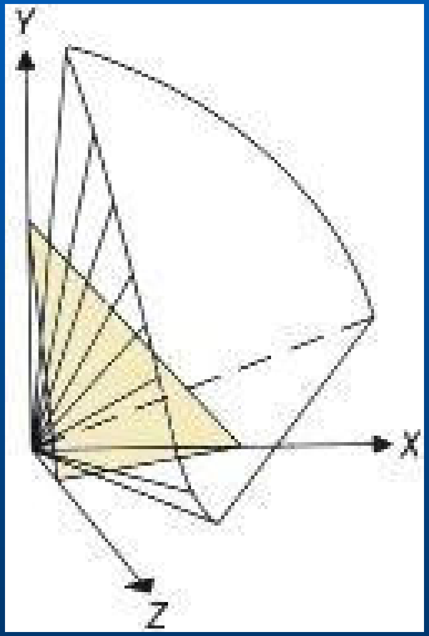
The Y primary is intentionally defined to have a color-matching function that exactly matches the luminous-efficiency function of the human eye.

Color Space Models

CIE 1931 XYZ color space

- **The Result of the Experiments: The cone of visible colors**





The X + Y + Z = 1 plane is shown as a triangle

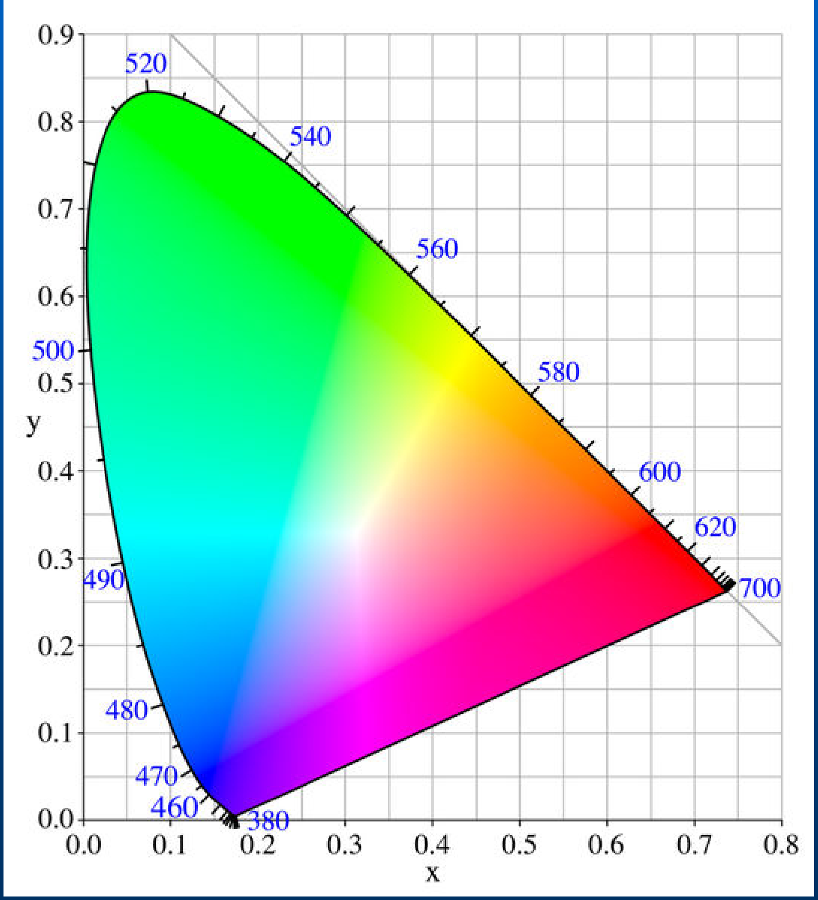
Color Space Models

CIE xyY Chromaticity Diagram

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

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

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

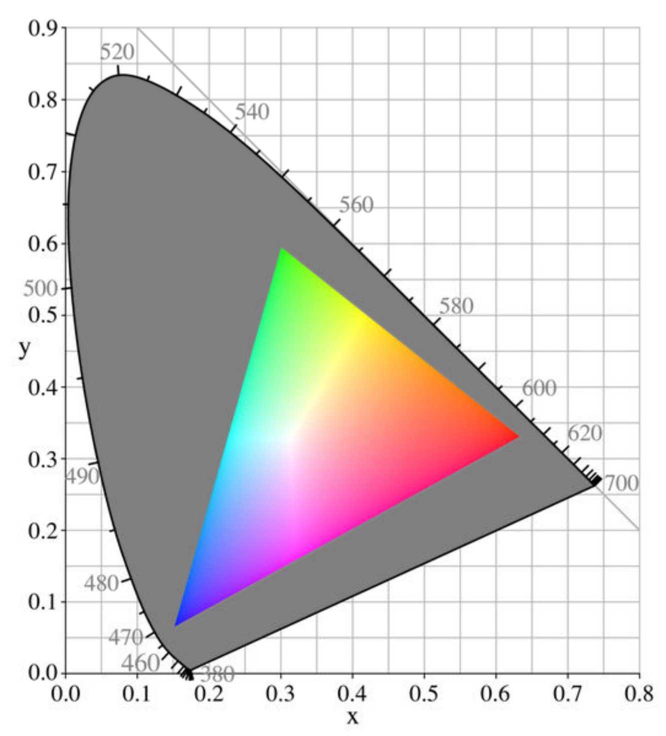


Y in xyY: measure of the brightness or luminance of a color.

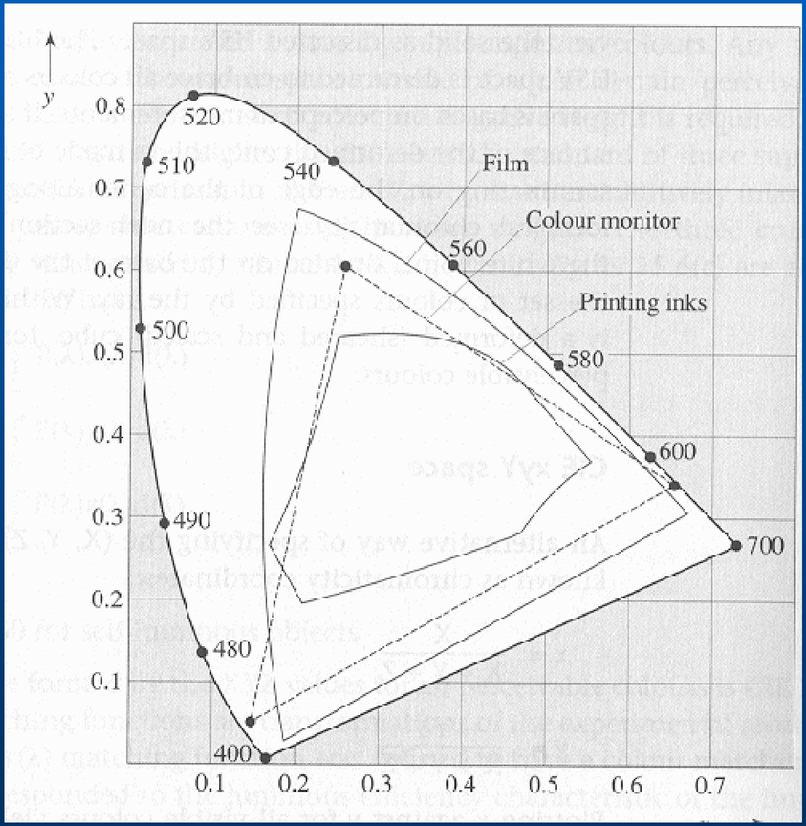
Color Space Models

Color Gamut

- **The range of color representation of a display device**



A typical CRT gamut



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Color Space

HSV

- **Hue: Quantity that distinguishes color family, say red from yellow, green from blue.**
- **Saturation (Chroma): Color intensity (strong to weak). Intensity of distinctive hue, or degree of color sensation from that of white or grey.**
- **Value (Luminance): Light color or dark color.**

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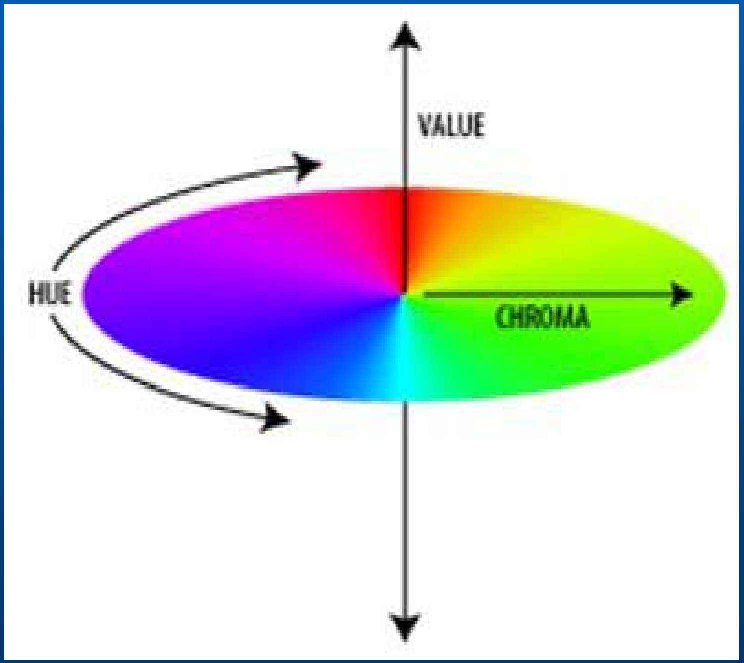
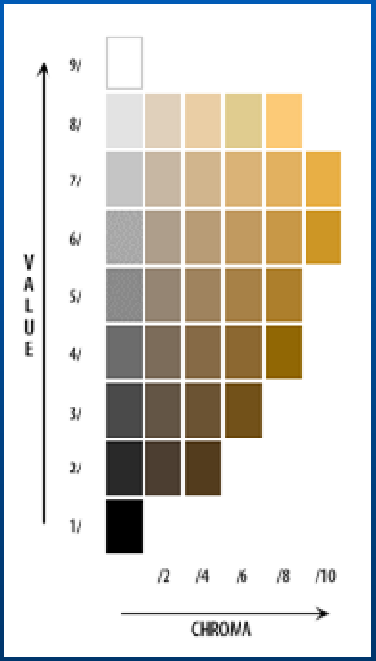
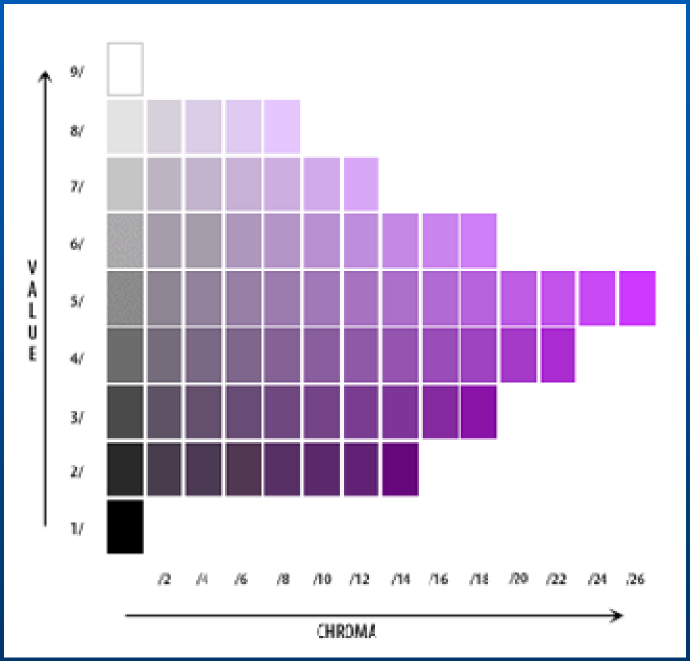
Color Space

HSV

- **Photoshop uses this model to get more control over color**



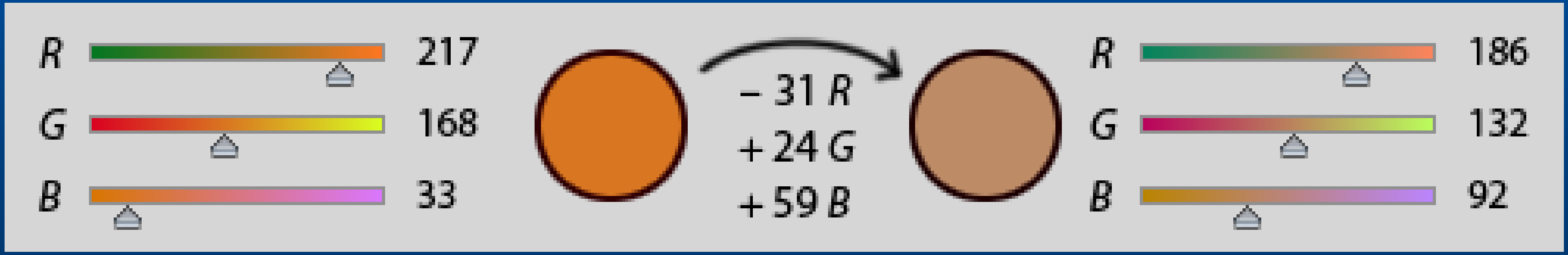




Color Space

HSV vs. RGB

- **Example color control**
- **From a relatively colorful orange → a less saturated orange**
- **RGB: we would need to readjust all three R, G and B sliders**
- **HSV: we can just readjust the 'Saturation' related slider**

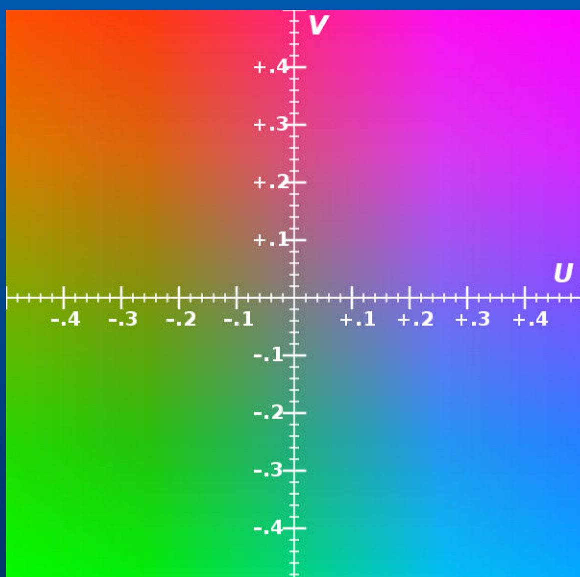


- **Sample Application of HSV color space: Object detection based on color filtering.**

Color Space

YUV

- **Y: Luminance**
- **U and V: Chrominance**



Example of U-V color plane

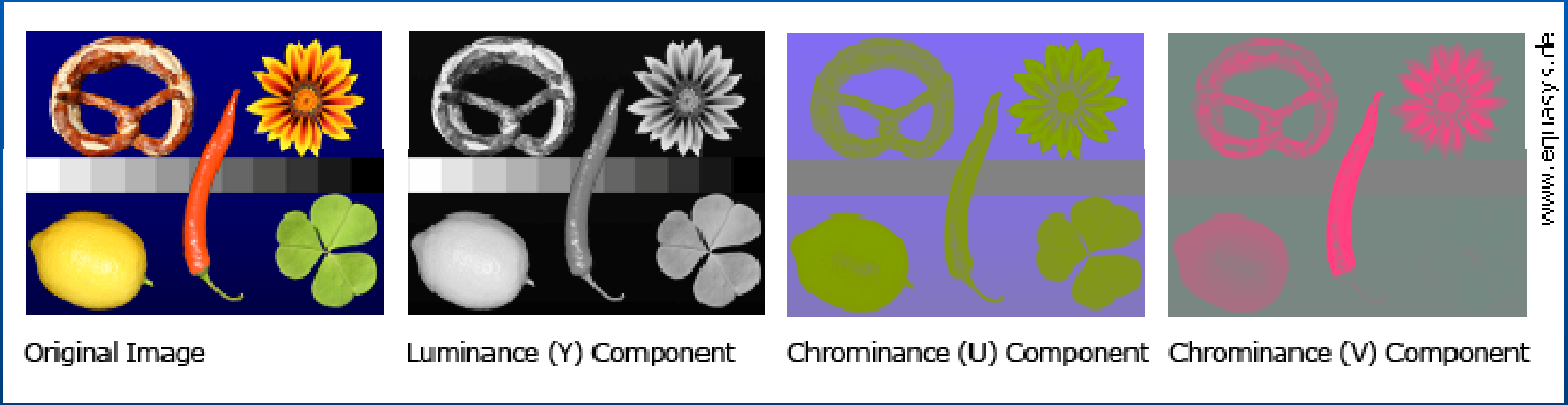
Think of BW and Color TVs

Taking human perception into account, allowing reduced bandwidth for chrominance components
(Since the human eye is less sensitive to chrominance than luminance)

No need for color space conversion when our image processing technique only uses luminance component.

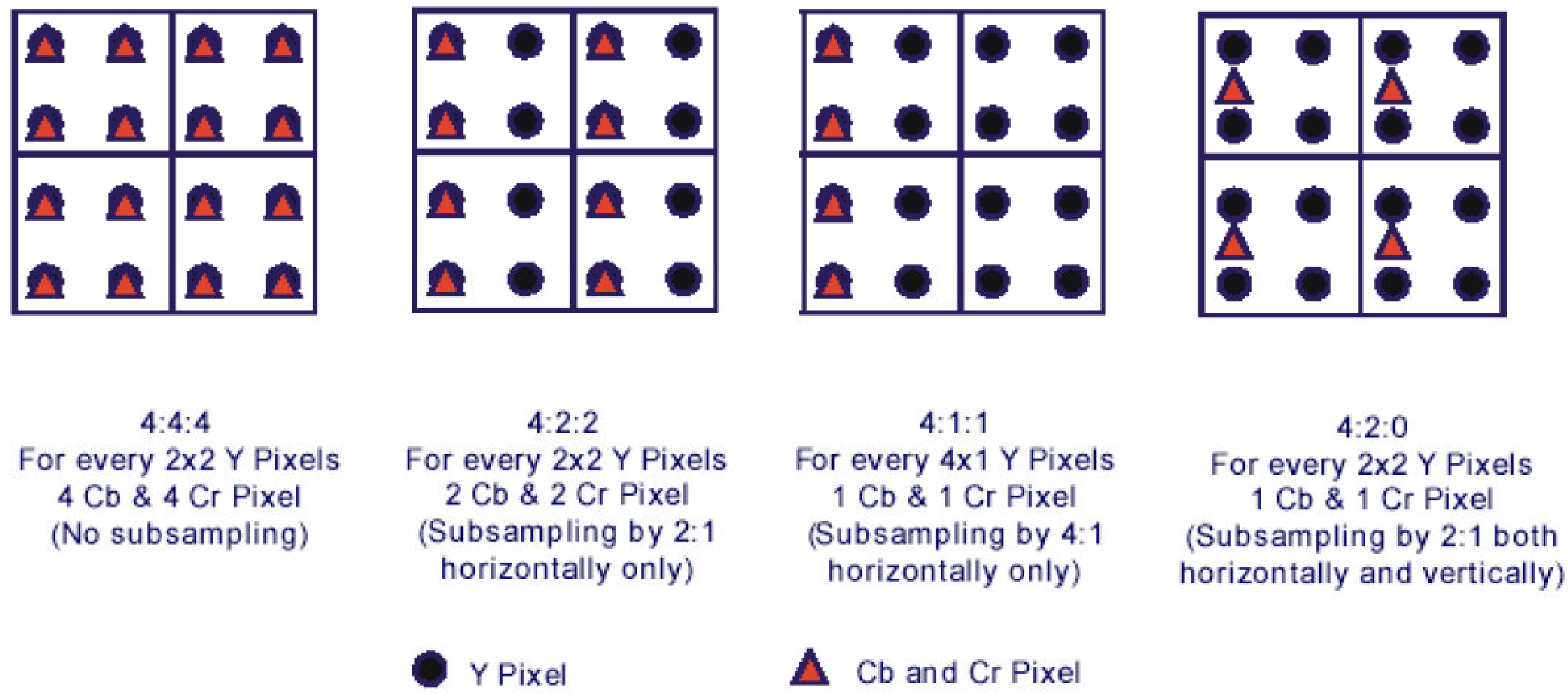
YUV

Color Components



Color Space

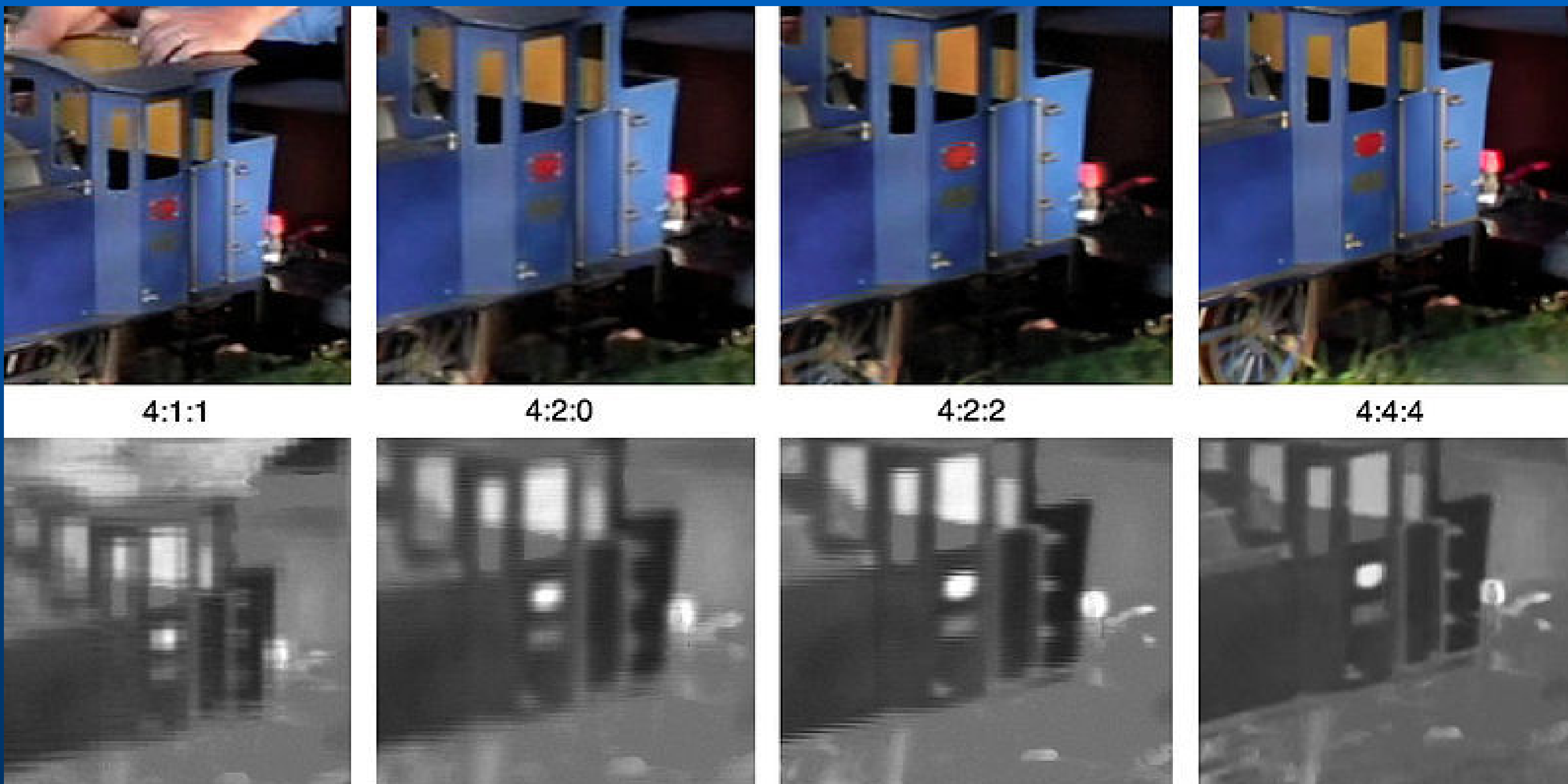
Subsampling in YUV or YCbCr



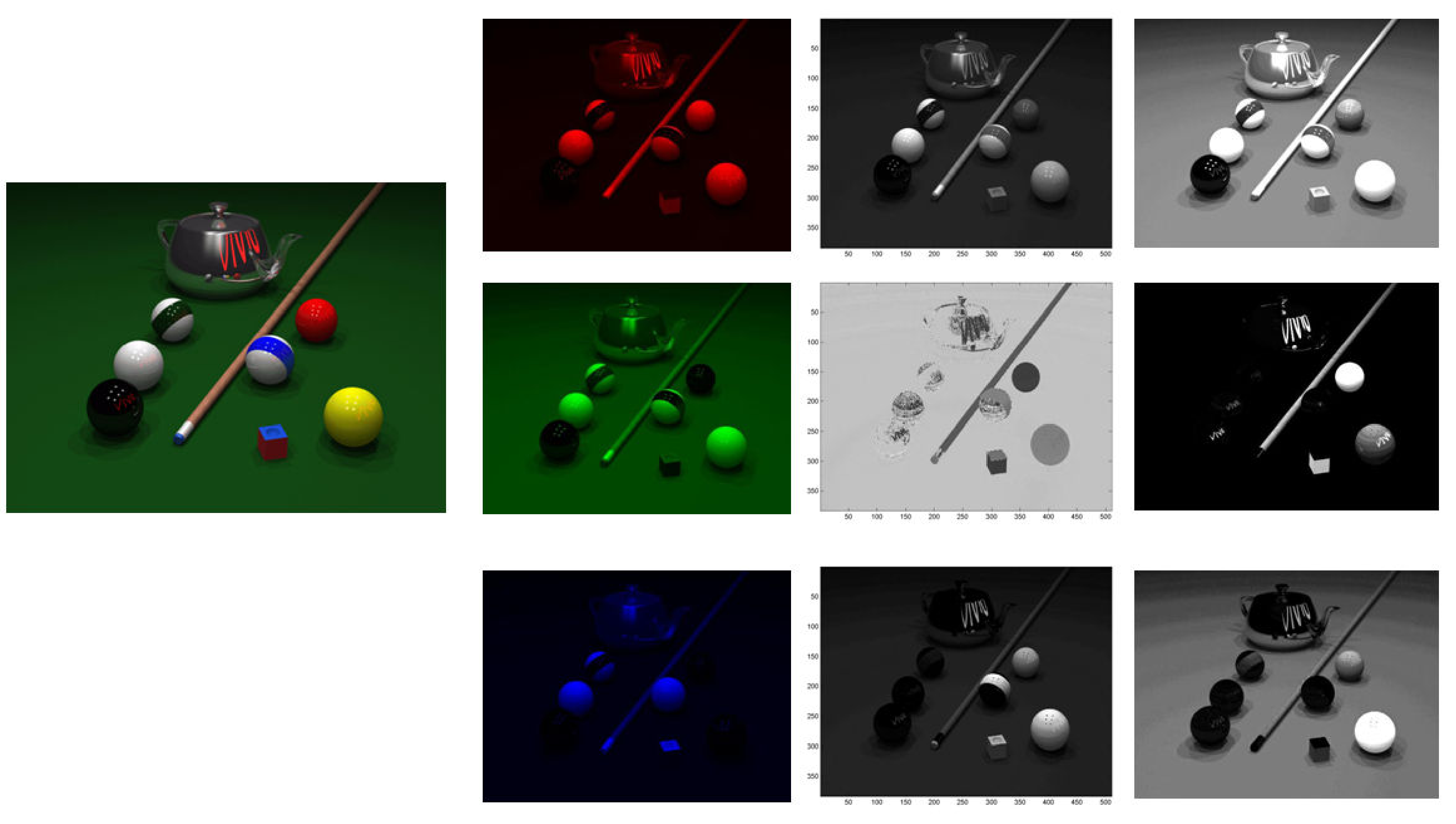
Color Space

This image shows the difference between four subsampling schemes. Note how similar the color images appear. The lower row shows the resolution of the color information.

Difference Between Four Schemes



RGB, HSV, YUV



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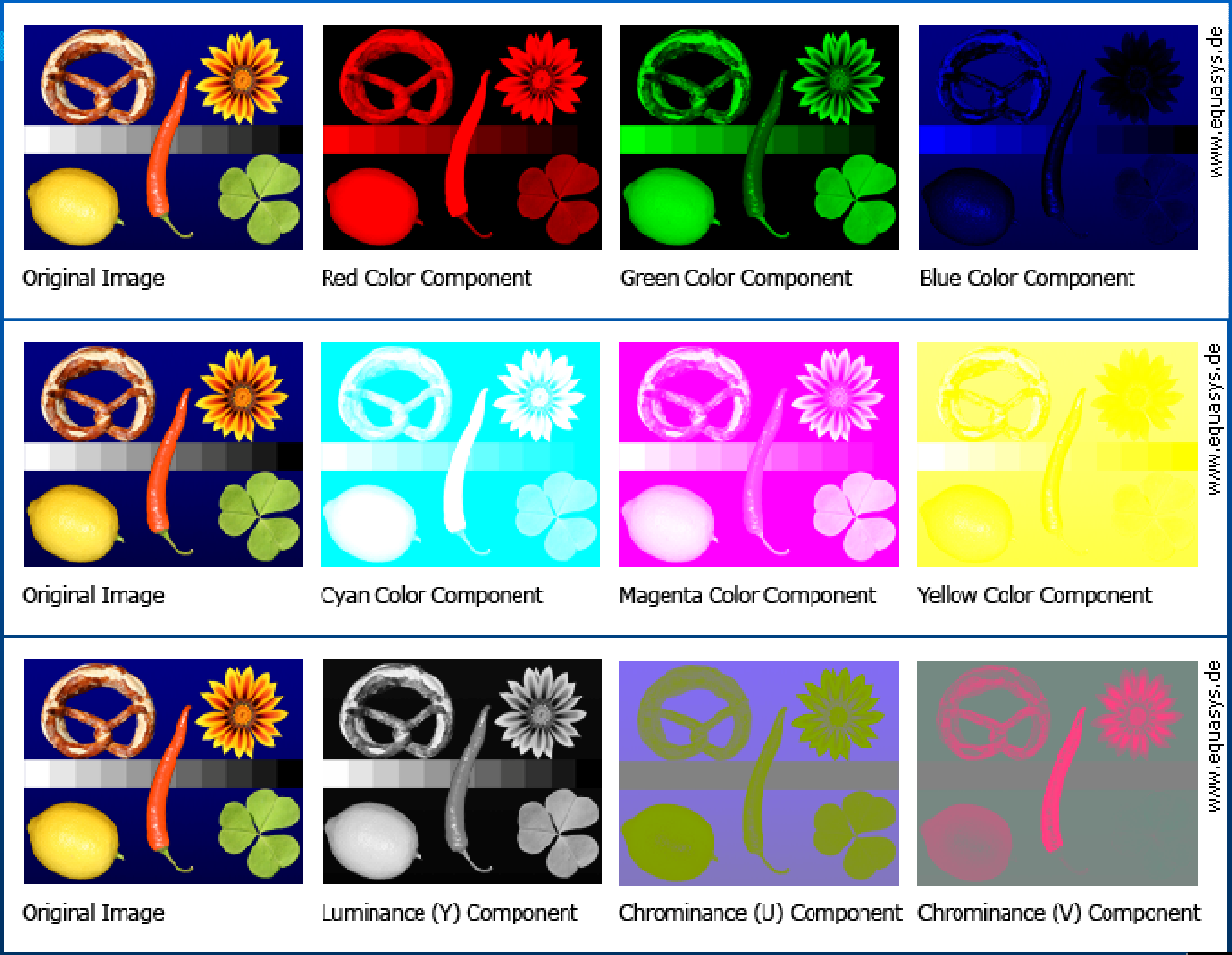
RGB, CMY, YUV



Original Image
Red Color Component
Green Color Component
Blue Color Component
www.equasys.de
Original Image
Cyan Color Component
Magenta Color Component
Yellow Color Component
www.equasys.de
Original Image
Luminance (Y) Component
Chrominance (U) Component
Chrominance (V) Component
www.equasys.de

Color Space Conversion

RGB and YUV

RGB to YUV

```
Y  =         (0.257 * R) + (0.504 * G) + (0.098 * B) + 16
Cr = V =   (0.439 * R) - (0.368 * G) - (0.071 * B) + 128
Cb = U = -(0.148 * R) - (0.291 * G) + (0.439 * B) + 128
```

YUV to RGB

```
B = 1.164(Y - 16)                     + 2.018(U - 128)
G = 1.164(Y - 16) - 0.813(V - 128) - 0.391(U - 128)
R = 1.164(Y - 16) + 1.596(V - 128)
```

Color Space Conversion

RGB and CMYK

CMY to RGB

$$\begin{aligned} Red &= 1 - Cyan \\ Green &= 1 - Magenta \\ Blue &= 1 - Yellow \end{aligned}$$

RGB to CMY

$$\begin{aligned} Cyan &= 1 - Red \\ Magenta &= 1 - Green \\ Yellow &= 1 - Blue \end{aligned}$$

CMY to CMYK

$$\begin{aligned} Black &= minimum(Cyan, Magenta, Yellow) \\ Cyan &= (Cyan - Black)/(1 - Black) \\ Magenta &= (Magenta - Black)/(1 - Black) \\ Yellow &= (Yellow - Black)/(1 - Black) \end{aligned}$$

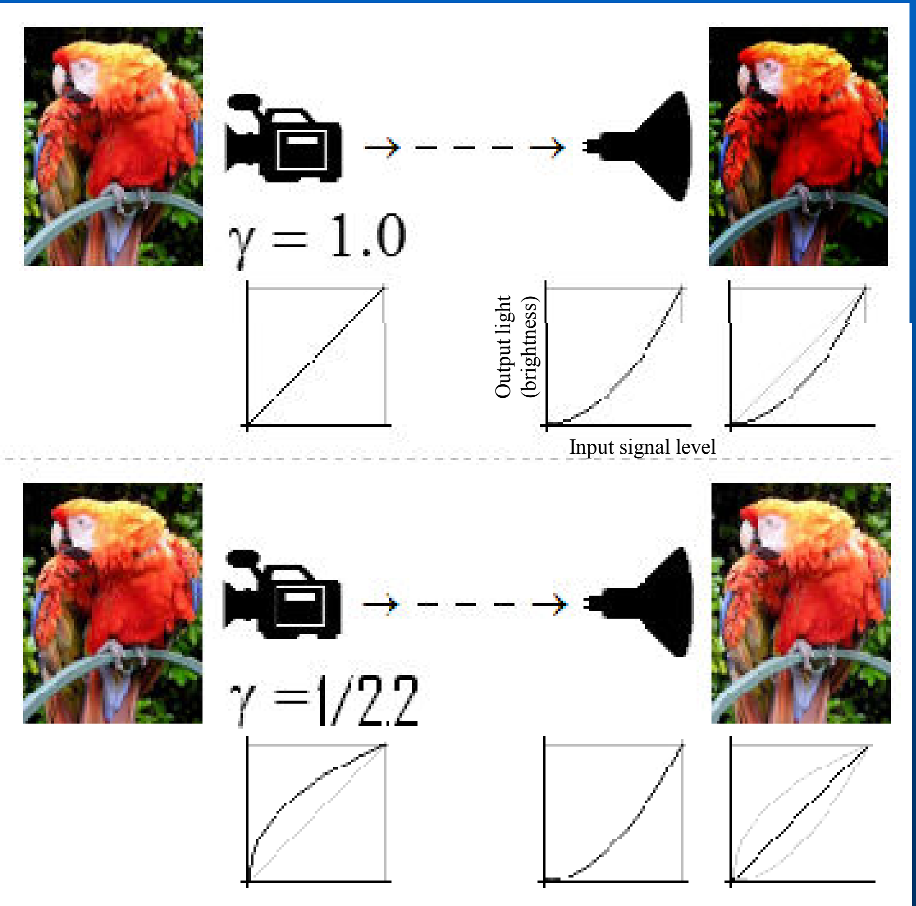
CMYK to CMY

$$\begin{aligned} Cyan &= minimum(1, Cyan * (1 - Black) + Black) \\ Magenta &= minimum(1, Magenta * (1 - Black) + Black) \\ Yellow &= minimum(1, Yellow * (1 - Black) + Black) \end{aligned}$$

Color Space

Gamma Correction

$$\gamma = \frac{\log(V_{out})}{\log(V_{in})}$$



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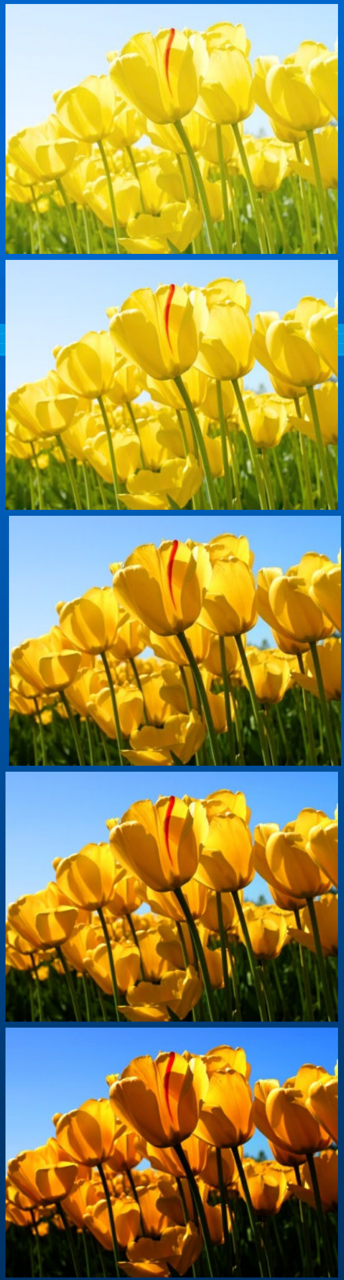
Gamma control in HDTVs (May be found in advanced picture settings menu)

Source: Piers Clerk, ISF Calibrator, www.homecinemaengineering.com

Low gamma



High gamma

Looks “milky”, flat and lacks punch

Low gamma (e.g. 1.5)

With visible details in the black areas and white areas.

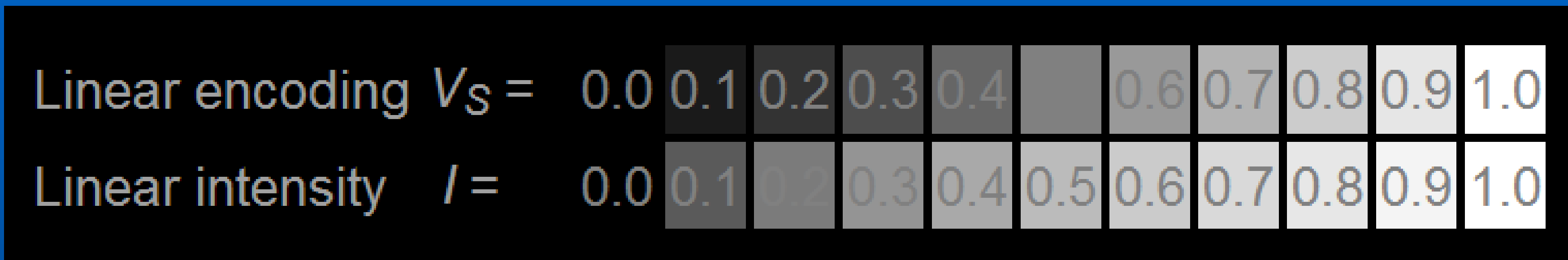
Normal gamma (e.g. 2.2)

Has loads of punch; but no detail in the black areas

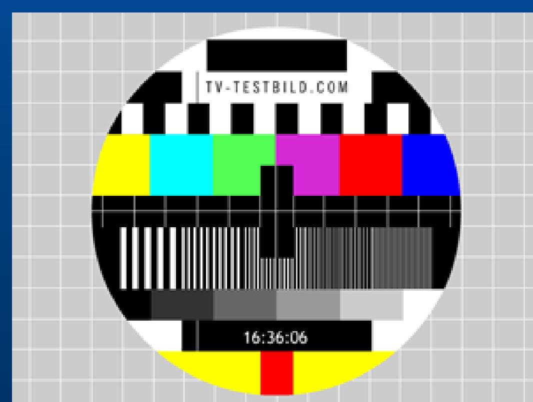
High gamma (e.g. 3.0)

Color Space

Gamma Correction

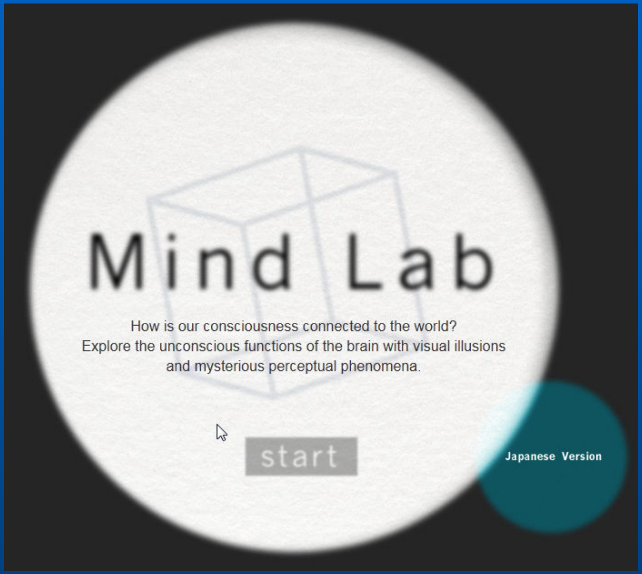


Difference between a scale with linearly-increasing encoded luminance signal (linear input) and a scale with linearly-increasing intensity (i.e., gamma-corrected) scale (linear output).



Visual perception

Visit Mind Lab Website



http://jvsc.jst.go.jp/find/mindlab/english/index.html

How is our consciousness connected to the world?

Explore the unconscious functions of the brain with visual illusions and mysterious perceptual phenomena

Thank You

Next Session: Image I

FIND OUT MORE AT...

1. http://ce.sharif.edu/~m_amiri/

2. http://www.dml.ir/