Lecture
Computer Vision
Chapter 1 – Introduction

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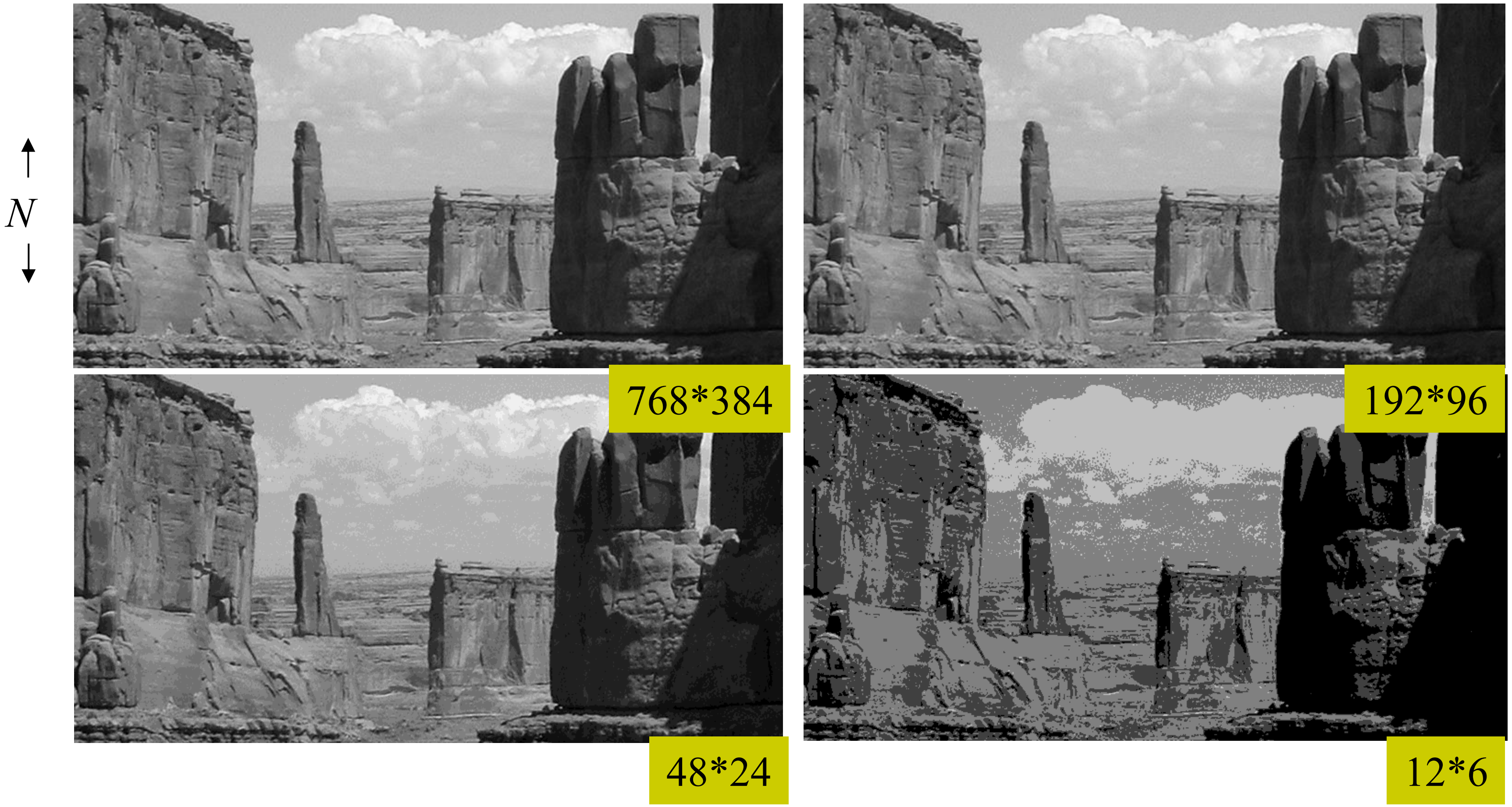
Image Representation - Introduction

- Representation at pixel level does not represent well visual content

- Task: Find appropriate representations for
  - color
  - shape
  - texture
  - objects
  - regions

Spatial Resolution
(German: „Ortsauflösung“)



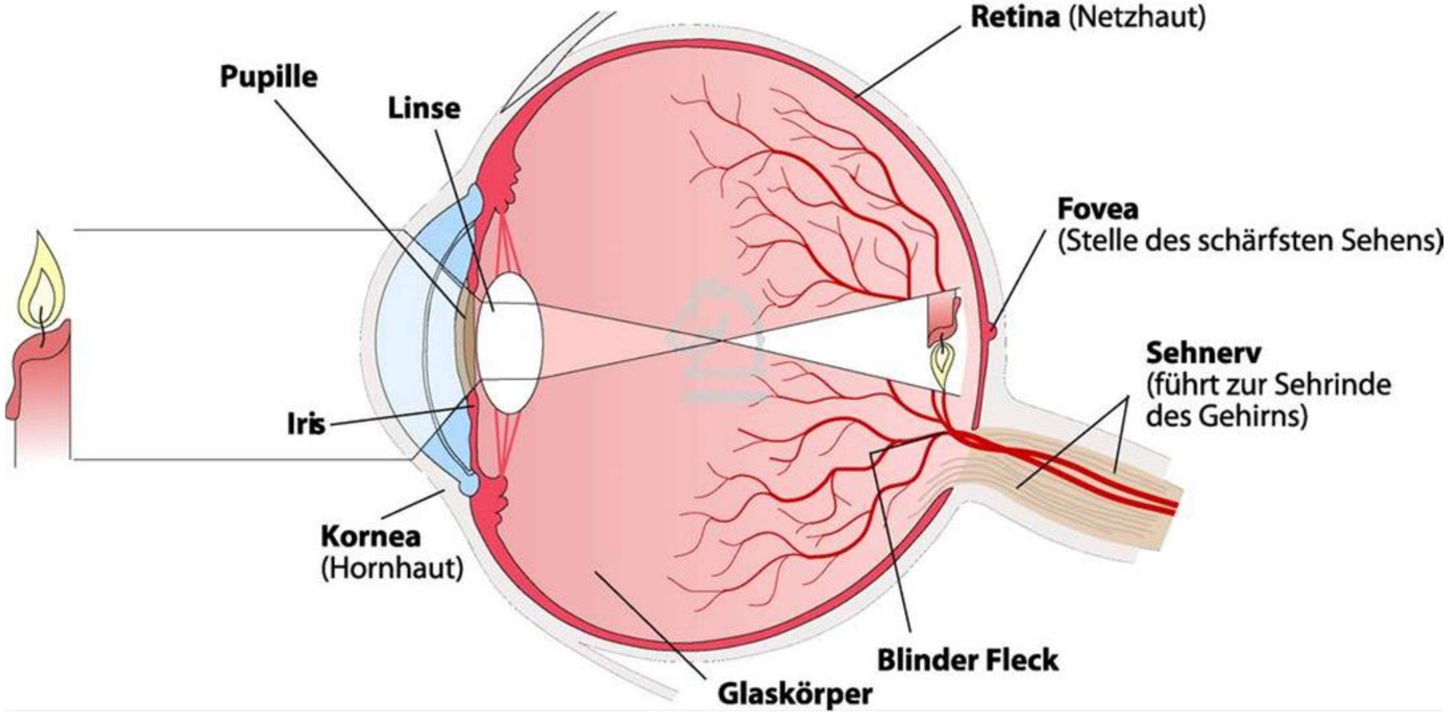
Source: K. Tönnies, Lecture material „Grundlagen der Bildverarbeitung“, 2005

Resolution of Luminance

Source: K. Tönnies, Lecture material „Grundlagen der Bildverarbeitung“, 2005

Reduction of contrast (number of grey levels) has less impact on image perception / scene recognition than reducing spatial resolution

Human Eye

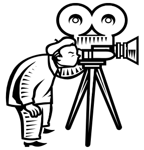


Source: Prof. Schwaninger,
http://www.casra.ch/en/about-us/team/teaching/101002-grundlagen-der-allgemeinen-psychologie-wahrnehmungspsychologie.html

Today‘s Film Recommendation
from TIB AV-Portal (av.tib.eu)

„Die Umkehrbrille und das aufrechte Sehen“

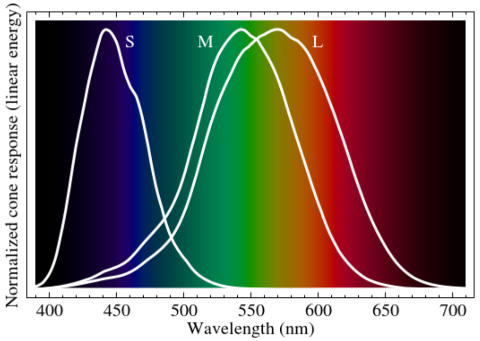
Stummfilm, 1950

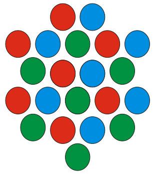


https://av.tib.eu/media/10429?1086

Color perception

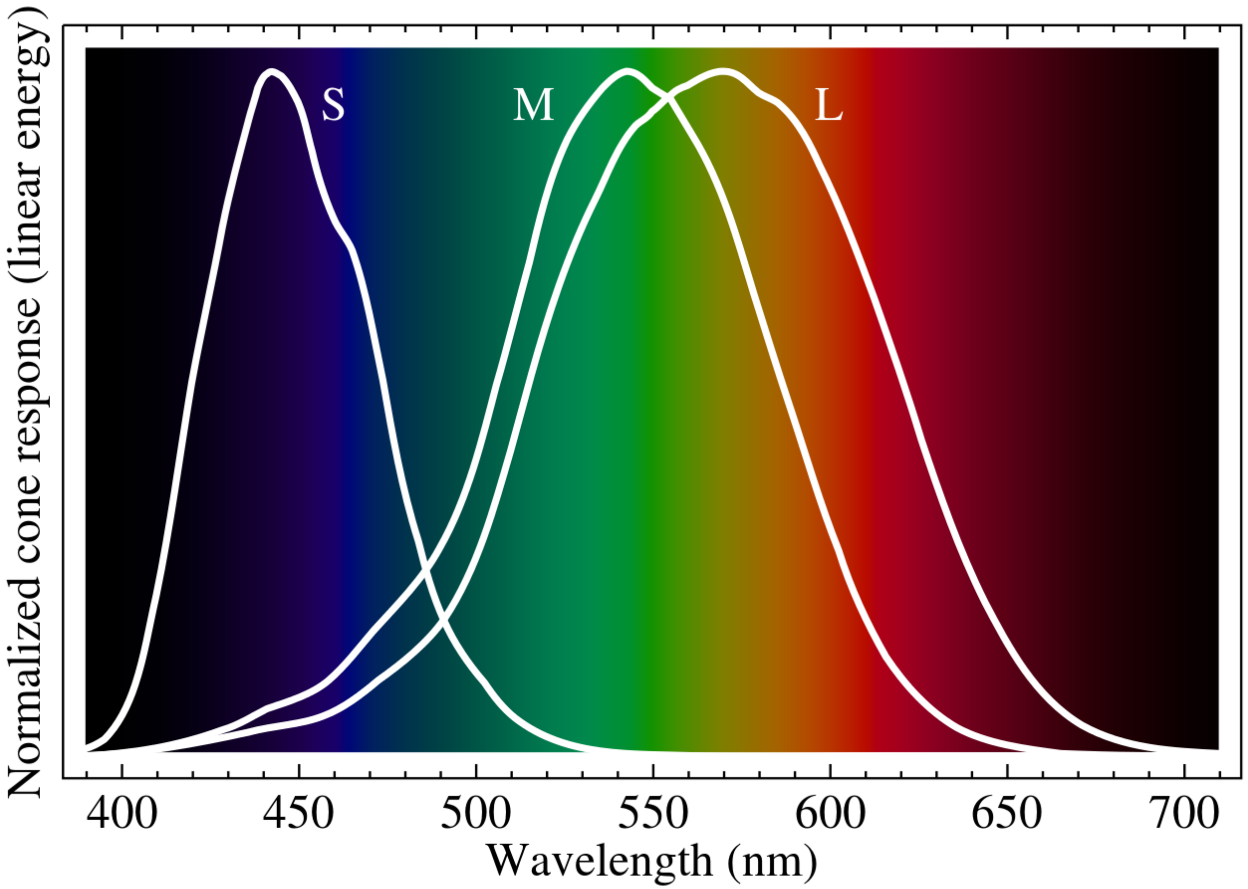
1. Color perception relies on three cell types of cones (“Zapfen”)
    - Their sensitivity with respect to wavelength differs significantly
    - All “visible” wave lengths approximated by 3 basis waves (spectra)
    - Color can be represented via an additive red-green-blue signal
2. Brightness is perceived via rods (“Stäbchen”)





Source of image (oublicc domain)
https://en.wikipedia.org/wiki/Color_vision#/media/File:Cone-fundamentals-with-srgb-spectrum.svg

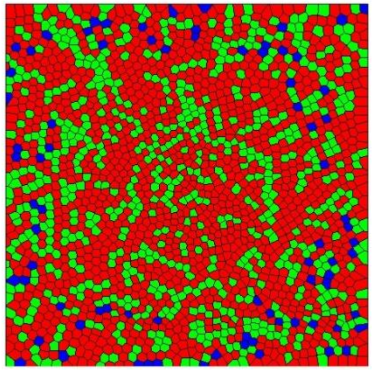
Color Response of Cone Cells



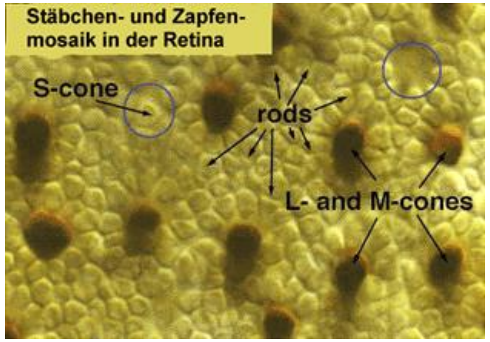
Source of image (oublicc domain)
https://en.wikipedia.org/wiki/Color_vision#/media/File:Cone-fundamentals-with-srgb-spectrum.svg

Human Perception:
„Resolution“ of Luminance and Color

1. Cone cells („Zapfen“):
   - ~6 millions
   - Active only for day light
   - Broader than rod cells



2. Rod cells („Stäbchen“)
   - ~120 millions (!):
   - „Resolution“
   - Always actice, even for low light intensity
   - can even measure low number of photons



Source of image (top): http://www.allpsych.uni-giessen.de/karl/html/heidelberg/heidelberg.html
Source of image (bottom): http://www.zum.de/Faecher/Materialien/beck/12/bs12-36.htm

Modelling Color
Different Color Spaces

1. RGB: Red, Green, Blue

2. HSB/HSV/HLS
   - Hue
   - Saturation
   - Brightness (or Value, or Lightness)

3. YC_bC_r (YUV in analog world)
   - Y: Luminance
   - C_b: Blue difference level
   - C_r: Red difference level

4. There are many other color spaces…

Modelling Color with RGB Color Space

RGB color cube: Red, Green, Blue

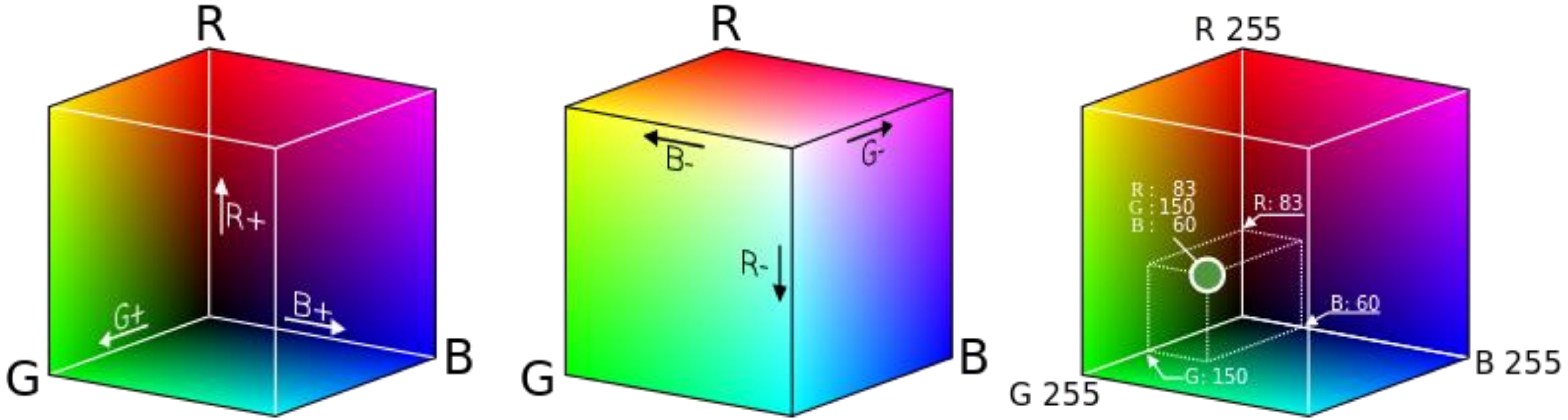
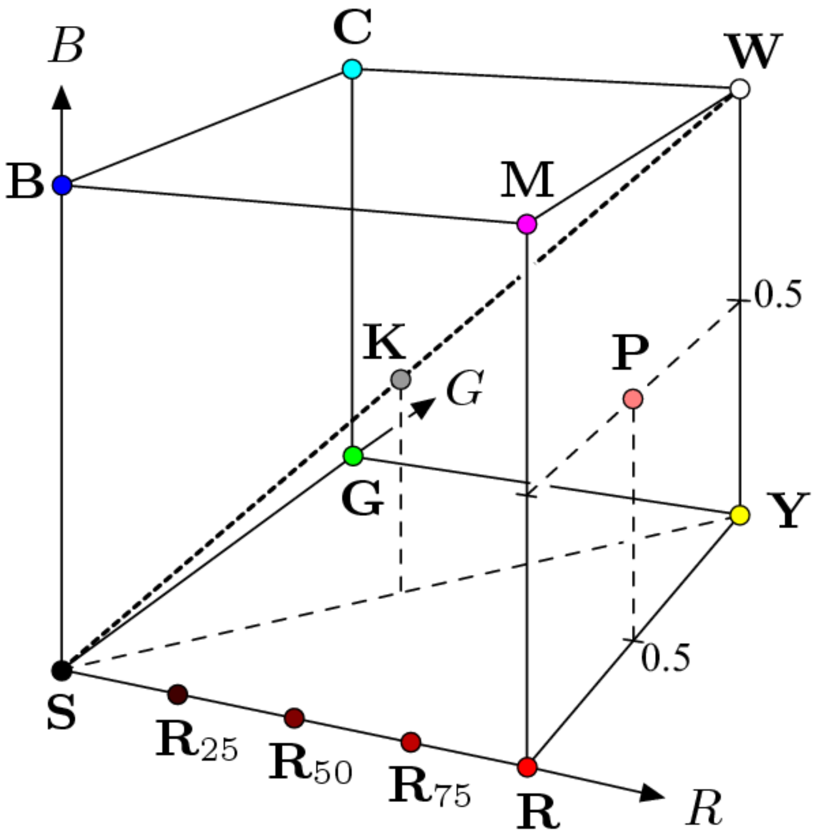


Image source: https://commons.wikimedia.org/wiki/File:RGB_color_cube.svg?uselang=de

RGB Color Space

$$\mathbf{C}_i = (R_i, G_i, B_i)$$ RGB color pixel



RGB-Werte

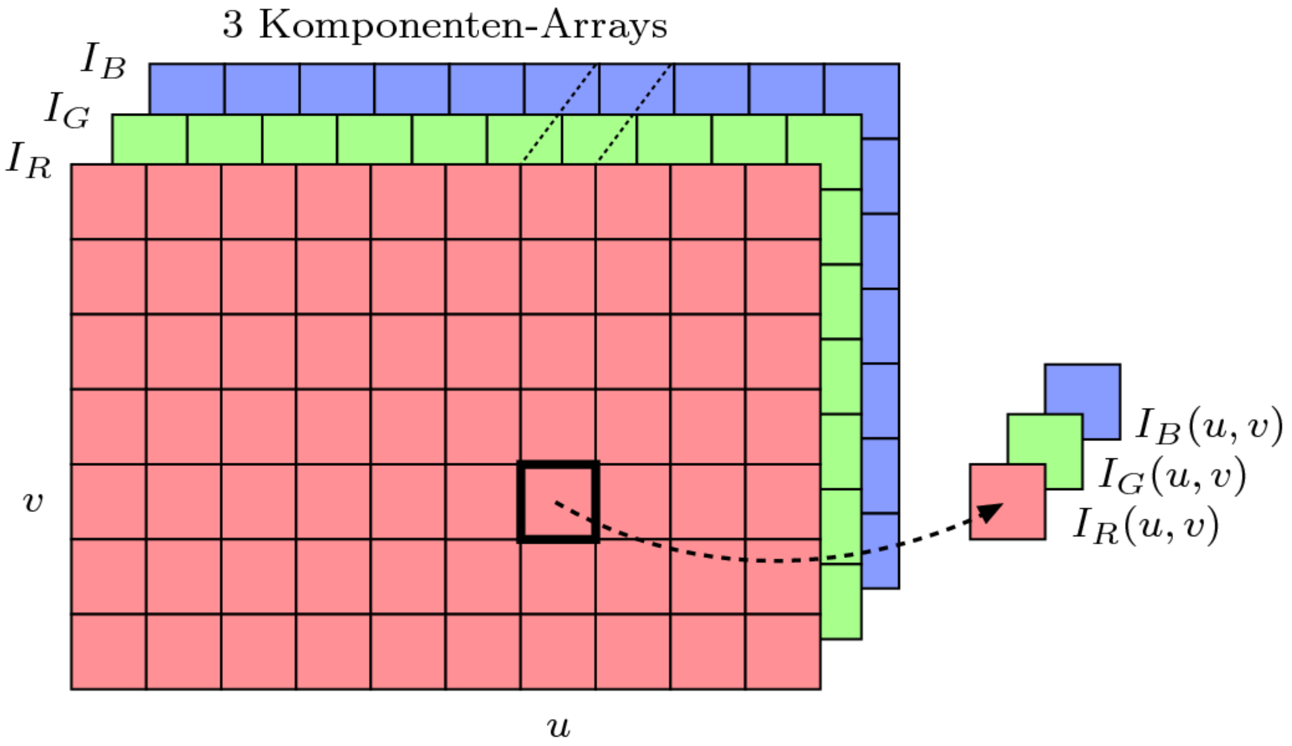
Pkt.	Farbe	R	G	B
S	Schwarz	0.00	0.00	0.00
R	Rot	1.00	0.00	0.00
Y	Gelb	1.00	1.00	0.00
G	Grün	0.00	1.00	0.00
C	Cyan	0.00	1.00	1.00
B	Blau	0.00	0.00	1.00
M	Magenta	1.00	0.00	1.00
W	Weiß	1.00	1.00	1.00
K	50% Grau	0.50	0.50	0.50
$\mathbf{R}_{75}$	75% Rot	0.75	0.00	0.00
$\mathbf{R}_{50}$	50% Rot	0.50	0.00	0.00
$\mathbf{R}_{25}$	25% Rot	0.25	0.00	0.00
P	Pink	1.00	0.50	0.50

RGB Color Components (Channels)

R G B

Image Representation in Memory/Files
Ordered by Components (RGB)

- „Planes“: Three compononets are separeted in 3 arrays of same size
- In memory or in files, these arrays are linear, of course

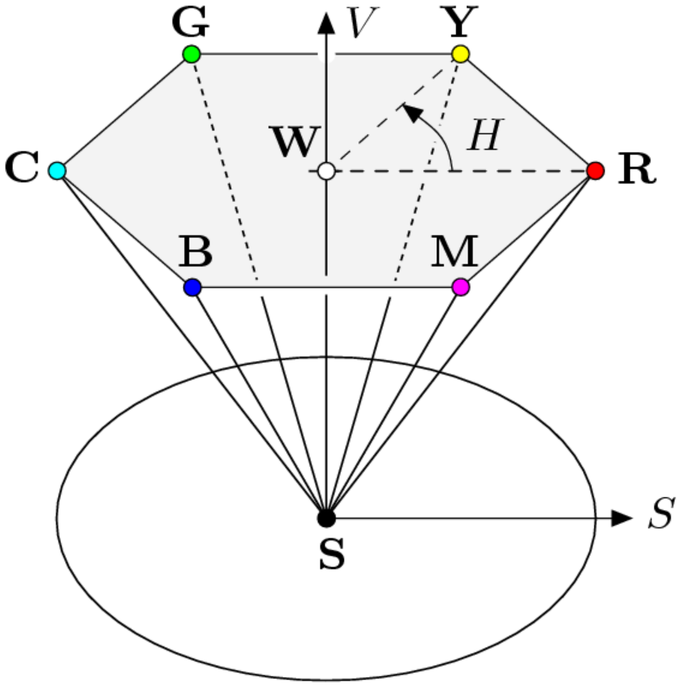


RGB Color Space

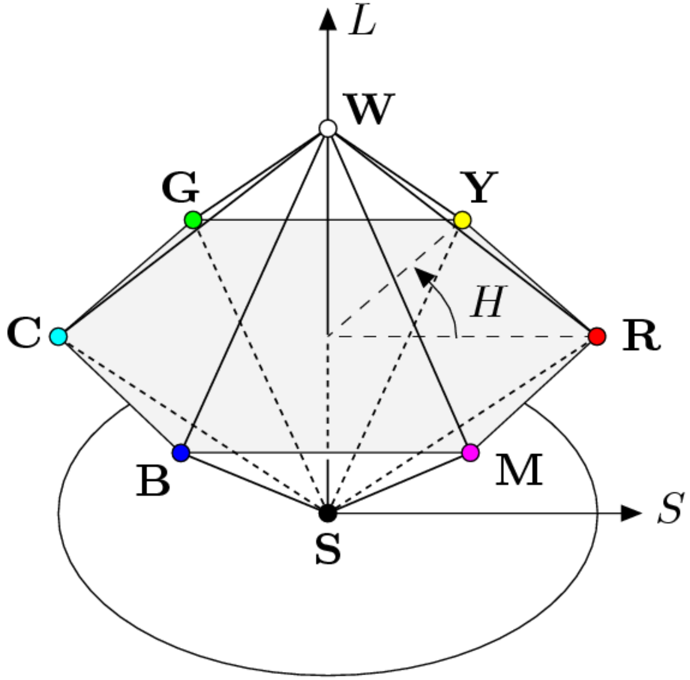
- According to monitors and display technology
- Easily usable from a programmer‘s perspective
- But
  - changes in RGB can be perceived differently, RGB is non-linear
  - if RGB value changes: Hue ***and*** saturation ***and*** brightness change
  - color properties are not represented explicitly
- Properties of displaying RGB are not defined
  - Appearance of colors depends on output device
  - This is addressed by more sophisticated color spaces

HSV and HLS Color Space

Hue ● Saturation ● Value/Lightness (traditional representations)



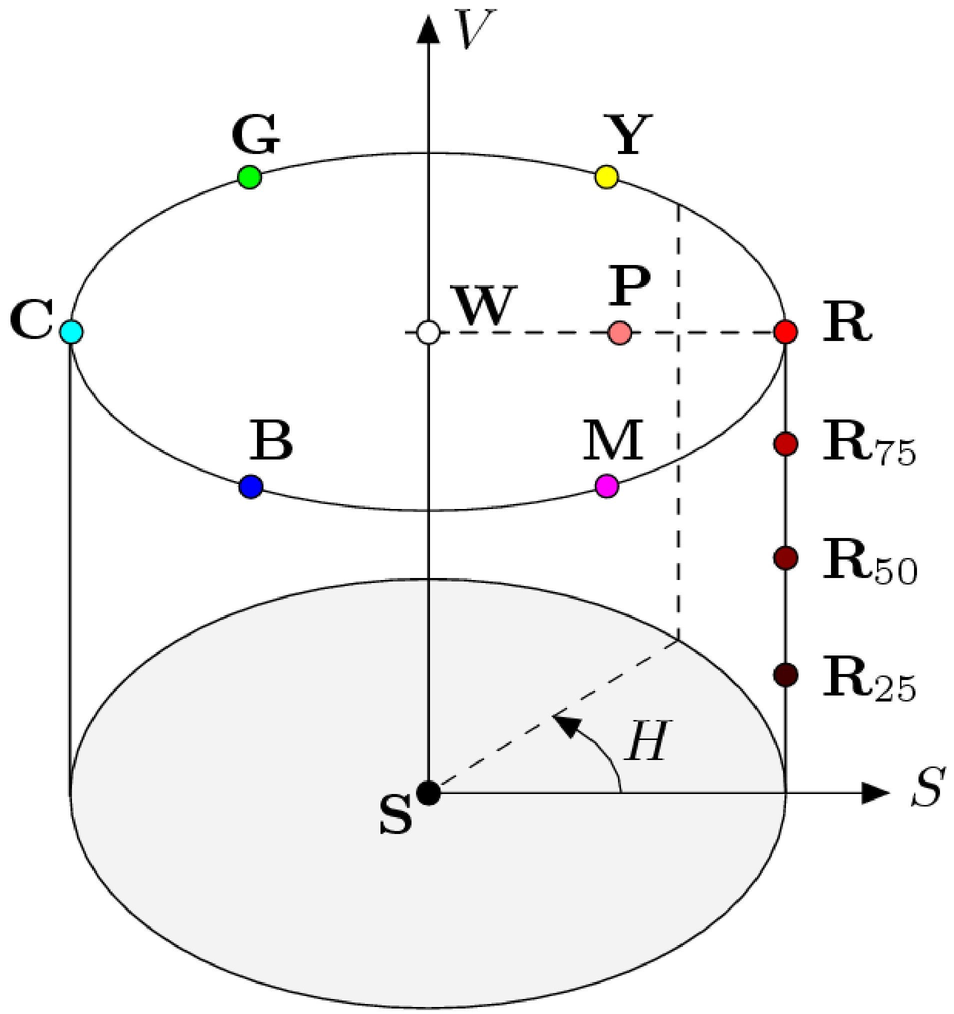
HSV color space



HLS color space

HSV Color Space (also HSB, HSI)

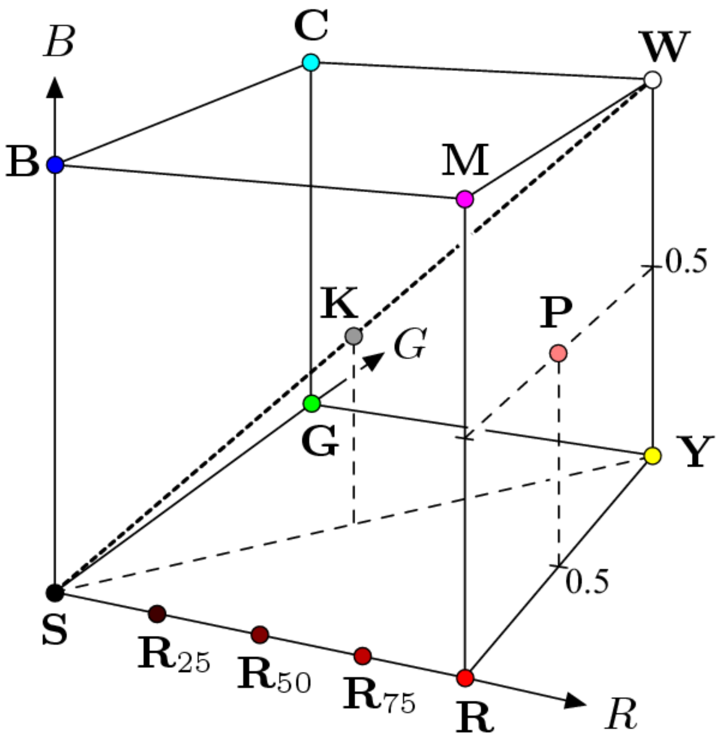
HSV: Hue/Saturation/Value
HSB: Hue/Saturation/Brightness
HSI: Hue/Saturation/Intensity

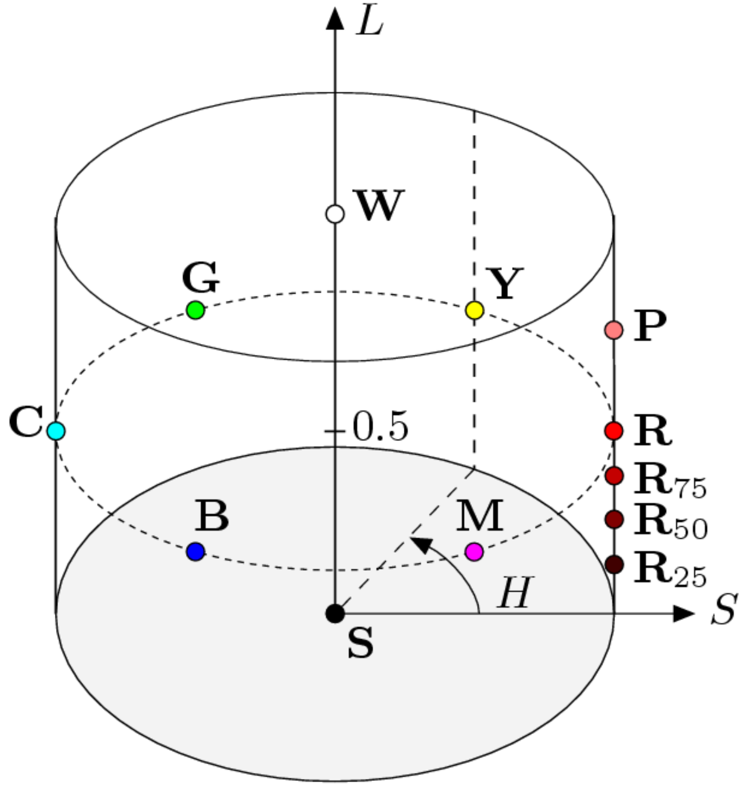


HLS Color Space (also HSL)

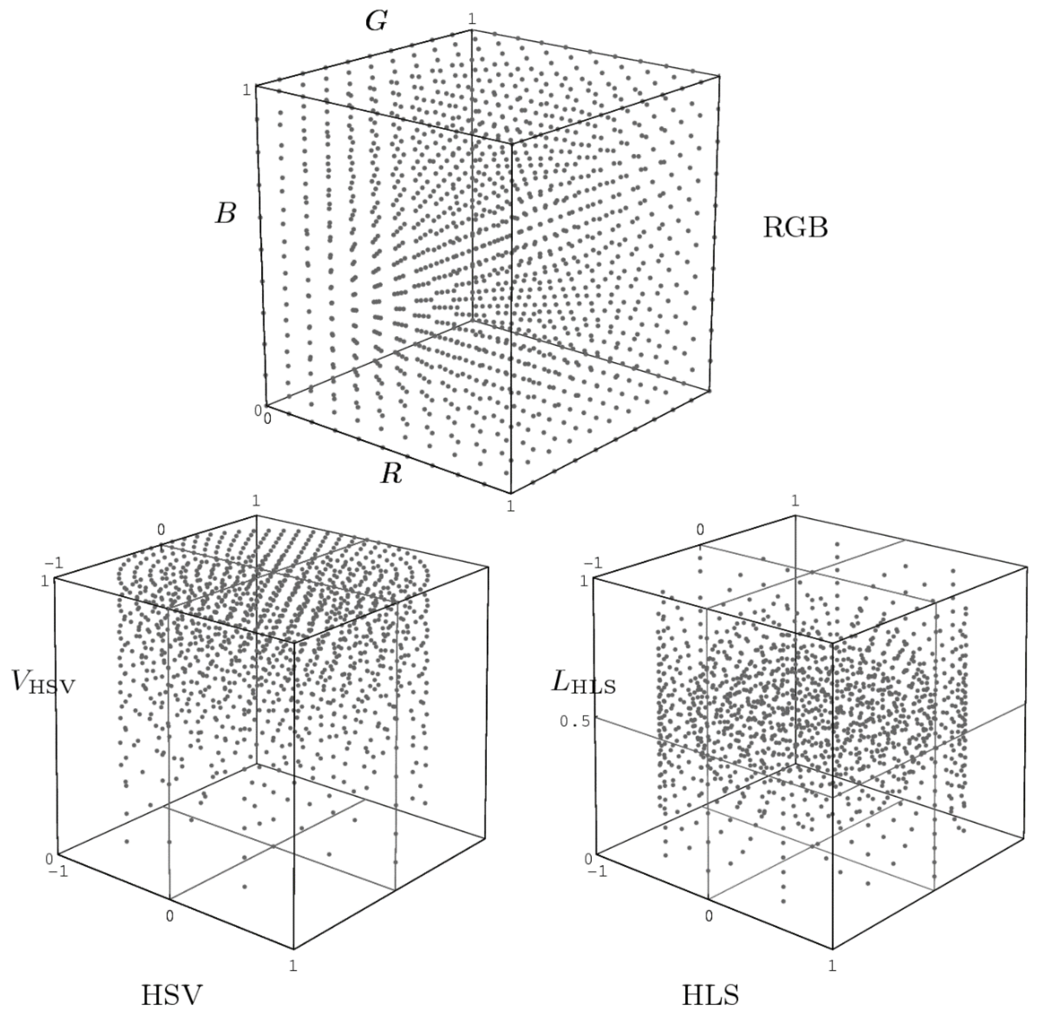
HLS: Hue/Lightness/Saturation (realistic representation)

HSL: Hue/Saturation/Lightness





Color Distribution in RGB/HSV/HLS



Assuming an equal distribution of colors in RGB

Color Space Conversion
RGB -> HSV (1)

Intermediate values

$$\boxed{C_{\text{high}} = \max(R,G,B),\ C_{\text{low}} = \min(R,G,B),\ C_{\text{rng}} = C_{\text{high}} - C_{\text{low}}}$$

Saturation

$$S_{\text{HSV}} = \begin{cases} \frac{C_{\text{rng}}}{C_{\text{high}}} & \text{für } \ C_{\text{high}} > 0 \\ 0 & \text{sonst} \end{cases}$$

Value

$$V_{\text{HSV}} = \frac{C_{\text{high}}}{C_{\max}}$$

Color Space Conversion
RGB → HSV (2)

Intermediate

$$\boxed{C_{\text{high}} = \max(R, G, B),\ C_{\text{low}} = \min(R, G, B),\ C_{\text{rng}} = C_{\text{high}} - C_{\text{low}}}$$

$$R' = \frac{C_{\text{high}} - R}{C_{\text{rng}}}, \qquad G' = \frac{C_{\text{high}} - G}{C_{\text{rng}}}, \qquad B' = \frac{C_{\text{high}} - B}{C_{\text{rng}}}$$

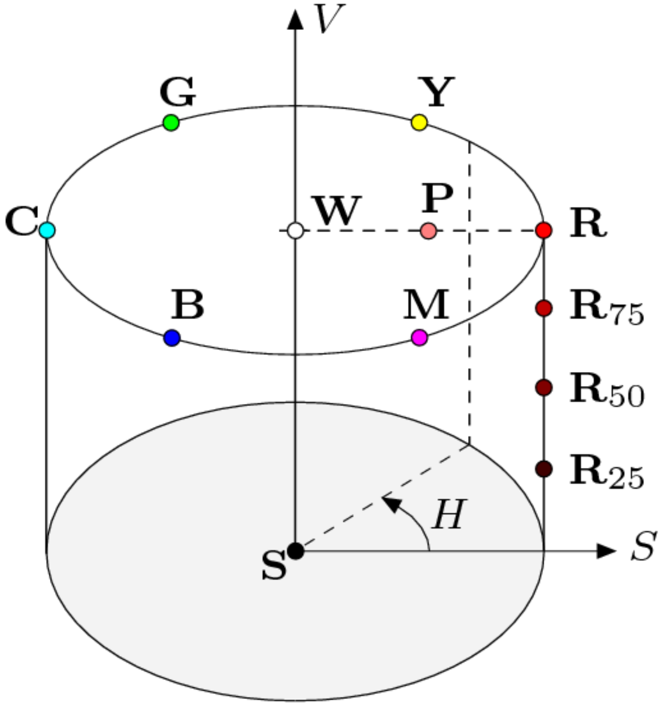
$$H' = \begin{cases} B' - G' & \text{wenn} \quad R = C_{\text{high}} \\ R' - B' + 2 & \text{wenn} \quad G = C_{\text{high}} \\ G' - R' + 4 & \text{wenn} \quad B = C_{\text{high}} \end{cases}$$

Hue

$$H_{\text{HSV}} \leftarrow \frac{1}{6} \cdot \begin{cases} (H' + 6) & \text{für } H' < 0 \\ H' & \text{sonst.} \end{cases}$$

All values in [0,1]

Some Particular HSV Color Values



RGB-/HSV-Werte

Pkt.	Farbe	R	G	B	H	S	V
S	Schwarz	0.00	0.00	0.00	—	0.00	0.00
R	Rot	1.00	0.00	0.00	0	1.00	1.00
Y	Gelb	1.00	1.00	0.00	1/6	1.00	1.00
G	Grün	0.00	1.00	0.00	2/6	1.00	1.00
C	Cyan	0.00	1.00	1.00	3/6	1.00	1.00
B	Blau	0.00	0.00	1.00	4/6	1.00	1.00
M	Magenta	1.00	0.00	1.00	5/6	1.00	1.00
W	Weiß	1.00	1.00	1.00	—	0.00	1.00
$\mathbf{R}_{75}$	75% Rot	0.75	0.00	0.00	0	1.00	0.75
$\mathbf{R}_{50}$	50% Rot	0.50	0.00	0.00	0	1.00	0.50
$\mathbf{R}_{25}$	25% Rot	0.25	0.00	0.00	0	1.00	0.25
P	Pink	1.00	0.50	0.50	0	0.5	1.00

Color Space Conversion:
RGB -> HLS

$$\boxed{C_{\text{high}} = \max(R, G, B),\ C_{\text{low}} = \min(R, G, B),\ C_{\text{rng}} = C_{\text{high}} - C_{\text{low}}}$$

Hue

$$H_{\text{HLS}} = H_{\text{HSV}}$$

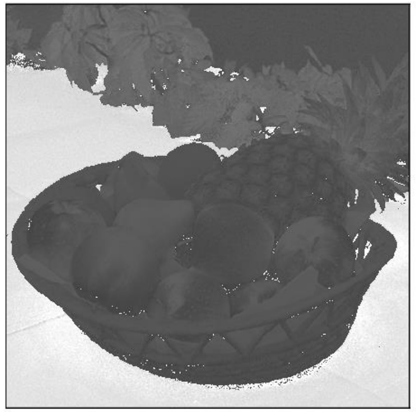
Lightness

$$L_{\text{HLS}} \leftarrow \frac{C_{\text{high}} + C_{\text{low}}}{2}$$

Saturation

$$S_{\text{HLS}} \leftarrow \begin{cases} 0 & \text{für } L_{\text{HLS}} = 0 \\ 0.5 \cdot \frac{C_{\text{rng}}}{L_{\text{HLS}}} & \text{für } 0 < L_{\text{HLS}} \leq 0.5 \\ 0.5 \cdot \frac{C_{\text{rng}}}{1 - L_{\text{HLS}}} & \text{für } 0.5 < L_{\text{HLS}} < 1 \\ 0 & \text{für } L_{\text{HLS}} = 1 \end{cases}$$

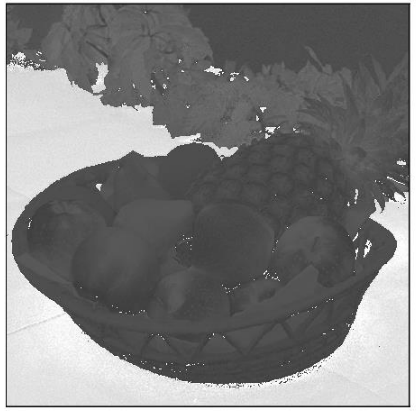
Examples for HSV and HLS



h_{HSV}

s_{HSV}

v_{HSV}

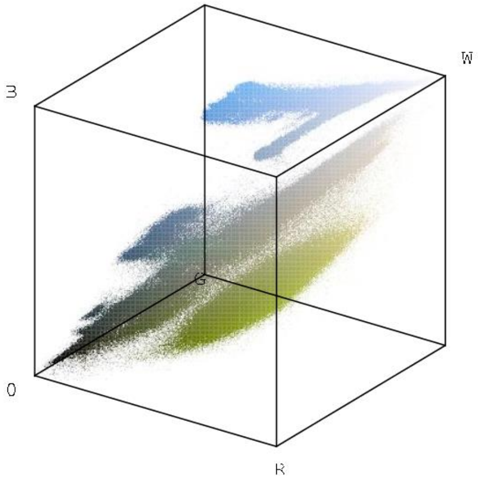


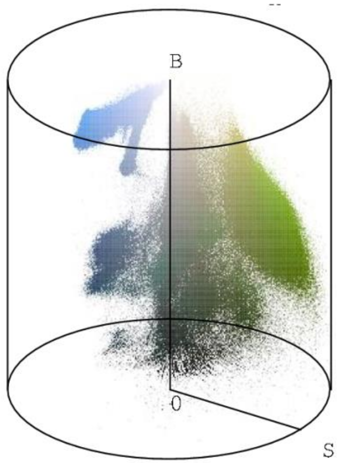
H_{HLS}

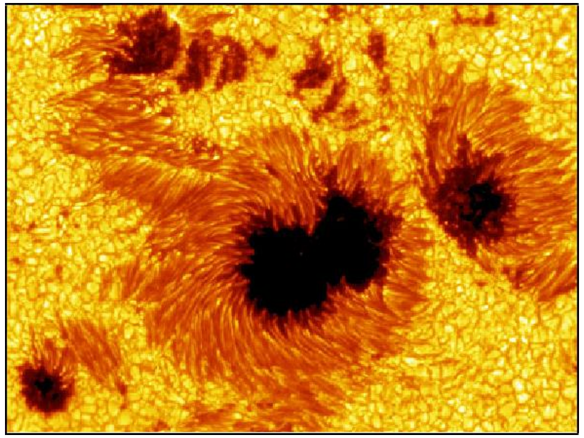
L_{HLS}

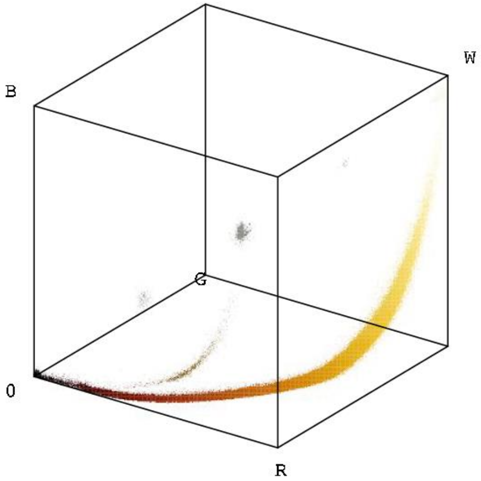
S_{HLS}

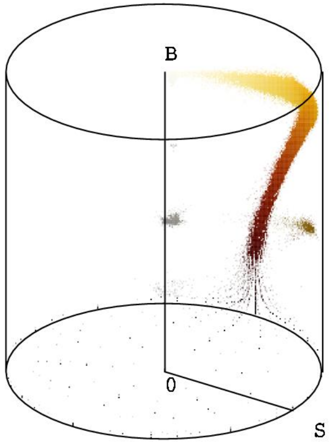
Color Distribution in RGB and HSV











Color Spaces for TV (Television)

- YUV/ YC_bC_r: Color space(s) for standardized recording, storage, transmission and display of color TV video (frames)
- Color space is separated in (analog TV)

  1 luminance componente Y and

  2 color components U, V
- YUV -> PAL/NTSC analog TV
- YC_bC_r -> digital TV
- Subsampling of chrominance (Cb, Cr) is used very often
  - „4:2:2“: only 1 Cb + 1 Cr is sampled for 2 pixels
  - „4:2:0“: only 1 Cb + 1 Cr is sampled for 4 pixels

YUV (Component) Color Space

- Color space conversion: YUV -> RGB

$$Y = 0.299 \cdot R + 0.587 \cdot G + 0.114 \cdot B$$
$$U = 0.492 \cdot (B - Y)$$
$$V = 0.877 \cdot (R - Y)$$

- In matrix form (linear mapping)

  RGB -> YUV

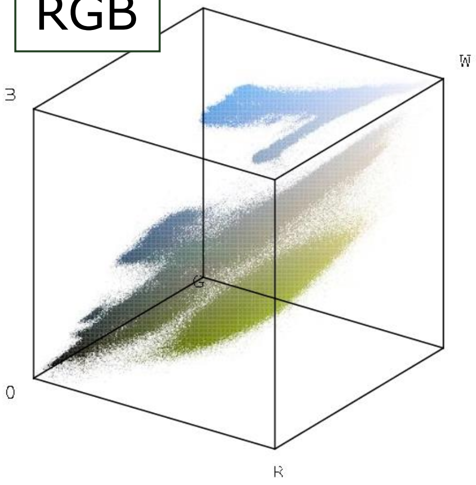
$$\begin{pmatrix} Y \\ U \\ V \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & -0.100 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

  YUV -> RGB

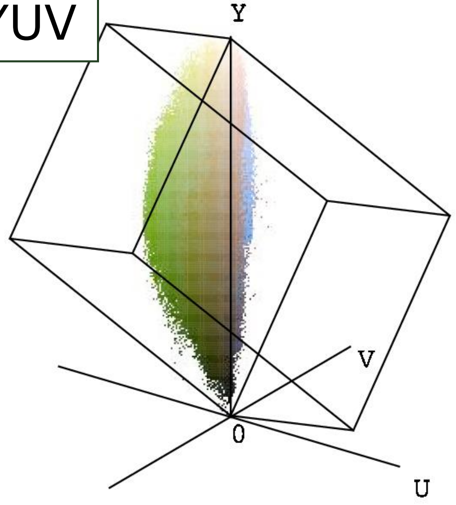
$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.000 & 0.000 & 1.140 \\ 1.000 & -0.395 & -0.581 \\ 1.000 & 2.032 & 0.000 \end{pmatrix} \cdot \begin{pmatrix} Y \\ U \\ V \end{pmatrix}$$

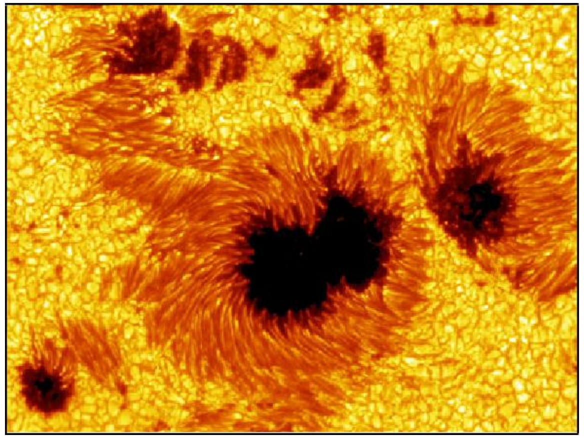
Color Distribution in RGB/YUV

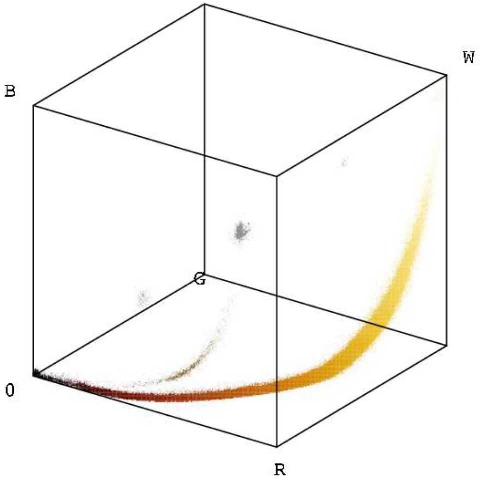
RGB

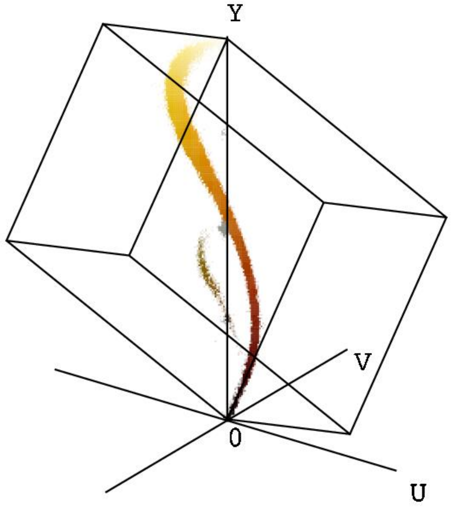


YUV









YC_bC_r Component Color Space

- Variant (extension) of YUV, international standard für digital TV
- Common for JPEG (JFIF, EXIF) as well

- RGB → YC_bC_r

$$\begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix} = \begin{pmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{pmatrix} \cdot \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

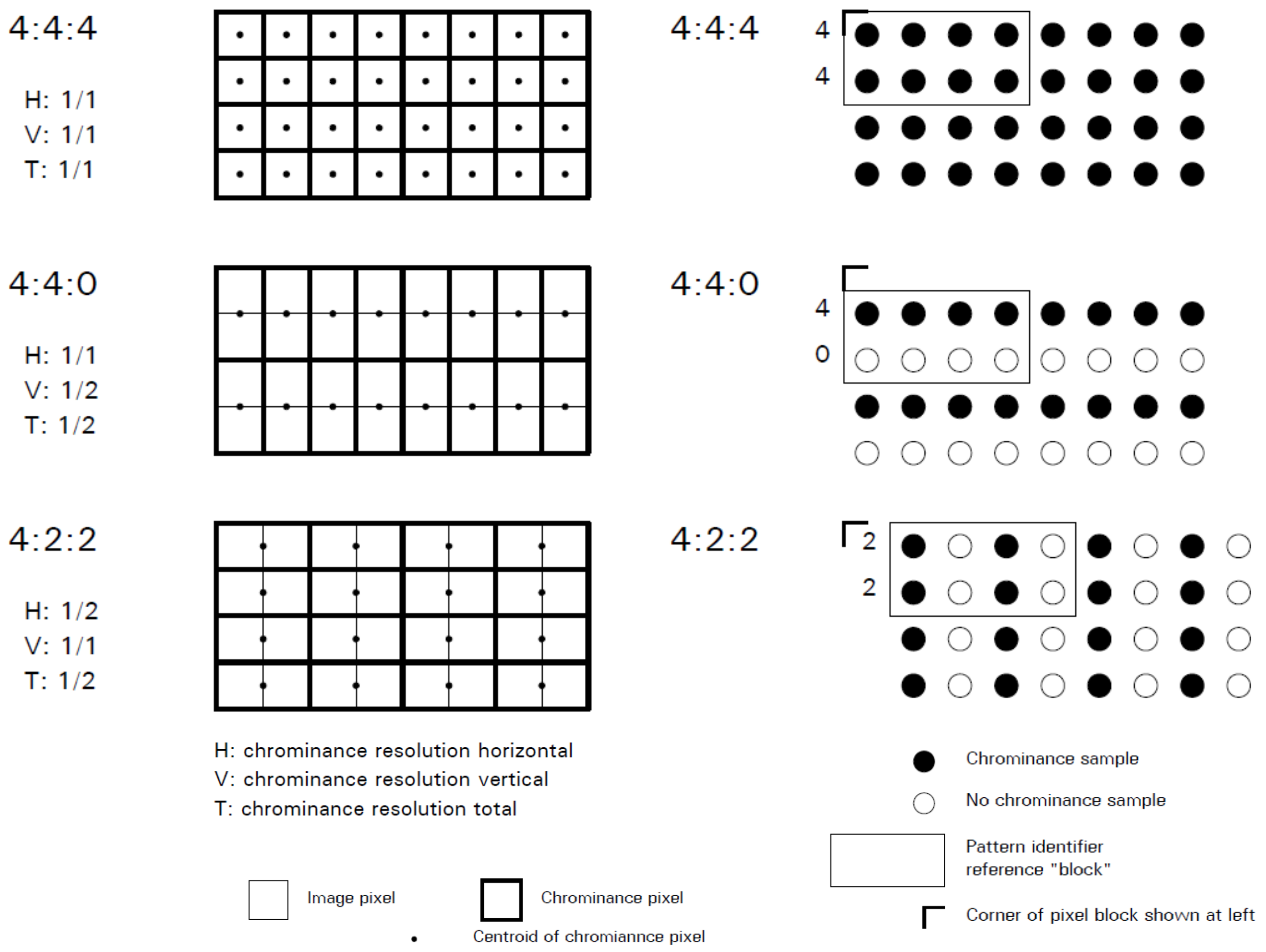
- YC_bC_r → RGB

$$\begin{pmatrix} R \\ G \\ B \end{pmatrix} = \begin{pmatrix} 1.000 & 0.000 & 1.403 \\ 1.000 & -0.344 & -0.714 \\ 1.000 & 1.773 & 0.000 \end{pmatrix} \cdot \begin{pmatrix} Y \\ C_b \\ C_r \end{pmatrix}$$

ITU-BT.601 (4:3 & 16:9 Digital-TV): $w_R=0.2990$, $w_B=0.114$

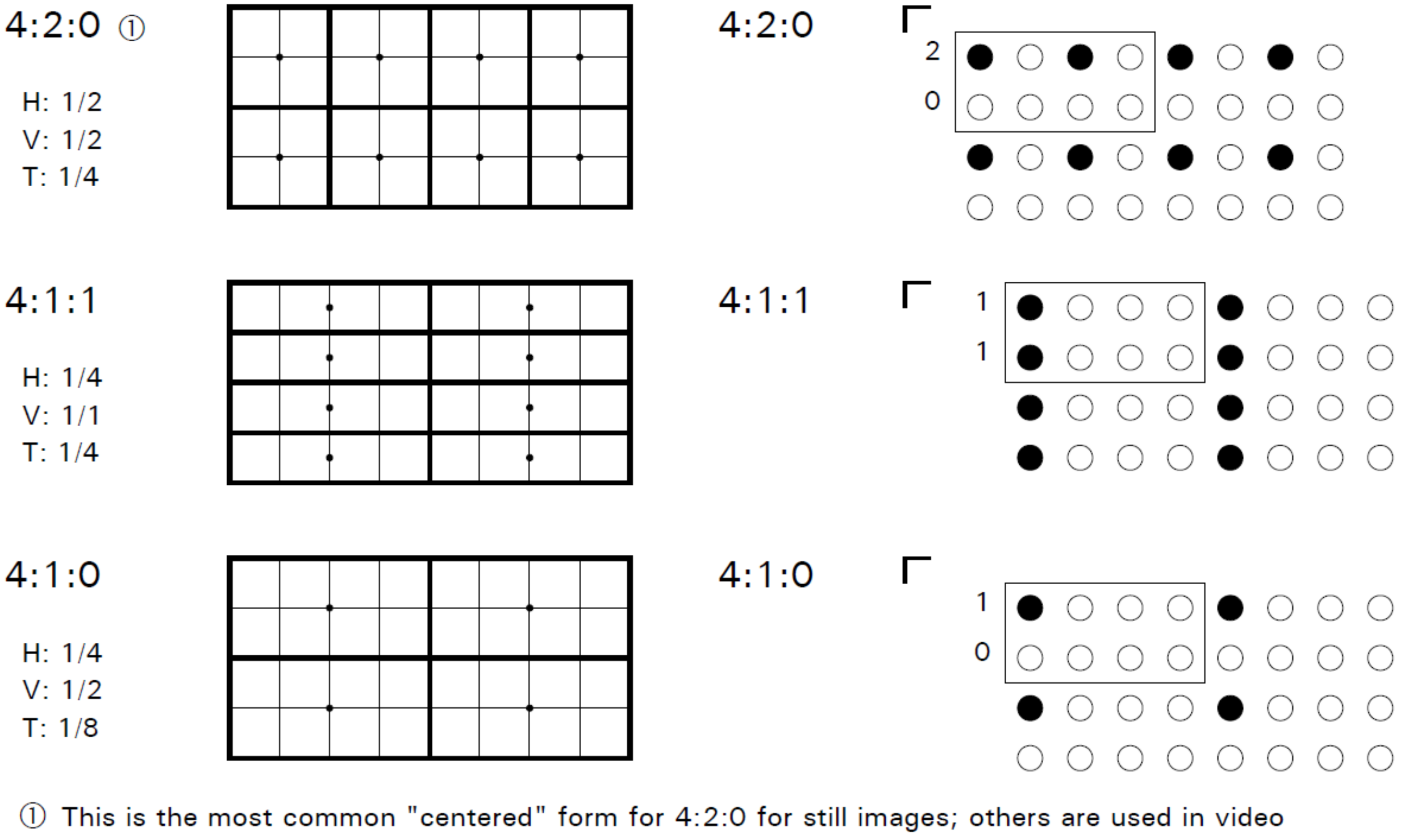
ITU-BT.709 (Digital-HDTV): $w_R=0.2125$, $w_B=0.0721$

Chrominance Subsampling



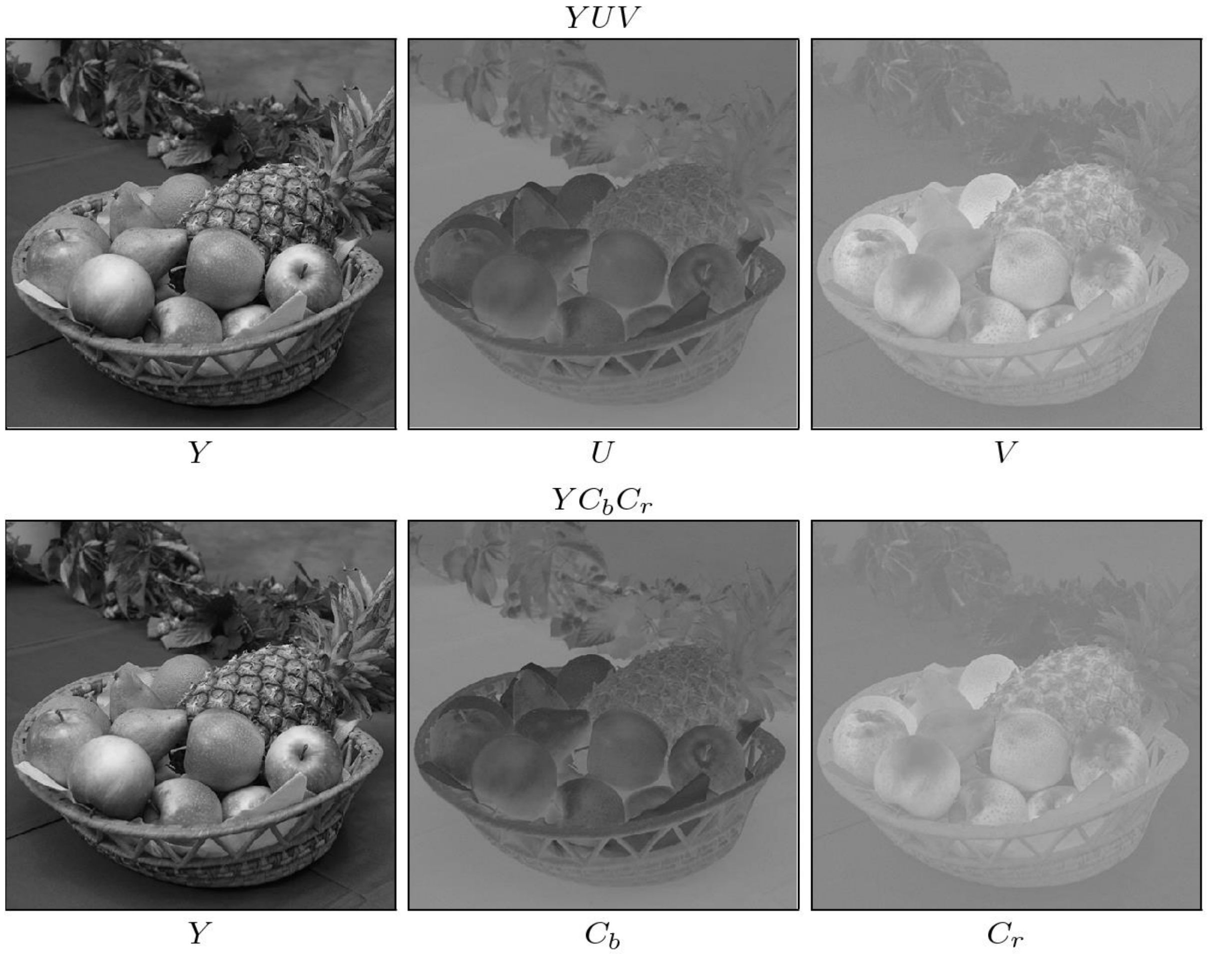
Source: Kerr, Douglas, 2012, http://dougkerr.net/pumpkin/articles/Subsampling.pdf

Chrominance Subsampling



Source: Kerr, Douglas, 2012, http://dougkerr.net/pumpkin/articles/Subsampling.pdf

Example: YUV and YC_bC_r Components



Lessons learned

- (Very) basic principles of color perception
- Introduction: color spaces
  - RGB
  - HLS
  - HSV
  - YCbCr (YUV)