

# Einführung in die Farbwissenschaft

## Color Description Systems



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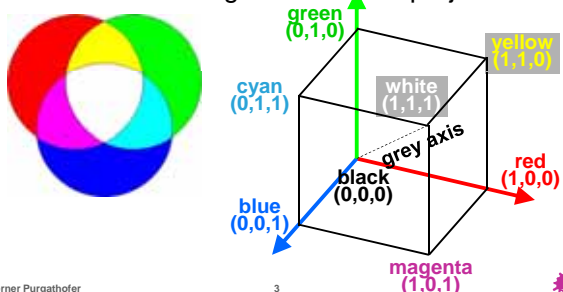
- color models
- color ordering systems

## Color Models

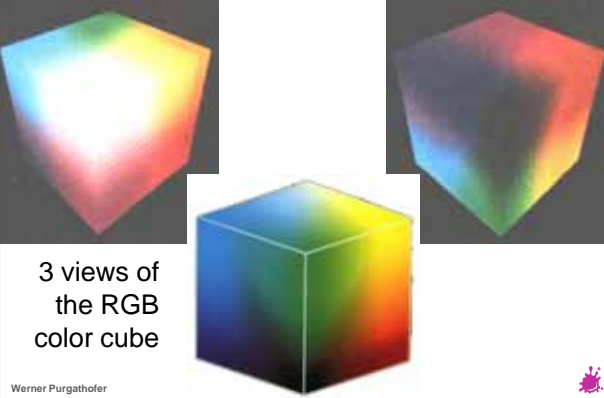
- RGB
- CMY(K)
- HLS, HSV, HSB, ...
- YCbCr, YIQ
- ...

## RGB Color Model

- **additive** color mixture
- primary colors **red, green, blue**
- used for describing monitors and projectors



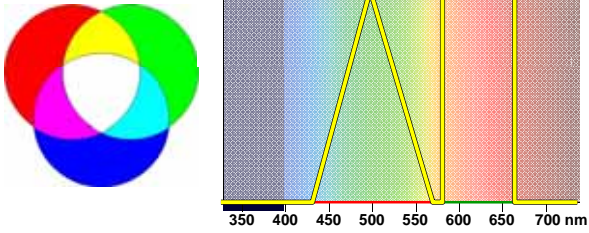
## RGB Color Model Images



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 are added

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### RGB Color Model Gamut

**RGB (X,Y) CHROMATICITY COORDINATES**

	NTSC Standard	CIE Model	Approx. Color Monitor Values
R	(0.670, 0.330)	(0.735, 0.265)	(0.628, 0.346)
G	(0.210, 0.710)	(0.274, 0.717)	(0.268, 0.588)
B	(0.140, 0.080)	(0.167, 0.009)	(0.150, 0.070)

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### CMY Color Model

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

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### CMY Color Model Images

$$\begin{bmatrix} C \\ M \\ Y \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

3 views of the CMY color cube

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### Subtractive Color Mixture

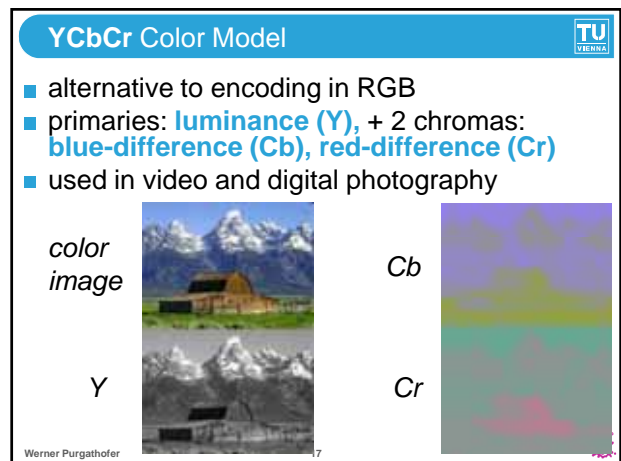
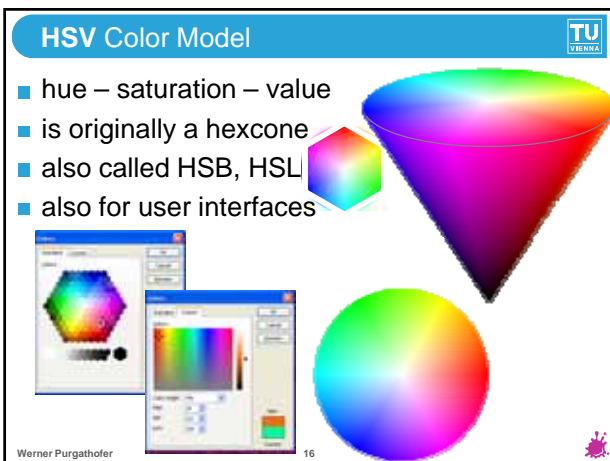
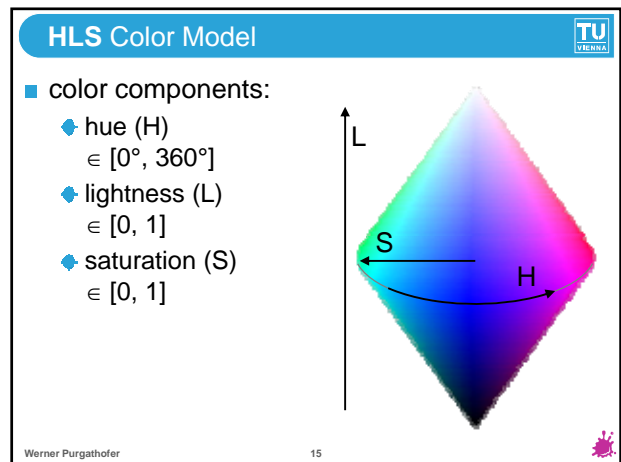
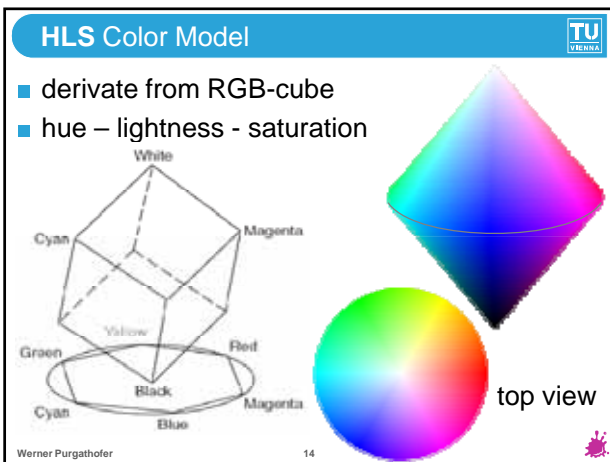
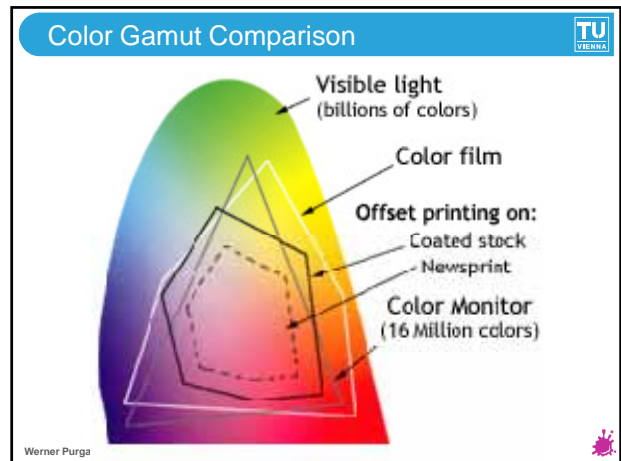
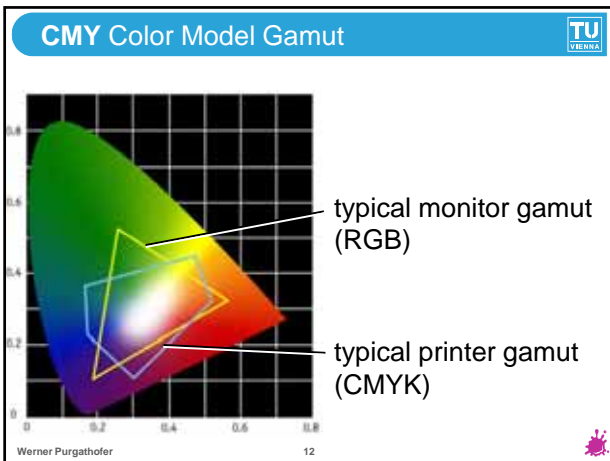
- filters are summed
- spectral curves have to be multiplied

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### Subtractive Color Mixture

- filters are summed
- spectral curves have to be multiplied

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### 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**, **Y<sub>C<sub>B</sub>C<sub>R</sub></sub>**, **Y'<sub>C<sub>B</sub>C<sub>R</sub></sub>**, **Y<sub>P<sub>B</sub>P<sub>R</sub></sub>**
- **YIQ** (formerly US TV norm), **Y'IQ** also related

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### Color Ordering Systems

- classification of color ordering systems
- Munsell system
- NCS, HIS
- RAL
- DIN
- Coloroid

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### 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



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### Color Ordering System Usage


- color schemes
  - ◆ websites
- UI design
  - ◆ consistent, pleasing colors
- interior design
- product design

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### Munsell Color Ordering System

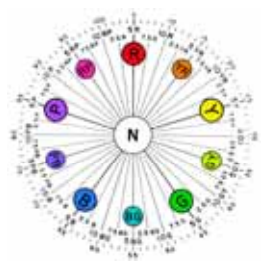
- defined in 1905 by artist Alfred Munsell (1858-1918)
- goal: a perceptually uniform color system
- defined for solid colors under Illuminant C
- used in design, photography, art, architecture, research
- color is described by three attributes:
  - ◆ **Hue (H), Value (V), Chroma (C)**



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### 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

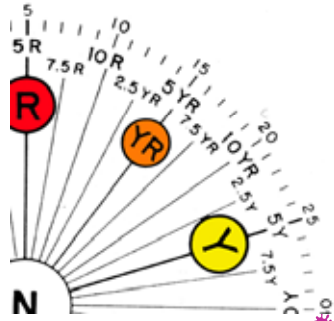


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## Munsell Hue #2



- 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]



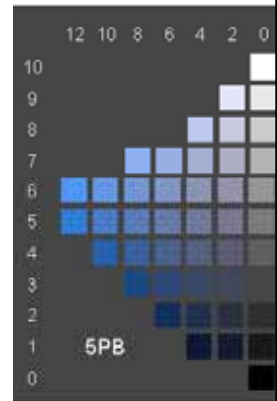
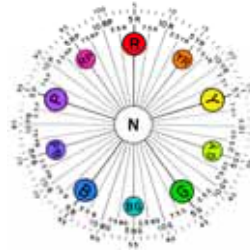
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## Munsell Value Scale (V)



- in the range between 0 and 10
- perceptually uniform



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## Munsell Chroma Scale (C)



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

notation: H V/C

**5P 5/10**

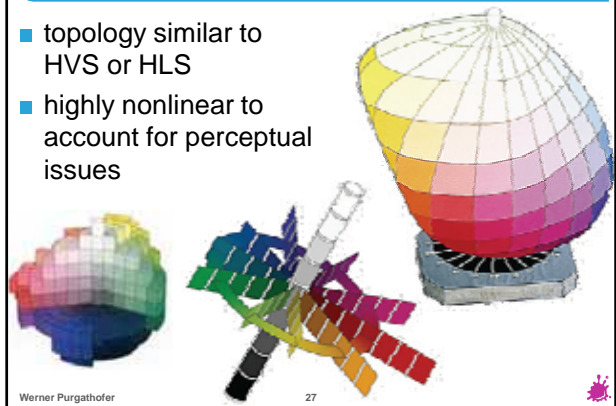
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## Munsell Color Solid Shape



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



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## Sample Munsell Color



**5 GY 7 / 10**

5 GY - hue  
7 - value  
10 - chroma

= *light saturated yellow-green*

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## 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



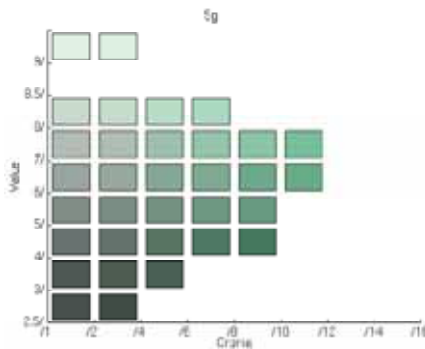
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## Munsell BOC Sample Page



- pages differ significantly in size and shape for varying hues!



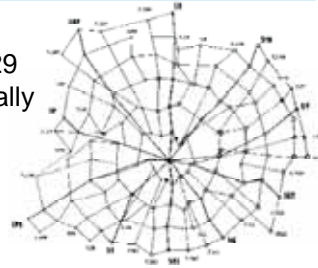
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## Munsell Perceptual Uniformity



- 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



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## 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 ( $\phi$ )**

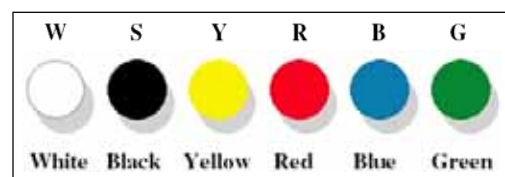
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## NCS Basics



- based on opponent color theory of Hering
- colors are described as relative mixtures of the 6 primaries



- e.g. medium grey is 50% black + 50% white

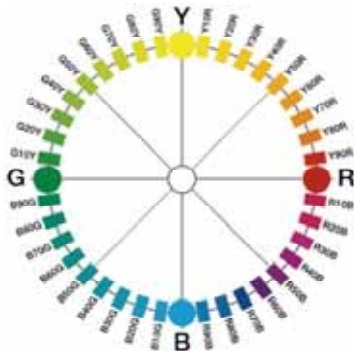
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## NCS Hue



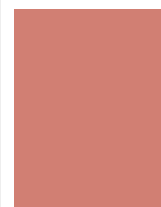
- described by the perceived contribution of red, yellow, green and blue
- E.g. 80% Y + 20% R = Y20R



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## Sample NCS Color



### S 2030-Y90R


S - 2nd edition of NCS  
 20 - „blackness“ in %  
 30 - „chromaticness“ in %  
 Y90R - yellow with 90% red  
 = *desaturated orange-red*

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### NCS Color Atlas

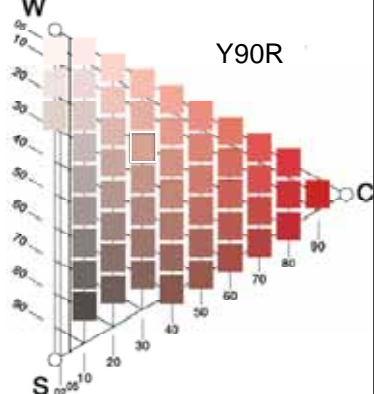
- based on the NCS system
- 1750 colors (15 x 15 mm)
- CIE XYZ values for illuminant C are provided
- 40 different hues, blackness & chroma increase in steps of 10%
- not all possible NCS colors are included, since no pigments are known for some of them (!)



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### NCS Color Atlas Sample Page

- vertical: „blackness“
- horizontal: „chromaticity“
- individual pages for each hue



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### Munsell vs. NCS

<ul style="list-style-type: none"> <li>5 primaries with approximately perceptually uniform spacing</li> <li>lightness values spaced approximately perceptually evenly</li> <li>somewhat intuitive color notation</li> </ul>	vs.	<ul style="list-style-type: none"> <li>4 primaries at angles of 90°, no perceptual spacing, which leads to noticeably uneven sampling in the blue region of the atlas</li> <li>lightness values spaced perceptually unevenly</li> <li>reasonably useful and intuitive notation</li> </ul>
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### RAL-Farben

- Reichs-Ausschuss für Lieferbedingungen founded in Germany in 1925
- 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

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### RAL Classic System

- register RAL-840 HR: enumeration of solid colors for the paint industry
- contains 210 colors
- no color ordering - the numbering of the colors is pretty arbitrary
- no guarantees / minimum standards are provided by RAL



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### RAL Classic System Examples

RAL 1011		Braunbeige	PAL 1017		Safrangelb
RAL 1012		Zitronengelb	PAL 1018		Zinngelb
RAL 1013		Perlweiß	PAL 1019		Graubeige
RAL 1014		Elfenbein	PAL 1020		Olivgelb
RAL 1015		Hellelfenbein	PAL 1021		Rapsengelb
RAL 1016		Schwefelgelb			

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## RAL Effect System



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

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## 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 ( $0^{\circ}$ - $360^{\circ}$ ), chroma (0-100), lightness (20-90)



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## 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



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## 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

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## DIN Specification of Colors



- colors are defined through:
  - ◆ **Hue** (*Bunnton*, T)
  - ◆ **Saturation** (*Sättigungsstufe*, S)
  - ◆ **Darkness** (*Dunkelstufe*, D)

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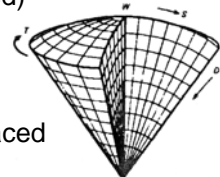
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## DIN Hue



- **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



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## DIN Saturation and Darkness



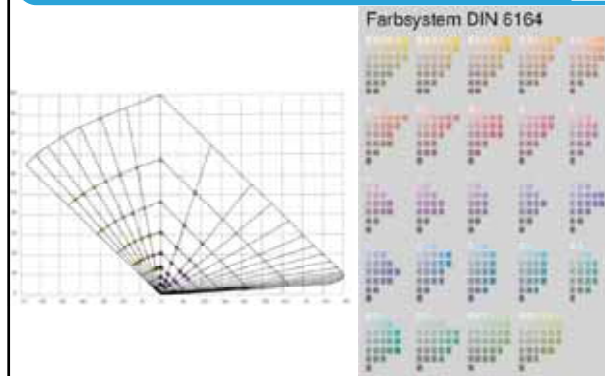
- **Saturation (S)**: measure for the distance from the achromatic point of equal luminance
- **Darkness (D)**: measure of brightness relative to maximal brightness of pure color
  - ◆ not a particularly good correlate of perceived brightness
  - ◆ attempts to ensure that e.g. the appearance of color wheels is perceptually uniform

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## DIN Graphics



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## DIN Relevance



- 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

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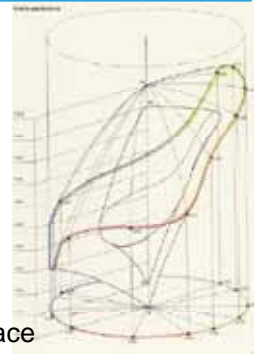
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## Coloroid



- developed between 1962 and 1980 by Nemcsics
- parameters:
  - ◆ **Hue**
  - ◆ **Saturation**
  - ◆ **Brightness**
- novelty: non-linear (but well-defined) mapping which provides „aesthetic uniformity“ of the color space



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## Aesthetic Sequences



- goal: being able to automatically find color sequences which are aesthetically pleasing
  - ◆ e.g. for colors with the same A and T values, sequences where the V values constitute a geometrical sequence are harmonic
- the whole field of automatic color selection is still an active research area

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## Traditional Color Ordering System Validity



- it is impossible to exactly predict the appearance of a color sample under a different illuminant
- all “traditional” COS are tied to the illuminants they were devised for
- relative aesthetic criteria - e.g. harmony of related color sets - may break down if illuminant changes



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