Exercises (Lectures 2 and 3)
Computer Vision 1
Master AI

EXERCISE 1:
To calculate the color of light sources, the following intuitive color models are used: intensity I, chromaticity xy, hue H and saturation S. Let's assume, for simplicity reasons, that sunlight S is given by $X = Y = Z = 100$. Further, let $X = 100$, $Y = 100$ en $Z = 150$ be the values for a given artificial lamp A.

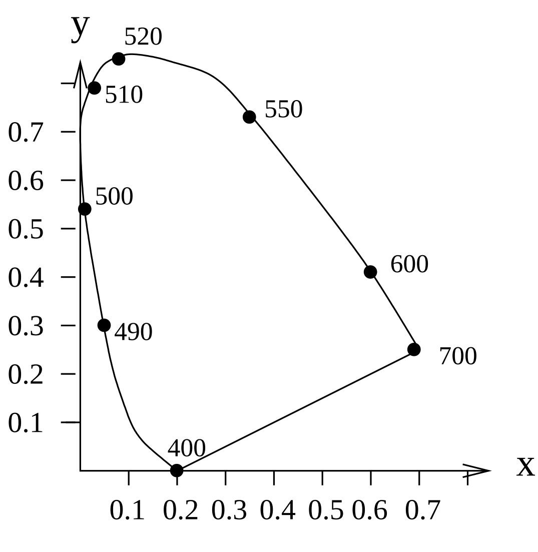

Figure 1: *Chromaticity diagram.*

- (a) Calculate the intensity I of the two light sources S and A.
- (b) Calculate the chromaticy values $x = X/(X+Y+Z)$, $y = Y/(X+Y+Z)$ and plot these in the chromaticity diagram given in Figure 1.
- (c) What the estimated hue of the light sources S and A with reference white light B at $X = 120$, $Y = 100$ and $Z = 100$.
- (d) Rank the light sources with respect to their saturation S.
- (e) Plot the region of colors which is produced through the mixture of S, A and B.

EXERCISE 2:
We consider the representation of colors in a color space. In Figure A.1 (see attachment), the color matching functions of the CIE X, Y and Z primary colors are given. Further, in table 1 (see attachment) their spectral values are given with 10 nm interval (e.g. the spectral color of 500 nm has the following tri-stimulus values $\bar{x} = 0.0049$, $\bar{y} = 0.323$ and $\bar{y} = 0.2720$). Given a light source $K(\lambda)$ and an object $\rho(\lambda)$ with certain spectral distributions, then $X = \int_\lambda K(\lambda)\rho(\lambda)\bar{x}(\lambda)d\lambda$, $Y = \int_\lambda K(\lambda)\rho(\lambda)\bar{y}(\lambda)d\lambda$ and $Z = \int_\lambda K(\lambda)\rho(\lambda)\bar{z}(\lambda)d\lambda$. It is assumed that $K(\lambda)$ is a white light source i.e. equal energy distribution over all wavelengths.

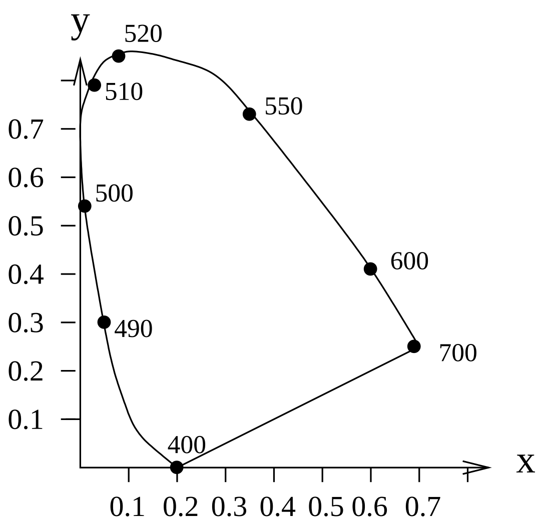

Figure 2: *Color scheme.*

- (a) Compute X, Y and Z for a given object color A of 500 nm i.e. $\rho(\lambda_{500}) = 1$ and 0 otherwise. Further, calculate the chromaticity coordinates $x = \frac{X}{X+Y+Z}$, $y = \frac{Y}{X+Y+Z}$ and $z = \frac{Z}{X+Y+X}$ of A.
- (b) Plot color A as a small circle in the chromaticity diagram given in Figure 2.
- (c) Given an object color B of 580 nm (i.e. $\rho(\lambda_{580}) = 1$ and 0 otherwise), find X, Y and Z and the chromaticity coordinates x, y en z.
- (d) Plot color B as a small cross in the chromaticity diagram.
- (e) Given a color C consisting of the colors A of 500 nm and B of 580 nm. Compute X, Y en Z and the chromaticity coordinates x, y en z.
- (f) Plot the color as a small triangle in the chromaticity diagram.
- (g) If the white light source $K(\lambda)$ varies (only) in intensity what would happen with the values X, Y, Z and x, y en z of the colors A, B and C? What will be the consequence?
- (h) The tri-stimulus values of a given lamp L are as follows $X = 98.04$, $Y = 100.00$ and $Z = 118.12$. Compute the chromaticity coordinates x, y and z and plot color L with a small rectangle in the chromaticity diagram.
- (i) Indicate, by three different lines, the colors which are generated by the mixture of L with A, B and C respectively.
- (j) What is the hue (dominant wavelength) of C with L as reference white?

- (k) Order the three colors A, B and C with respect to their saturation.
- (l) What are the complementary colors A^c, B^c and C^c for A, B en C respectively with L as reference white? Are these complementary colors pure (wavelength) or a mixture of pure colors?
- (m) Draw the region of colors which are generated by the mixture of A^c, B^c, C^c and L.
- (n) Given is a color with a spectral power distribution given in Figure A.2 (see attachment). Estimate the hue (dominant wavelength) and describe the amount of the saturation and intensity. What should be the approximated position of this color in the chromaticity diagram?
- (o) Given is a color with spectral power distribution given in Figure A.3. Estimate the hue (dominant wavelength) and describe the amount of the saturation and intensity. What should be the approximated position of this color in the chromaticity diagram?
- (p) Given is a color with spectral power distribution given in Figure A.4. Estimate the hue (dominant wavelength) and describe the amount of the saturation and intensity. What should be the approximated position of this color in the chromaticity diagram?
- (q) For which of the three spectra a human will perceive the highest intensity? Explain your answer.

EXERCISE 3:

We consider the color of a matte, dull (not glossy) surface. The color at a specific location on the surface under white light illumination is given by the following simple reflection model $R = Ik_R \cos\theta$, $G = Ik_G \cos\theta$ and $B = Ik_B \cos\theta$, where I is the intensity of the white light source, k_R, k_G and k_B are the amount of red, green and blue reflected by the surface (i.e. color of the surface). Furthermore, $\cos\theta = \vec{n} \cdot \vec{l}$ is the dot product of the two-unit vectors $\vec{n}$ (i.e. surface normal) and $\vec{l}$ (i.e. direction of the light source), see Figure A.5.

- (a) Assume that the surface is flat and homogeneously colored. Explain why the intensity is higher when the surface normal coincides with the direction of the light source than observed under an angle with respect to the direction of the light source.
- (b) Assume that the color of the surface is yellow i.e. $R = 100$, $G = 100$, and $B = 10$. Explain what will happen with the values R, G and B if (only) the intensity of the light source will diminish. Plot the positions of the colors in the RGB-color space.
- (c) In case of a curved (not flat) surface, indicate where the colors will be positioned in the RGB-color space. Explain your answer.
- (d) A simple color invariant is given by R/G. Proof that R/G is independent of the (intensity) light source I, object geometry and the direction of the light source.
- (e) The values of R, G and B will vary for a curved surface. Give the approximated shapes of the histograms for a homogeneously (curved) surface for R, G, B and R/G. Which color models will you choose for the recognition of objects under varying light intensity. Explain your answer.
- (f) Consider the same surface. Assume that the surface is glossy (instead of matte). The reflection model is now given by $R = Ik_R cos\theta + Ik_s cos^n\alpha$, $G = Ik_G cos\theta + Ik_s cos^n\alpha$ and $B = Ik_B cos\theta + Ik_s cos^n\alpha$. k_s is the specular reflection coefficient and cos^n depends on the glossiness and α depends on the viewing condition. Plot the colors of the homogeneously colored (shiny) surface in RGB- and rgb-color space.
- (g) Proof that R/G is not a color invariant for shiny surfaces. Proof that $\frac{R-G}{R-B}$ is a color invariant for shiny surfaces.