Introduction to Colour Science

NPGR025

Unit 5: Beyond Colour Metric Spaces

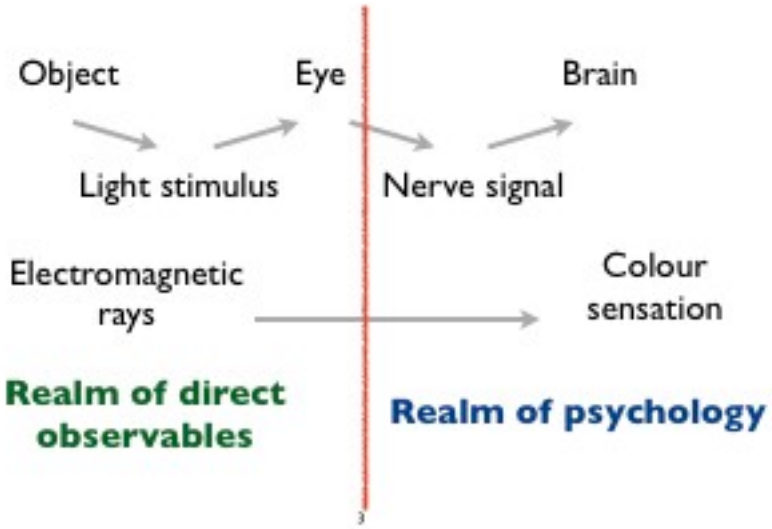
Computer Graphics Charles University

Sources:
COS Manuals
Manufacturer Specs

Colour Spaces

- Classification of Colour Spaces
- Colour Collections
  - RAL, Federal Standard 595, Pantone
- Colour Ordering Systems
  - Munsell system
  - NCS
  - RAL Design
  - DIN
- Coloroid

Colour - A Visual Sensation



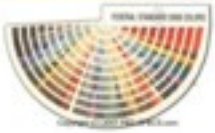
The Goal of Colorimetry

- *To provide unique identifiers for all colours*
- But there are many additional colour spaces beyond CIE RGB, XYZ, Lab: sRGB, Munsell, RAL, HSV...
- So, how do these relate to each other, and to Colorimetry?

Colour Spaces (CS)

- At least three fundamentally different types of CS exist:
  - Device Colour Spaces (RGB, CMYK)
  - Colour Metric Spaces (L*a*b, L*u*v)
    - Used to measure absolute values and differences - roots in colorimetry
  - Colour Ordering Spaces (Munsell, Coloroid)
    - Used to find colours according to some criterion
- In addition to these, there are also several standardised Colour Collections in use

Colour Collections



- Primary aim: provide a list of standardised colours
  - *No inherent ordering!*
    These are NOT Colour Spaces!

- Examples: Pantone, RAL Classic, FS 595
- Used in product specifications
- Physical samples are usually provided, and matching is done against those

RAL-Farben

- *Reichs-Ausschuß für Lieferbedingungen*
  - founded in Germany in 1925
- Provides two systems of standardised colours for industrial and design use
- RAL Classic
  - Numbered solid colours (4 digits)
- RAL Design
  - Perceptual colour space / atlas based on CIELAB

RAL Classic

- Register RAL-840 HR:
  enumeration of solid colours for the paint industry
- No colour ordering - the numbering of the colours is pretty arbitrary
- No guarantees / minimum standards are provided by RAL
- Four-digit numbers:
  e.g. RAL 4010

FS 595

- Federal Standard 595:
  enumeration of colours for U.S. military procurement
- Also used for civilian purposes in the U.S.
- Five-digit numbers:
  - First digit: gloss
  - Second digit: basic colour
  - Rest: colour number
- Example: FS 36375, Ghost Grey

Pantone

- Enumeration of colours
  plus a specification of how they can be created
- Older version: 15 basic colorants
- Newer version: 10 basic colorants (Pantone Goe system)
- Only a small subset of Pantone colours can be created by a standard CMYK process!
- Examples: Lufthansa 1235 C, Starbucks 3425 C

Colour Metric Spaces

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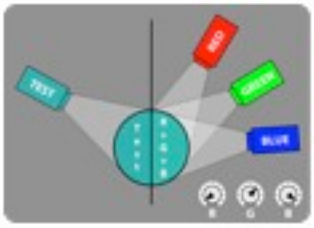


- Goal: find unique colour coordinates
- Result: Absolute Colour Spaces, a.k.a. Colour Metric Spaces, a.k.a. Universal Colour Spaces
- Unique coordinates for all perceivable colours
- Antonym: Device Colour Spaces

Colour Ordering Systems (COS)

- Primary aim: enable the user to intuitively choose colour values according to certain criteria
- Choice can yield single or multiple colour values
- Examples: Munsell, NCS, RAL Design, Coloroid

- Used in bottom-up parts of a design process
- Sometimes physical samples are provided

Colour Ordering System Sub-Types

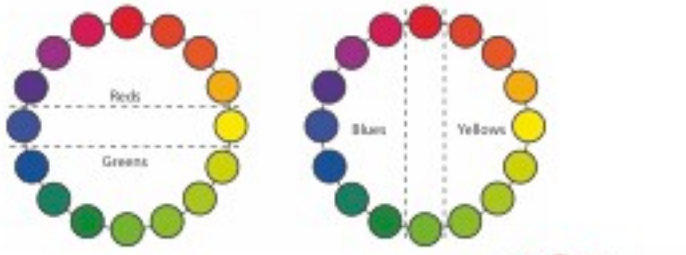
COS can be sub-divided into two categories:

- Absolute COS
  - Examples: Munsell, RAL Design
  - Unique colour coordinates - each entry is associated with one unique colour
- Relative COS
  - Examples: HSV, HLS
  - Front-ends to (usually) RGB
  - Dependent on the "parent" RGB space - HSV/HLS coordinates are *not* unique!

Colour Circle Taxonomy

- All of them contain the same colours, in the same basic order
- Not shown: the CMY circle, which is similar to the subtractive circle used by painters

Opponent Colour Circle Regions



- Somewhat arbitrary
- Present in all circle arrangements

(Absolute) COS Usage

- Colour Schemes
  - Websites
- UI Design
  - Consistent, pleasing Colours
- Interior Design
- Product Design

Colour Ordering Systems: Motivation

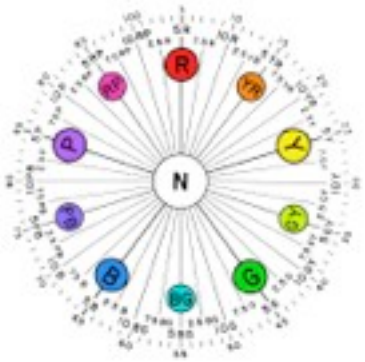
Possible COS Classification

- Heuristic, artistic approach:
  - Goethe
  - Bauhaus
  - Munsell
  - NCS
  - (RAL)
  - Ostwald
  - …
- Rigid, scientific / industrial approach:
  - Newton
  - CIE XYZ, Lab, Luv
  - Munsell
  - NCS
  - RAL
  - …

Munsell COS

- Defined in 1905 by artist Alfred Munsell
- Goal: a perceptually uniform colour system
- Defined for solid colours under Illuminant C
- Used in design, photography, art, architecture, research
- Colour is described by three attributes:
  - Hue (H), Value (V), Chroma (C)

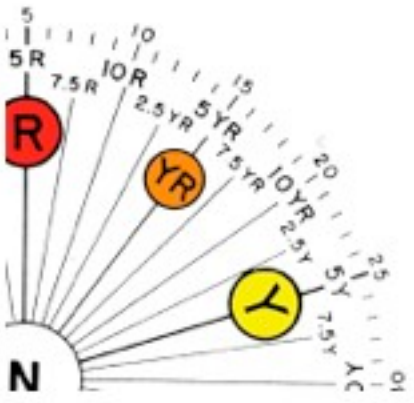
Hue Scale (H)



- 5 primary colours
  - Red (R), Yellow (Y), Green (G), Blue (B), Purple (P)
- 5 secondary colours
  - YR, GY, BG, PB, RP
- Arbitrary subdivision of circle into 100 steps for fine-grained overall hue number

Munsell Hue #2

- Second, equivalent notation for hue is defined on a scale between (0,10] centered on each of the primary and secondary colours
- 5 = pure hue
- More intuitive than plain number [0,100]



Value Scale (V)

- In the range between 0 and 10
- Perceptually uniform

Chroma Scale (C)

- Values start from 0 (grey) - higher values mean more saturated colours
- No universal max value - dependent on hue and value
- max C (dark colour) > max C (light colour)
- Shape of colour space is not symmetrical!

Munsell Colour Solid Shape

- Topology similar to HVS or HLS
- Highly nonlinear to account for perceptual issues

Sample Munsell Colour

5 GY 7 / 10

5 GY - hue

7 - value

10 - chroma

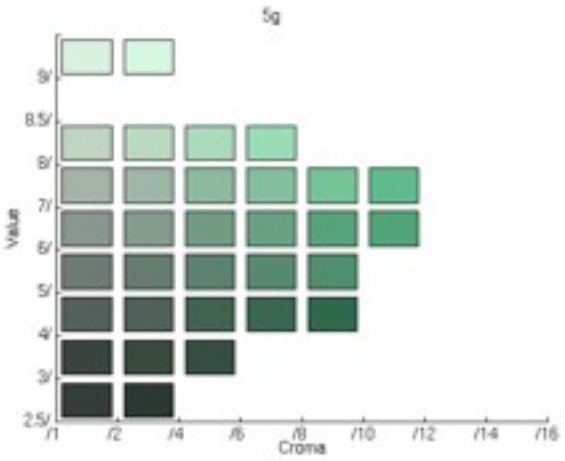
Light saturated yellow-green

Munsell Book of Color

- Colour 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

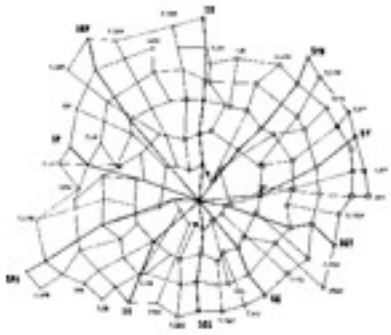
Munsell BOC Sample Page

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



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



Natural Colour System (NCS)

- Developed in Sweden, recommended by the Swedish institute of standards
- Mainly used in Scandinavia and there particularly in architecture and interior design
- Its main focus lies on the description of colour appearance
- Values:
  - Blackness (s), chromaticness (c), hue (Φ)

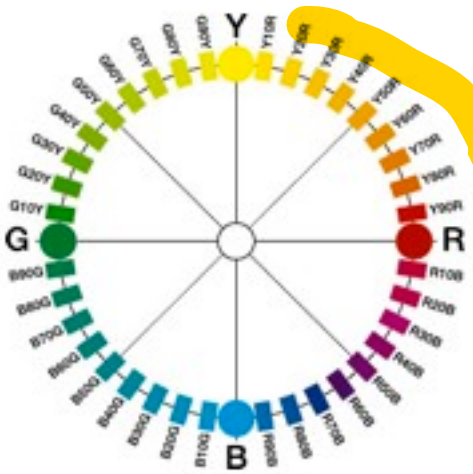
NCS Basics

- Based on opponent colour theory of Hering
- Colours are described as relative mixtures of the 6 primaries

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

NCS Hue

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



Sample NCS Colour

S 2030-Y90R

S - 2nd edition of NCS

20 - „blackness“ in %

30 - „chromaticness“ in %

Y90R - yellow with 90% red

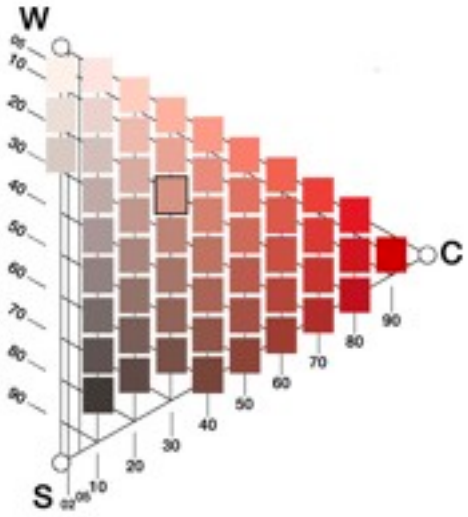
Desaturated orange-yellow

NCS Colour Atlas

- Based on the NCS system
- 1750 colours (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 colours are included, since no pigments are known for some of them (!)

NCS Colour Atlas Sample Page

- Vertical: „blackness“
- Horizontal: „chromaticity“
- Individual pages for each hue



Munsell vs. NCS #1

- 5 primaries with approximately perceptually uniform spacing
- 4 primaries at angles of 90 degrees, no perceptual spacing, which leads to noticeably uneven sampling in the blue region of the atlas

Munsell vs. NCS #2

- Lightness approximately perceptually spaced
- Somewhat intuitive colour notation
- Lightness values spaced perceptually unevenly
- Reasonably useful and intuitive notation

RAL Design System

- Genuine colour ordering system / colour atlas
- Goal: easy and convenient way of choosing colours 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
- Comparatively small physical atlas (# of samples)

DIN Colour System

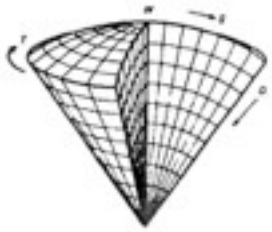
- Developed from 1941 onwards by Manfred Richter for the DIN as a replacement for Ostwald's model
- First presented 1953, refined 1963
- Goal: definition of a perceptually uniform colour space (but uniformity only within a single coordinate)
- Based on large-scale experiments with test subjects

DIN Specification of Colours

- Colours are defined through:
  - Hue (Buntton, T), saturation (Sättigungsstufe, S) and darkness (Dunkelstufe, D)
- Hue is defined as colours which have the same dominant wavelength
  - Reason: easy interoperability with CIE XYZ
  - Penalty: perceptually non-uniform hues

DIN Hue

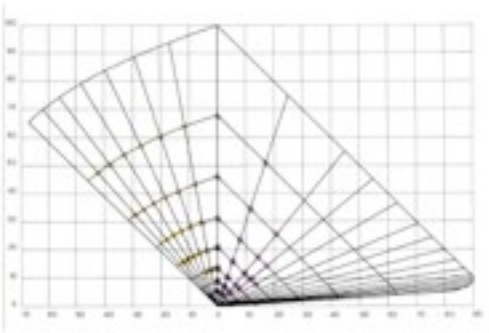
- 24 main hues were identified in experiments and numbered from T=1 (red) to T=24 (green)
- Goal of the experiments was to find hues which are more or less evenly spaced



DIN S and D

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

DIN Graphics

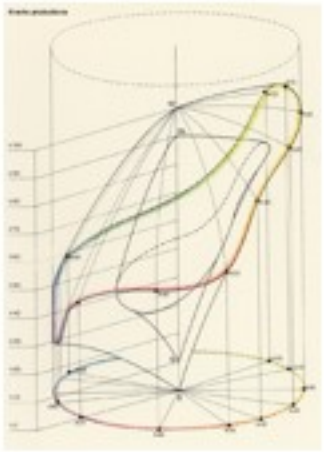


DIN Relevance

- The main difference to the Munsell system is D, which groups colours in levels of equal relative brightness instead of absolute brightness
- DIN also produced a colour 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 between 1962 and present in Budapest
- Parameters are Hue, Saturation and Brightness
- Novelty: non-linear (but well-defined) mapping which provides „aesthetic uniformity“ of the colour space



Aesthetic Sequences

- Goal: being able to automatically find colour sequences which are aesthetically pleasing
  - E.g. for colours with the same A and T values, sequences where the V values constitute a geometrical sequence are harmonic
- The whole field of automatic colour selection is still an active research area!

Traditional COS Validity

- It is impossible to exactly predict the appearance of a colour 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 colour sets - may break down if illuminant changes!

Spectral COS - s/COS

- What would be useful: a COS which ultimately yields reflection spectra that satisfy aesthetic criteria across multiple illuminants
- Problems
  - Implicit step from colour to spectral space - this is (seriously) underdetermined
  - Results probably sub-optimal for any given illuminant
  - If one were to derive a "harmonic" set of spectra - how does one realise it in practice?
- The name of this proposal indicates that this is not a

Spectral COS - Possible Solutions

- Choosing of colours has to be done in colour space - no direct spectral selection
- Conversion of colour values to spectra needs boundary conditions anyway
  - One could use a library of real spectral colorant reflectance data as constraints
  - With a physically plausible mixing model this should yield realisable colours
- Evaluation of aesthetic criteria for each illuminant

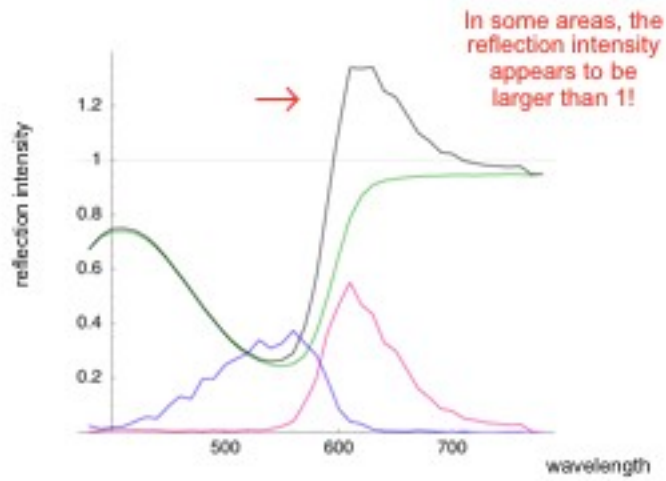
s/COS Spectrum Derivation Proposal

- User picks colour(s) in an existing COS
- Spectra for these colour values have to be found - initial derivation:
  - Constrained spectral reconstruction for COS illuminant
- Evaluation and optimisation of these spectra under all other illuminants - iterative process:
  - Metameric changes are made under original illuminant
  - New spectra are re-evaluated - process stops if "overall score" for all illuminants is good enough

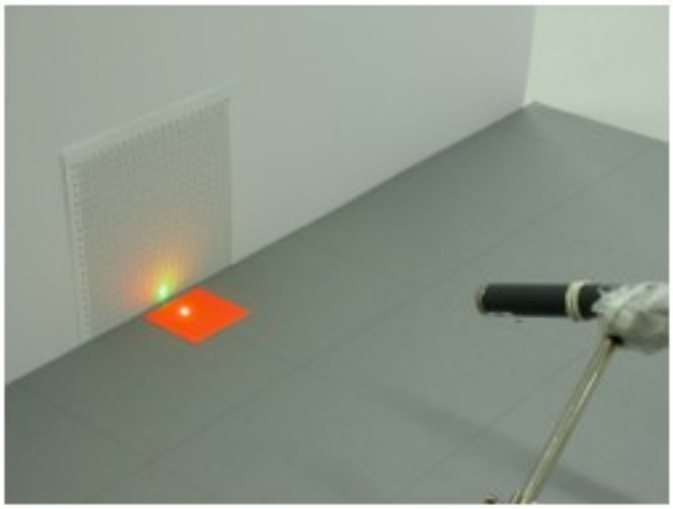
Beyond s/COS: Fluorescence

- Most traditional COS allow choice according to three characteristics:
  - Hue, saturation, lightness (or similar properties)
- Fluorescent colours bundle incident light to a particular output frequency band
  - Very bright and colourful appearance
- This adds at least one (possibly two) dimension(s) to the selection process
  - Intensity, fluorescence target area

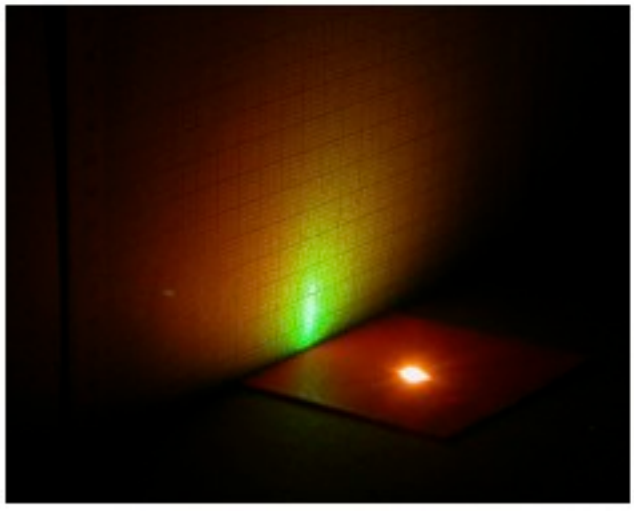
Fluorescence: Energy Transfer



Fluorescent BRDF Experiment



Plain vs. Fluorescent Sample



Conclusions

- Traditional colour space COS are fundamentally limited
- How one might transcend their limitations to define spectral COS is not entirely clear
- Even if one had a s/COS available, inclusion of fluorescent colours would pose a challenge of its own