

Visual Computing

Exercise 7: Light & Colors

Hand-out Date: 15 November 2022

Goals

- Understand the theoretical basics of light and colors
- Understand the theoretical basics of color spaces
- Working with the CIE-Charts

Resources

The lecture slides and exercise slides are accessible via the course web page
<https://cvg.ethz.ch/teaching/visualcomputing>.

Exercise 1) Definitions

Explain the following expressions: Luminous Flux, Luminous Intensity, Illumination, Luminance, Color Stimulus Specification

Exercise 2) Color Spaces

- a) How do you transform a specification in RGB into CMY?
- b) Why were color spaces such as RGB, CMY, YIQ, and HSL specified, and where are they being applied?
- c) Provide the values for a medium gray in the following color modes: RGB, CMY, YIQ and HSV.

Exercise 3) RGB-color space and white point calibration

The *RGB*-colourspace is a subspace of the *XYZ*-colourspace. Assume the base vectors are directly related to the used phosphors often used in monitors, also known as ITU-R BT.709-standard. The color components *x* and *y* of the *RGB*-base vectors are given in the table below.

	<i>R</i>	<i>G</i>	<i>B</i>
<i>x</i>	0.64	0.30	0.15
<i>y</i>	0.33	0.60	0.06

The white point is identified as (0.9505, 1.0000, 1.0890).

- a) Name one advantage and one disadvantage of the *RGB*-color space. Furthermore, list one color space each, which does not have this advantage or disadvantage.
- b) Evaluate the z-component of the *RGB*-base vectors.
- c) Provide the equation system for the white point calibration. Name the calibration parameters *CR*, *CG* and *CB*.
- d) Suppose $CR = 0.6445$, $CG = 1.1919$ and $CB = 1.2031$ are given as a solution. Evaluate the transformation matrix from the linear color space *RGB* into the color space *XYZ*.

Exercise 4) Color space transformation to PAL and NTSC

In this exercise we focus on the transformation from colors in the sRGB-color space into the broadly known color spaces used in television, namely PAL and NTSC.

- a) In order to be compatible with old black and white systems, the first channel of the PAL-color space (also known as YUV-color space) is the *Y*-coordinate of the *XYZ*-color space. Since the *Y*-coordinate

$$Y = 0.2126 * R + 0.7152 * G + 0.0722 * B$$

contains a major green component, *Cb* and *Cr* are chosen in a way such that they contain a major blue respectively red component:

$$Cb = B - Y, Cr = R - Y.$$

Finally norming the *Cb*- and the *Cr*-channels leads to the YUV- or PAL-color space:

$$U = 0.49 Cb, V = 0.88 Cr$$

Provide the transformation matrix from the sRGB-color space into the YUV-color space.

- b) The YIQ- or NTSC-color space is used as the US television standard. It is created from the PAL-color space, by swapping the *U*- and *V*-coordinates followed by a rotation by 33 degrees around *Y*-axis. Evaluate the transformation matrix for the conversion from PAL to NTSC. You do not have to evaluate trigonometric expressions.
- c) The YIQ-channels are splitting the bandwidth proportional to 8:5:2 during the transfer of NTSC color signals. Why is such an uneven bandwidth being used?

Exercise 5) Pseudo colors

Given is an algorithm, which provides a gray scale image (e.g. Mandelbrot). The intensities lie between 0 and $2^{24}-1$. How would you colorcode the image in order to map the whole intensity range of the image? High intensity values should correspond to warm colors such as red, while low intensity values should correspond to cold colors such as blue. *Remark: A coding in gray colors in true-color-systems allows only 256 samples and is therefore, not sufficient for most applications.*

Exercise 6) CIE-Chart

- Which properties does a mixed color in the CIE-Chart have to its primaries?
- Which meaning does the connection between 770nm and 380nm have in this chart?
- The figure below shows a CIE-Chart. Add following primaries into the chart.

	x	y	Y
C1	0.1	0.8	12
C2	0.6	0.3	26
C3	0.2	0.05	10

- d) Determine the dominant wavelengths λ_1 , λ_2 and λ_3 of the 3 primaries.
- e) For each primary, draw the isoline of constant saturation passing through it into the chart.
- f) Determine the primary C_{123} , which is the sum (in the XYZ-space) of the 3 primaries C_1 , C_2 and C_3 . Add it to the chart.
- g) Can all spectral colors with full saturation be mixed from three linearly independent primaries?

