Farbe

Color Description Systems
Color Description Systems

- color models
- color ordering systems
Color Models

- RGB
- CMY(K)
- HLS, HSV, HSB, ...
- YCbCr, YUV
- ...
- **additive** color mixture
- primary colors red, green, blue
- used for describing monitors and projectors
RGB Color Model Images

3 views of the RGB color cube
Additive Color Mixture

- **light** is summed
- spectral curves have to be added
Additive Color Mixture

- **light** is summed
- spectral curves have to be added
Additive Color Mixture

- **light** is summed
- spectral curves are added
- light is summed
- spectral curves are added
RGB Color Model Gamut

RGB (X,Y) CHROMATICITY COORDINATES

<table>
<thead>
<tr>
<th>NTSC Standard</th>
<th>CIE Model</th>
<th>Approx. Color Monitor Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>R (0.670,0.330)</td>
<td>(0.735, 0.265)</td>
<td>(0.628, 0.346)</td>
</tr>
<tr>
<td>G (0.210, 0.710)</td>
<td>(0.274, 0.717)</td>
<td>(0.268, 0.588)</td>
</tr>
<tr>
<td>B (0.140, 0.080)</td>
<td>(0.167, 0.009)</td>
<td>(0.150, 0.070)</td>
</tr>
</tbody>
</table>

CIE RGB gamut

color monitor gamut
CMY Color Model

- subtractive color mixture
- primary colors cyan, magenta, yellow
- used for describing hardcopy devices

![Diagram of CMY color model with color coordinates]

- cyan: \( (1,0,0) \)
- magenta: \( (0,1,0) \)
- yellow: \( (0,0,1) \)
- red: \( (0,1,1) \)
- green: \( (1,0,1) \)
- blue: \( (1,1,0) \)
- white: \( (1,0,0) \)
- black: \( (1,1,1) \)
CMY Color Model Images

3 views of the CMY color cube

\[
\begin{bmatrix}
  C \\
  M \\
  Y
\end{bmatrix} = 1 - \begin{bmatrix}
  R \\
  G \\
  B
\end{bmatrix}
\]
Subtractive Color Mixture

- **filters** are summed
- spectral curves have to be multiplied
Subtractive Color Mixture

- **filters** are summed
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Subtractive Color Mixture

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- spectral curves have to be multiplied
CMY + Key = CMYK

- C + M + Y is never pure black
- “Key” (black) is used for neutral shades
- \((C,M,Y) \rightarrow (C - K, M - K, Y - K, K)\)
  where \(K = \text{min} \ (C, M, Y)\)
- example: \((0.3, 0.5, 1) \rightarrow (0, 0.2, 0.7, 0.3)\)
- saves a lot of color ink

\[
\begin{align*}
\text{Cyan} & \quad + \quad \text{Magenta} & \quad + \quad \text{Yellow} & \quad = \quad \text{CMYK} \\
\text{Cyan} & \quad + \quad \text{Magenta} & \quad + \quad \text{Yellow} & \quad + \quad \text{Key} & \quad = \quad \text{CMYK}
\end{align*}
\]
Ideal Yellow Ink

- all blue is eliminated
- green + red is also yellow!
Ideal Cyan Ink

- all red is eliminated
- blue + green is also cyan!
Ideal Magenta Ink

- all yellow is eliminated
- blue + red is magenta!

\[
\begin{align*}
&350 & 400 & 450 & 500 & 550 & 600 & 650 & 700 \text{ nm} \\
\end{align*}
\]
**CMY Color Model Gamut**

- **typical monitor gamut (RGB)**
- **typical printer gamut (CMYK)**
Color Gamut Comparison

Visible light (billions of colors)

Color film

Offset printing on:
- Coated stock
- Newsprint

Color Monitor (16 Million colors)
HLS Color Model

- derivate from RGB-cube
- hue – lightness - saturation
HLS Color Model

- color components:
  - hue (H) \( \in [0^\circ, 360^\circ] \)
  - lightness (L) \( \in [0, 1] \)
  - saturation (S) \( \in [0, 1] \)
HSV Color Model

- hue – saturation – value
- is originally a hexcone
- also called HSB, HSL
- also for user interfaces
YCbCr Color Model

- alternative to encoding in RGB
- primaries: luminance ($Y$), + 2 chromas: blue-difference ($Cb$), red-difference ($Cr$)
- used in video and digital photography
Related to YCbCr Color Model:

- **Y’CbCr**
  - Y’ = luma instead of luminance = b/w brightness of a pixel in a video (PAL)
  - luma is gamma-corrected luminance
  - analog version called YPbPr

- **YUV**
  - name used for YCbCr and Y’CbCr (!)
  - other notations also used:
    - Y’UV, YC_B C_R, Y’C_B C_R, YP_B P_R
    - YIQ (formerly US TV norm), Y’IQ also related
Color Ordering Systems

- classification of color ordering systems
- Munsell system
- NCS, HIS
- RAL
- DIN
- Coloroid
Color Ordering Systems (COS)

- **primary aim**: enable the user to intuitively choose color values according to certain criteria
- choice can yield single or multiple color values
- **examples**: Munsell, NCS, RAL Design, Coloroid
- used in bottom-up parts of a design process
- sometimes physical samples are provided
Color Ordering System Usage

- color schemes
  - websites
- UI design
  - consistent, pleasing colors
- interior design
- product design
Munsell Color Ordering System

- defined in 1905 by artist Alfred Munsell (1858-1918)
- goal: a perceptually uniform color system
- defined for solid colors under Illuminant C
- used in design, photography, art, architecture, research
- color is described by three attributes:
  - Hue (H), Value (V), Chroma (C)
Werner Purgathofer 32

Munsell Hue Scale (H)

- 5 primary colors
  - Red (R), Yellow (Y), Green (G), Blue (B), Purple (P)

- 5 secondary colors
  - YR, GY, BG, PB, RP

- arbitrary subdivision of circle into 100 steps for fine-grained overall hue number

Werner Purgathofer
second, equivalent notation for hue is defined on a scale between (0,10] centered on each of the primary and secondary colors.

5 = pure hue

more intuitive than plain number [0,100]
Munsell Value Scale (V)

- in the range between 0 and 10
- perceptually uniform
Munsell Chroma Scale (C)

- values start from 0 (grey)
  - higher values mean more saturated colors
- no universal max value
  - dependent on hue and value
- shape of color space is not symmetrical!
- Munsell color example:

  notation:   H V/C

  5P 5/10
Munsell Color Solid Shape

- topology similar to HVS or HLS
- highly nonlinear to account for perceptual issues
Sample Munsell Color

5 GY 7 / 10

5 GY - hue
7 - value
10 – chroma
Munsell Book of Color

- color atlas based on the Munsell system
- commercially available since ca. 1940 in varying forms
- designed to be used under CIE illuminant C
- tables of XYZ values available for these viewing conditions
pages differ significantly in size and shape for varying hues!
system was „reformulated“ in 1929 to be more perceptually uniform than before

recent investigations showed that it still leaves something to be desired

however, the MCS is still a valuable resource because it has been studied so extensively
Natural Color System (NCS)

- developed in Sweden, recommended by the Swedish Institute of Standards
- mainly used in Scandinavia, particularly in architecture and interior design
- its main focus lies on the description of color appearance
- attributes:
  - Blackness (s), Chromaticness (c), Hue (Φ)
**NCS Basics**

- Based on opponent color theory of Hering
- Colors are described as relative mixtures of the 6 primaries

<table>
<thead>
<tr>
<th>W</th>
<th>S</th>
<th>Y</th>
<th>R</th>
<th>B</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>White</td>
<td>Black</td>
<td>Yellow</td>
<td>Red</td>
<td>Blue</td>
<td>Green</td>
</tr>
</tbody>
</table>

e.g. medium grey is 50% black + 50% white
described by the perceived contribution of red, yellow, green and blue

E.g. 80% Y + 20% R = Y20R
Sample NCS Color

S 2570-Y60R

S - 2nd edition of NCS
25 - „blackness“ in %
70 - „chromaticness“ in %
Y60R - yellow with 60% red

= rather saturated redish orange
Natural Color System (NCS)

Musterzimmer
K10

Wandfarbe: NCS S 2570 Y60R orange

Boden: Hornbach

5m²
NCS Color Atlas

- based on the NCS system
- 1750 colors (15 x 15 mm)
- CIE XYZ values for illuminant C are provided
- 40 different hues, blackness & chroma increase in steps of 10%
- not all possible NCS colors are included, since no pigments are known for some of them (!)
- vertical: „blackness“
- horizontal: „chromaticity“
- individual pages for each hue
<table>
<thead>
<tr>
<th>Munsell</th>
<th>vs.</th>
<th>NCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 primaries with approximately perceptually uniform spacing</td>
<td></td>
<td>4 primaries at angles of 90°, no perceptual spacing, which leads to noticeably uneven sampling in the blue region of the atlas</td>
</tr>
<tr>
<td>lightness values spaced approximately perceptually evenly</td>
<td></td>
<td>lightness values spaced perceptually unevenly</td>
</tr>
<tr>
<td>somewhat intuitive color notation</td>
<td></td>
<td>reasonably useful and intuitive notation</td>
</tr>
</tbody>
</table>
RAL-Farben

- Reichs-Ausschuss für Lieferbedingungen in Germany defined colors in 1927
- today provides 2 systems of normed colors for industrial and design use
  - RAL Classic
    - numbered solid colors (4 digits)
  - RAL Design
    - perceptual color space
    - atlas based on CIELAB
RAL Classic System

- register RAL-840 HR: enumeration of solid colors for the paint industry
- contains 213 colors
- no color ordering - the numbering of the colors is pretty arbitrary
- no guarantees / minimum standards are provided by RAL
# RAL Classic System Examples

<table>
<thead>
<tr>
<th>RAL 1011</th>
<th>Braunbeige</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAL 1012</td>
<td>Zitronengelb</td>
</tr>
<tr>
<td>RAL 1013</td>
<td>Perlweiß</td>
</tr>
<tr>
<td>RAL 1014</td>
<td>Elfenbein</td>
</tr>
<tr>
<td>RAL 1015</td>
<td>Hellelfenbein</td>
</tr>
<tr>
<td>RAL 1016</td>
<td>Schwefelgelb</td>
</tr>
<tr>
<td>RAL 1017</td>
<td>Safrangelb</td>
</tr>
<tr>
<td>RAL 1018</td>
<td>Zinkgelb</td>
</tr>
<tr>
<td>RAL 1019</td>
<td>Graubeige</td>
</tr>
<tr>
<td>RAL 1020</td>
<td>Olivgelb</td>
</tr>
<tr>
<td>RAL 1021</td>
<td>Rapsgelb</td>
</tr>
</tbody>
</table>
RAL Effect System

- introduced in 2007
- contains 420 colors + 70 metallic colors
- based on water-soluble paints (no lead, cadmium...)

RAL Design System

- from 1993
- genuine color ordering system / color atlas
- 1688 colors
- goal: easy and convenient way of choosing colors based on CIELAB
- coordinates: hue (0°-360°), chroma (0-100), lightness (20-90)
RAL Design System

- 7-digit RAL-D coordinates (e.g. 010 30 40) are a widely accepted industrial standard
- „front end for CIELAB“
- pages of varying size and shape
DIN 6164 Color System

- developed from 1941 onwards by Manfred Richter for Deutsche Industrie Norm (DIN)
- first presented 1953, refined 1963
- goal: definition of a perceptually uniform color space (but uniformity only within a single coordinate)
- based on large-scale experiments with test subjects
colors are defined through:

- **Hue** (*Buntton, T*)
- **Saturation** (*Sättigungsstufe, S*)
- **Darkness** (*Dunkelstufe, D*)
**Hue** is defined as colors which have the same dominant wavelength

- reason: easy interoperability with CIE XYZ
- penalty: perceptually non-uniform hues

24 main hues were identified in experiments and numbered from T=1 (red) to T=24 (green)

goal of the experiments was to find hues which are more or less evenly spaced
**DIN Saturation and Darkness**

- **Saturation** (S): measure for the distance from the achromatic point of equal luminance

- **Darkness** (D): measure of brightness relative to maximal brightness of pure color
  - not a particularly good correlate of perceived brightness
  - attempts to ensure that e.g. the appearance of color wheels is perceptually uniform
main difference to the Munsell system is D, which groups colors in levels of equal relative brightness instead of absolute brightness

DIN also produced a color atlas for the system with approximately 1000 samples

for practical, industrial purposes DIN is being replaced since 1986 by the less complicated RAL systems
Coloroid

- developed 1962-1980 by Antal Nemcsics
- parameters:
  - Luminocity (V)
  - Hue (A)
  - Saturation (T)
- novelty: non-linear (but well-defined) mapping provides „aesthetic uniformity“ of the color space