Exercises (first part)
Intelligent Multimedia Systems
Master AI, 2009

EXERCISE 1:
For the retrieval of images it is important to achieve color authenticity under different light sources such as sunlight or an artificial lamp. For simplicity reasons it is assumed that sunlight S is given by $X = Y = Z = 100$. Further, the X, Y en Z values of an artificial lamp depends on the color of the light source. To determine how an object color K is perceived under a light source with a specific color B (e.g. sunlight or lamp) you should perform the following steps:

- Compute the chromaticity coordinates $x = \frac{X}{X+Y+Z}$, $y = \frac{Y}{X+Y+Z}$ and $z = \frac{Z}{X+Y+X}$ of B.
- Draw these coordinates in the chromaticity diagram.
- Repeat this for color K.
- Draw a line from B through color K to the boundary of the chromaticity diagram. The point of intersection indicates the hue of the color i.e. the dominant wavelength of the perceived color.

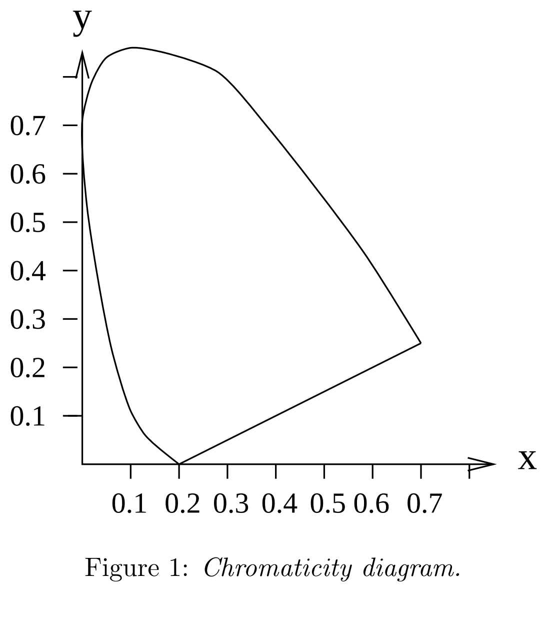

Figure 1: *Chromaticity diagram.*

- (a) Is it possible to produce a color which is green under sunlight and blue under artificial light? What will be the hue of the light source in this case? Calculate the estimated wavelength and plot this in the chromaticity diagram given in Figure 1.

- (b) Order the three colors B, sunlight S and K with respect to their saturation.
- (c) Plot the region of colors which is produced through the mixture of B, S and K.
- (d) Is it possible to perceive the color blue when observed in open air as red when when observed indoors.

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 color $K(\lambda)$ with a certain spectral distribution, then $X = \int_\lambda K(\lambda)\bar{x}(\lambda)d\lambda$, $Y = \int_\lambda K(\lambda)\bar{y}(\lambda)d\lambda$ and $Z = \int_\lambda K(\lambda)\bar{z}(\lambda)d\lambda$. It is assumed that $K(\lambda)$ is a white light source i.e. equal energy distribution over all wavelengths.

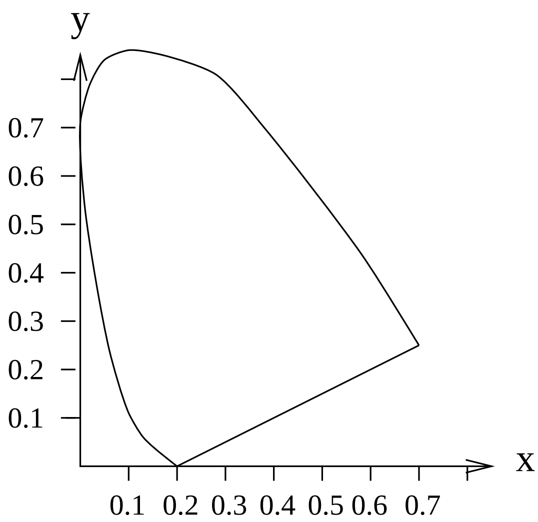

Figure 2: *Color scheme.*

- (a) Compute X, Y and Z for a given color A of 500 nm. 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 a color B of 580 nm, 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.