Visualisation, Rendering and Animation

2 VO / 1 KU (2001-2004)

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Short podcast version 2020

2nd Unit - Content

4. Color (Foley, van Dam, Chap.13)

- Color metrics, color models
- Color reproduction

5. Light-Material Interaction (Watt)

- Categories of Lighting Models
- Local Illumination Models
- Lighting Optimization (Möller, Haines)
- Shadow Generation

What is a color?

- Physical description: wavelengths
- Psychological perception: stimulus
- Computer description: color models
- - different sets of basis and coordinates
- - dithering/halftoning
- Color correction: ensure that percepted colors are correct

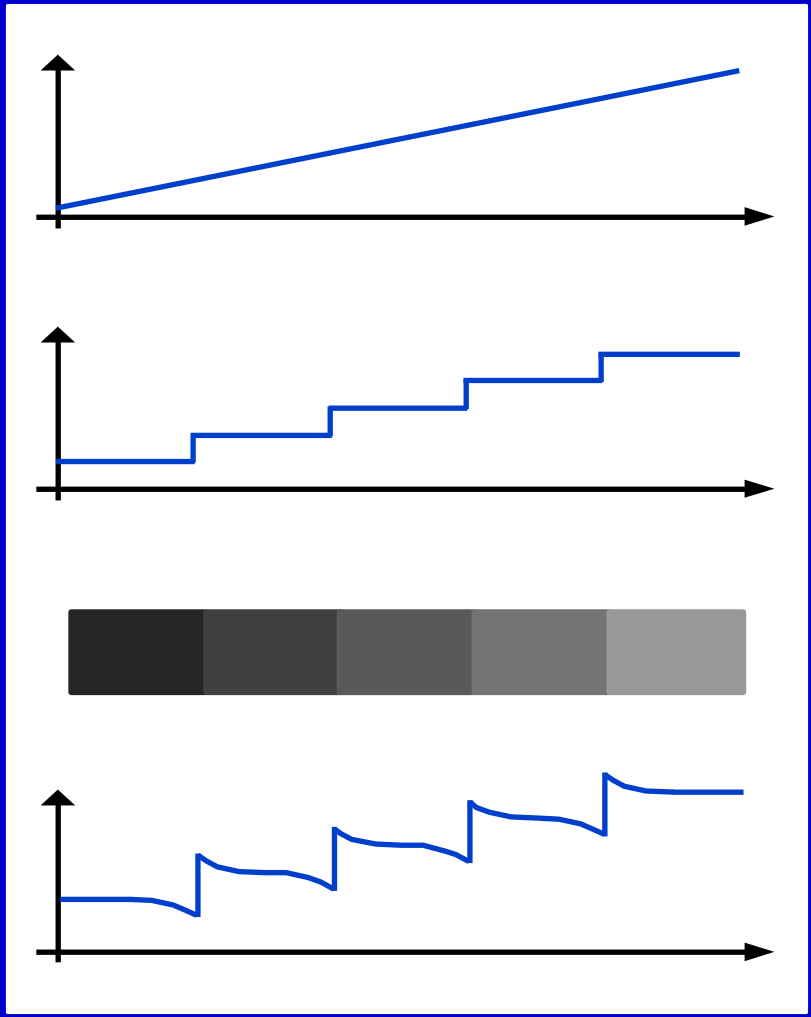
- by N. Holzschuch, UCT 1996: Color fidelity and Color spaces

Color and Color metrics

- Meaning perception
- Metrics means measure relation of colors to each other
- Light rays from self-luminous object or reflected at the object surface (electromagnetic wave)
- Transition from color stimulus evaluation to the experience of color

Experience of Color

- Color stimulus (given by object properties and illumination)
- Properties of surrounding objects
- Visual system of the viewer
- „Mach-band“ effect



Perceptual Term vs. Colorimetry

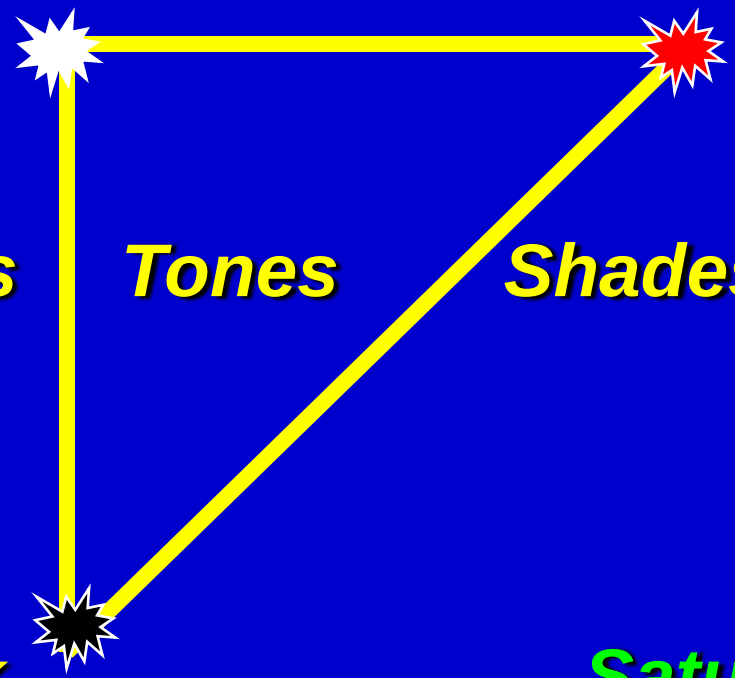
- Hue — Dominant wavelength
- Saturation — Excitation purity

- Lightness (reflecting objects) — Luminance
- Brightness (self-luminous objects) — Luminance

- Wavelengths from 400 nm to 700 nm

Artist Perception

- White
- Grays
- Black



Tints

Tones

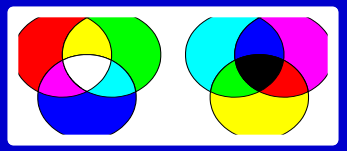
Shades

Pure color

Brightness

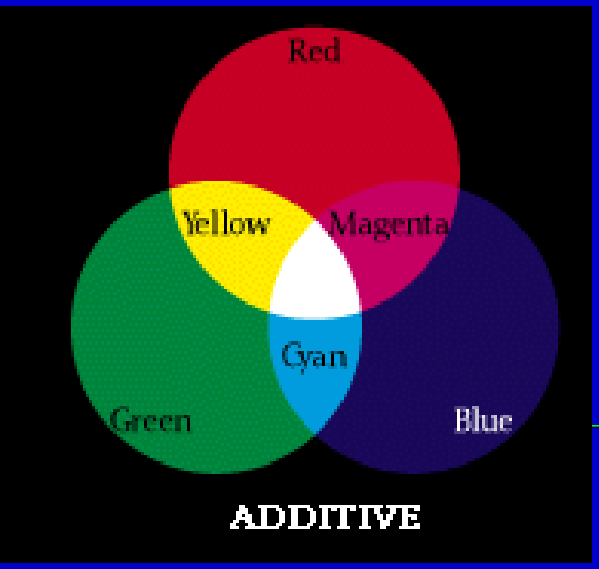
Saturation

Mixing Colors

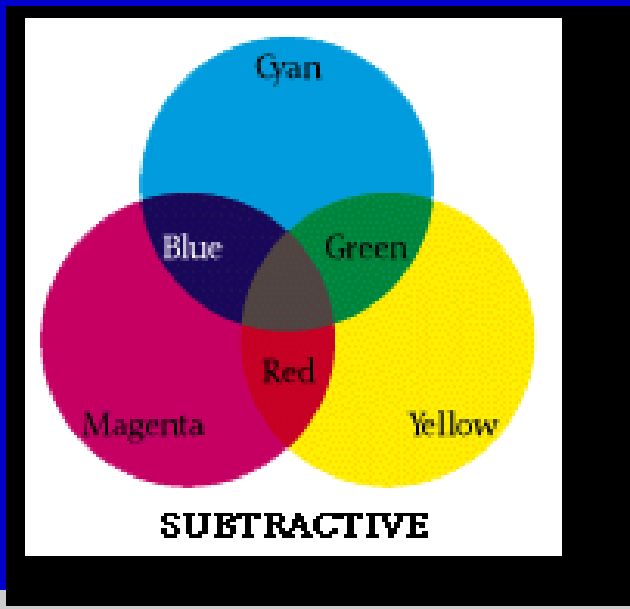


- **Additive color mixing** (pg.netgraphics.sk)
  - Combination of light rays
  - Examples: CRT, Video Beamer
- **Subtractive color mixing**
  - Combination of dye stuffs (pigments)
  - Examples: ink jet printer, -plotter

Goethe's triangle



http://www.cs.brown.edu/courses/cs092/VA10/HTML/start.html



Color Models

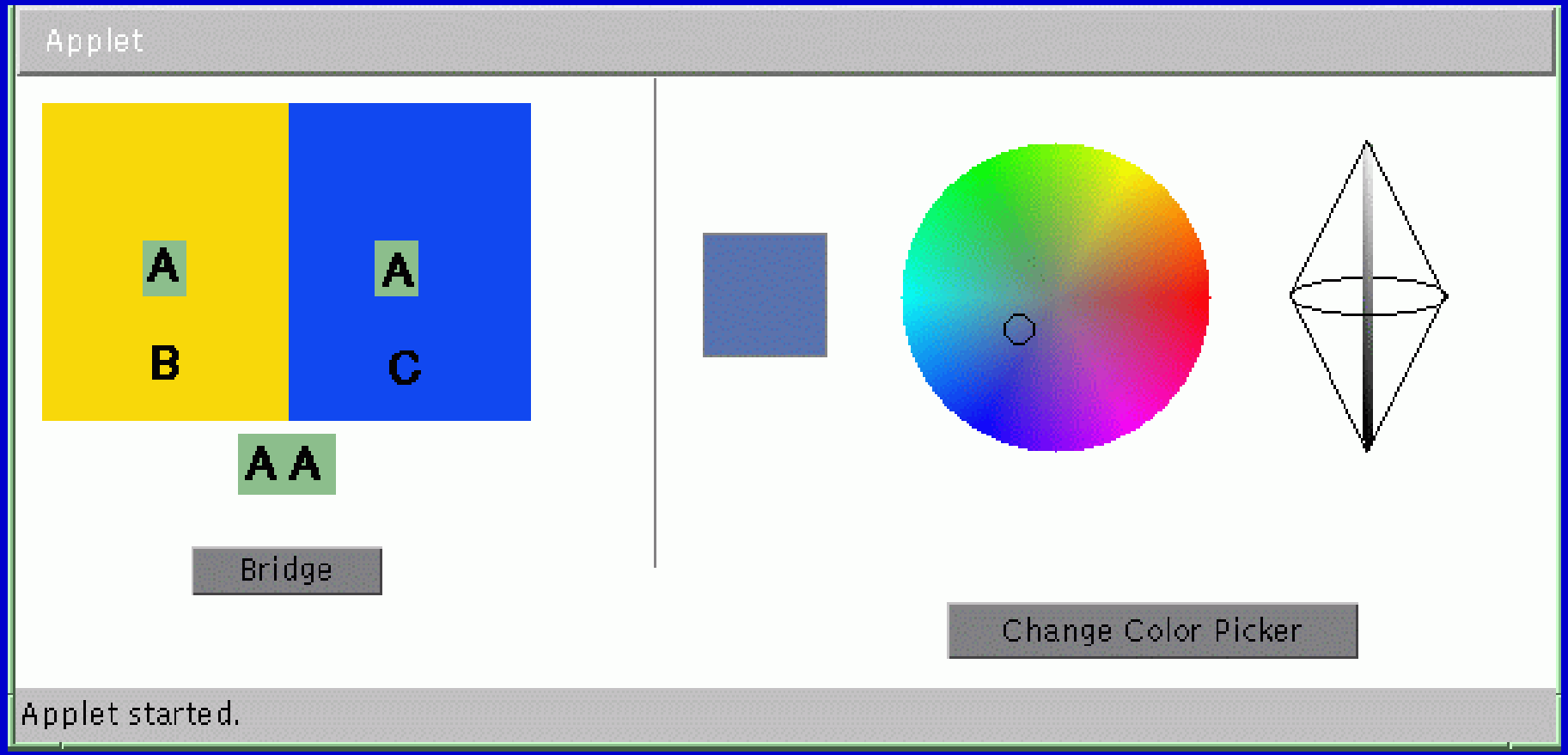
Comparison Criteria:

- Reference to human perception
- Representing of all colors
- Choosing colors of equal brightness
- Hardware-/user- oriented
- Intuitive or theoretic specification

Examples: CIE, CIE-LAB, CIE-LUV, RGB, CMY(K), HSV, HLS

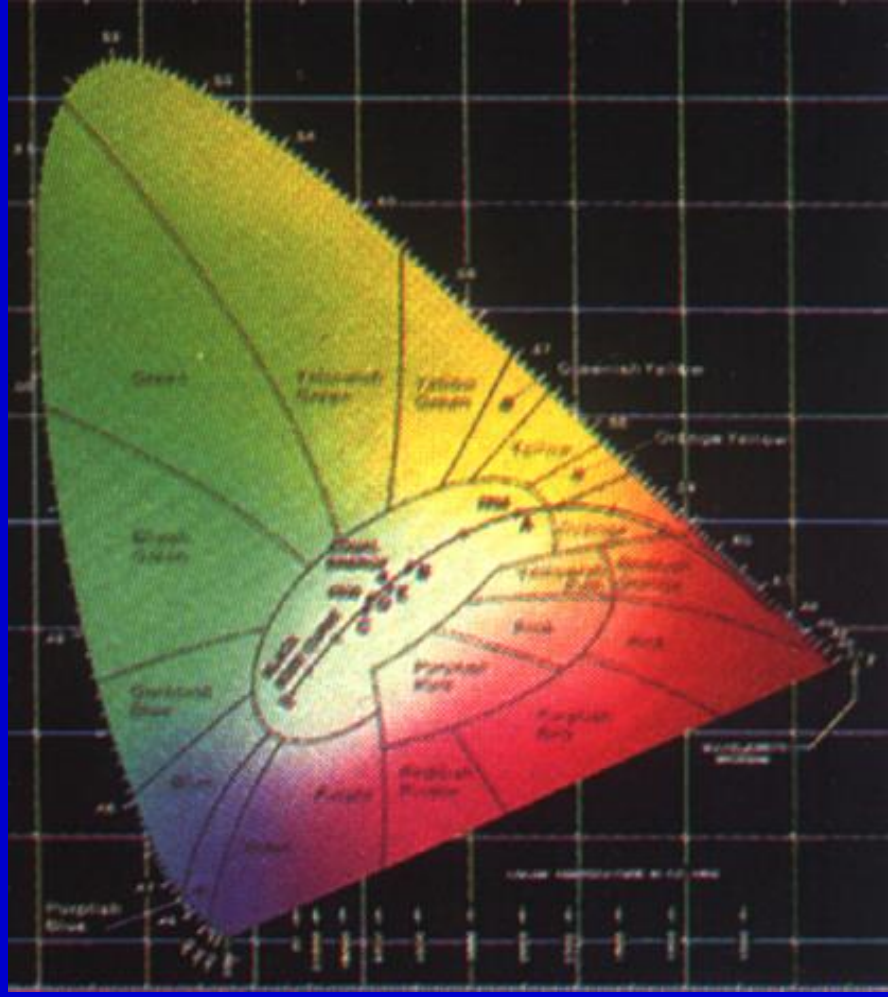
- http://www.cs.brown.edu/courses/cs092/VA10/HTML/start.html

One color appears as Two



CIE

- All visible colors defined (*chromaticity*)
- Colors of equal brightness
- Complement colors
- „ColorGamut“
- Different luminances *with the same chromaticity*
- Pure colors *(curved part)*



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CIE Central Bureau Kegelgasse 27 A-1030 Wien Austria

Standard Color Models

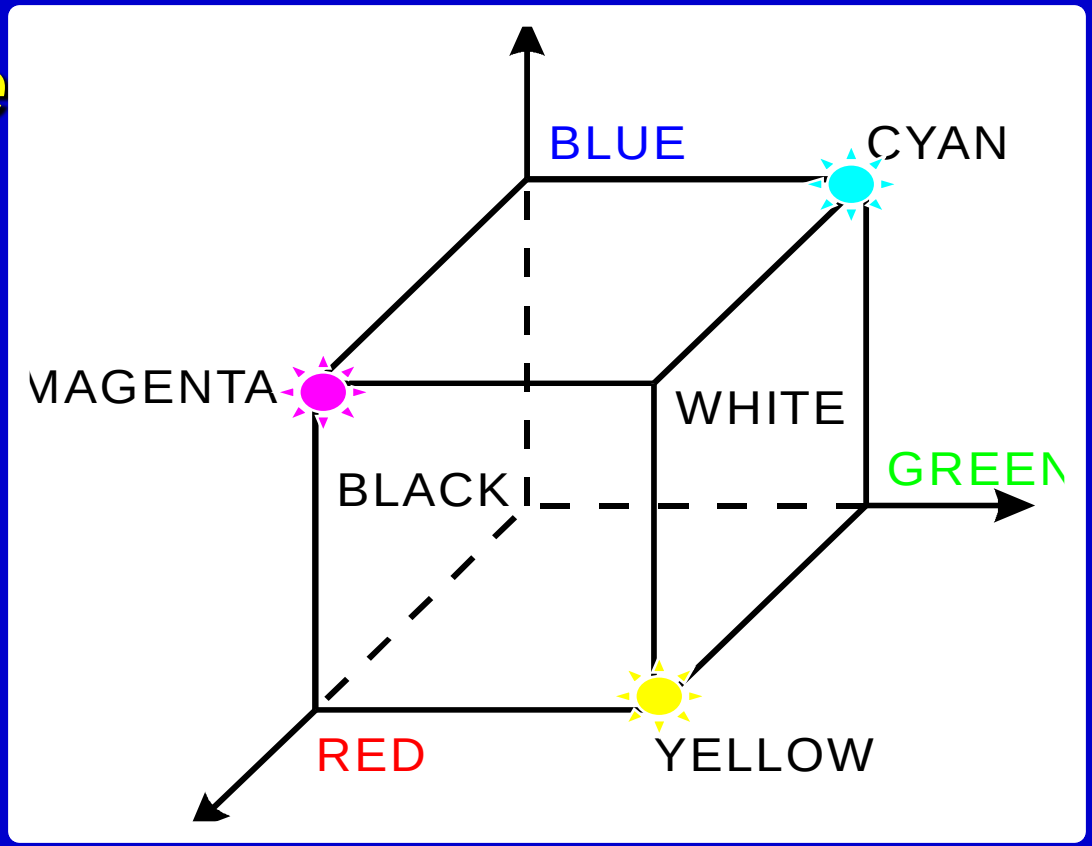
- Simple building of the model for the used hardware
- Based on additive or subtractive color mixing
- Output medium

Examples:

- RGB, CMY(K), YIQ, YCbCr - display based
- HSV, HLS - perception based

RGB – Color cube

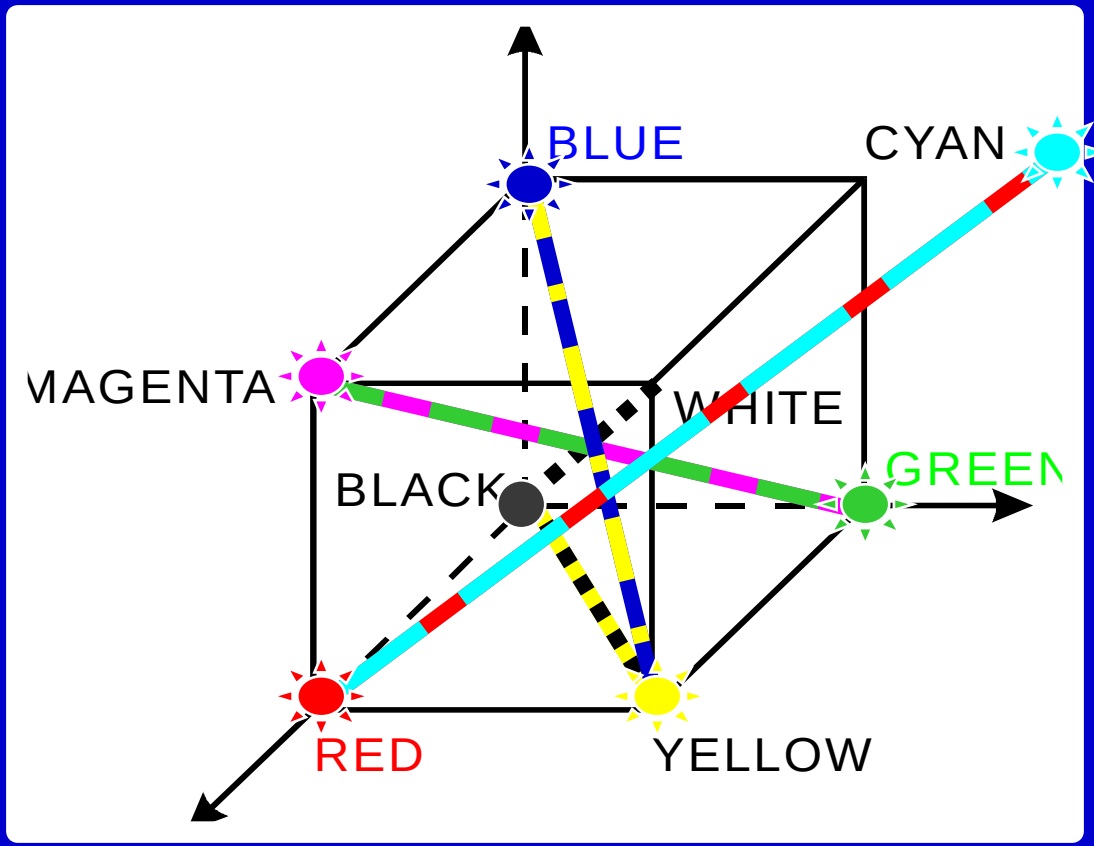
- System of 3 coordinates: red, green, blue
- Additive color
- mixing
- Usage: CRT



Complement color pairs

- R-C
- G-M
- B-Y
- K-Y
- W-K, black&white

- 5 EXTREMES

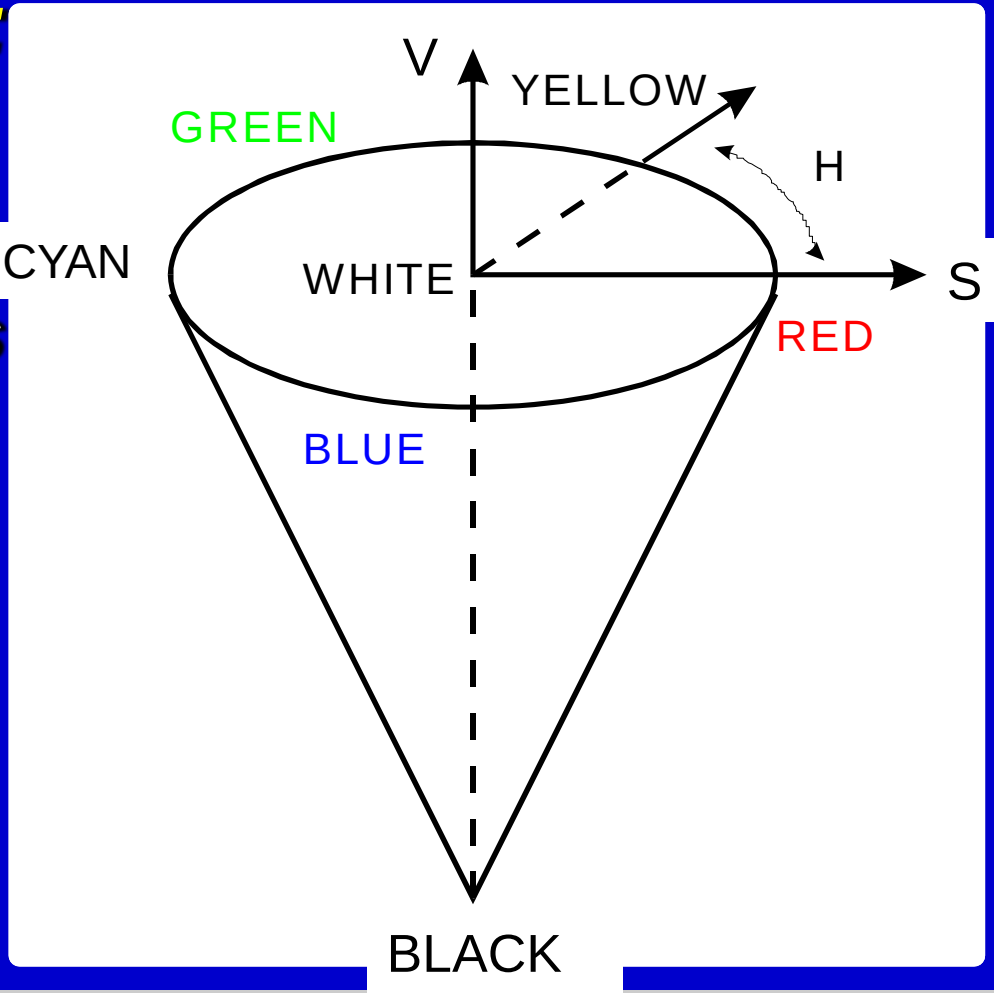


CMY/CMYK Color space

- 3D system: cyan, magenta, yellow
- Subtractive color mixing
- Usage: hard copy devices
- Conversion RGB -> CMY:
  R/G/B = 1 - C/M/Y
- CMYK: additional blacK component
  - K = min{C,M,Y}
  - C/M/Y = C/M/Y - K

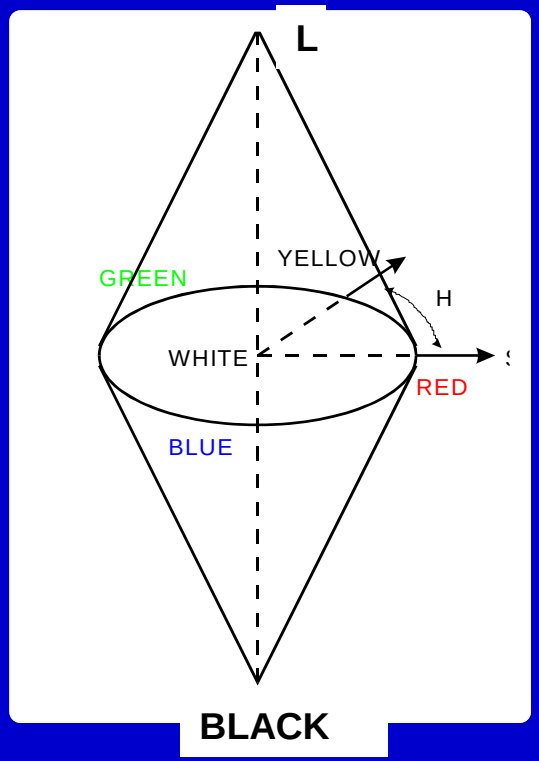
HSV

- ***Cylindric coordinate system:***
  - ***Value: height***
  - ***Saturation: distance to the axis***
  - ***Hue: angle in the SV-plane***
- ***Representable colors create a cone***



Other Models

- HLS
  - Hue
  - Lightness
  - Saturation
  - Doubled pyramid



- NCS - Natural Color System
- CNS - Color Naming System
- YIQ - NTSC color system

Natural Color System (NCS)

Basic colors:

blue, red, yellow, green

Color mixtures:

<SS><CC>-<F1><%%><F2>

- SS black contribution
- CC color contribution
- F1 color 1
- %% mixing proportion
- F2 color 2

Example:

4020-Y60R

Color Naming System (CNS) 1

Idea: *A HLS relative, verbal color model with 7 basic colors:*

red, green, blue, yellow, purple, orange, brown

Mixed colors:

Possible inbetweens for adjacent colors with the possible relationships:

- *25% / 75%: greenish-yellow*
- *50% / 50%: green-yellow*
- *75% / 25%: yellowish-green*

Color Naming System (CNS) 2

Levels of brightness:

very dark, dark, medium, light, very light

additionally: black, white

(0, 0.16, 0.33, 0.5, 0.66, 0.83, 1.00)

Saturations:

grayish, moderate, strong, vivid

Example:

very dark vivid red

Color Reproduction

- Representing of synthetic image at the display area or at the paper (Truecolor -> 2^n colors)
- Problem area 1 (raster displays):
  - geometric resolution satisfactory
  - radiometric resolution not fulfilled
- Problem area 2 (hardcopy methods):
  - geometric resolution more than satisfactory
  - radiometric resolution not fulfilled

Color Quantisation

Task specification: *Represent more colors using some appropriate colors with the help of color tables (LUT, look-up-table).*

Method:

- *Uniform quantisation*
- *Popularity method*
- *Median-cut method*
- *Octree-quantisation*

Uniform Quantising

TrueColor:

- 8 bit red (256 steps)
- 8 bit green (256 steps)
- 8 bit blue (256 steps)

16.7 million colors

256 color mode:

- 3 bit red (8 steps)
- 3 bit green (8 steps)
- 2 bit blue (4 steps)

8x8x4 = 256 colors

Popularity method

Idea: *Find the K most frequent colors and use them in the LUT.*

Realisation:

- *Table with the frequencies*
- *K most frequent colors selection*
- *apply the closest color in the table*

Pitfal:

minor details might be represented by strongly falsified colors

Median-cut Method

Idea: ***Each LUT entry should be represented by approximately equal number of pixels.***

Realisation:

- ***Divide the color cube to obtain 2 parts with the required property***
- ***Subdivide each kuboid with the most entries along the longest edge until K parts created***
- ***each median is the representative***

Comparison

Original

1	7	6	5
1	6	5	4
1	5	4	3
1	4	2	1

0	6	6	6
0	6	6	3
0	6	3	3
0	3	3	0

Uniform

1	5	5	5
1	5	5	4
1	5	4	4
1	4	1	1

Popularity

1	6	6	5
1	6	5	5
1	5	5	1
1	5	1	1

Median Cut

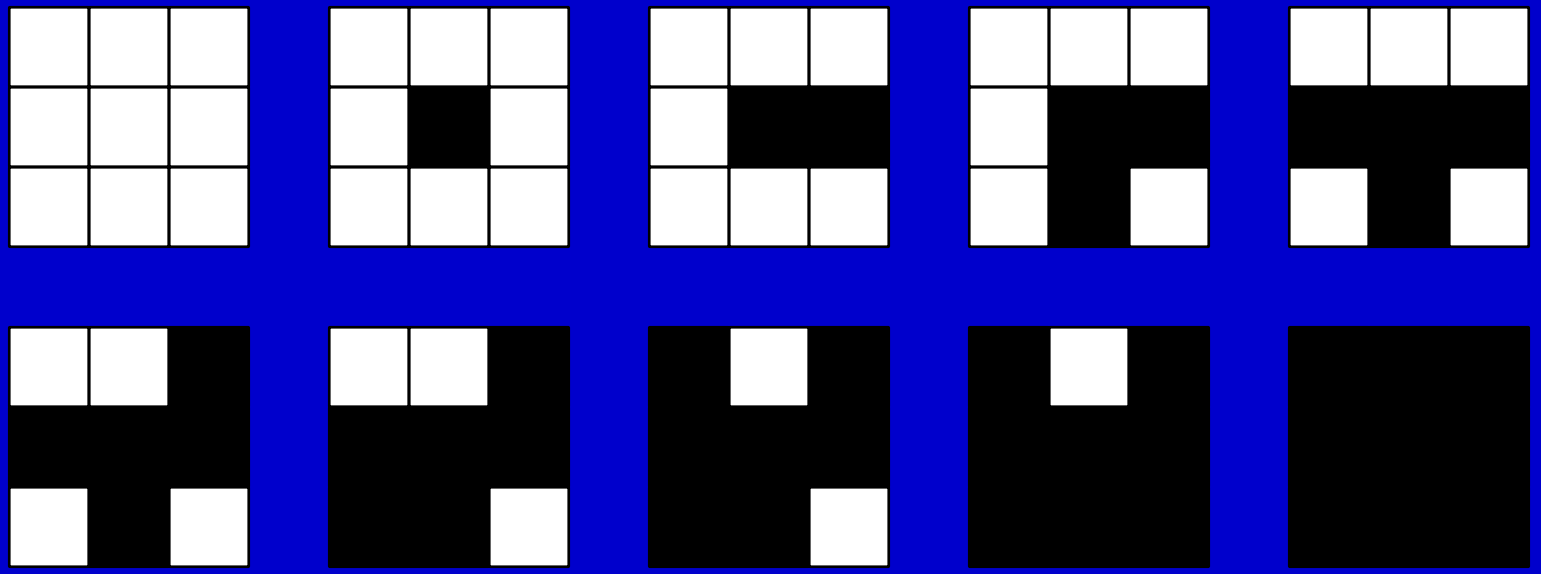
Dithering/Halftoning

- Simulate more color steps at expense of the geometric resolution
- Definition of dither matrices
  - grow the pattern outward from the center
  - N+1 level contains all points from level N
  - no structures produced
  - compact regions
- Alternative method: „Floyd-Steinberg“-error diffusion method

Dither matrices

Example for n=3:

- geometric resolution decreases by factor 3 (in each coordinate direction).
- radiometric resolution increases from 2 (monochromatic image) to 10.



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