OPT 422/222 - Color Technology
Homework #1

You will create a folder entitled ***ColorToolbox_Lastname*** for this class. Many of the assignments will specify adding a new function to be written to this folder. For this assignment, you will be creating one data structure, and three new functions. When you finish the full assignment .zip the folder, and upload it to Blackboard.

1. Create a **structure** of CIE observers and illuminant data.
    a. Read in the following text files and store the data in each file in a structure named "cie" with the fields indicated in step c). *Note* that the illuminant F file contains 12 illuminants. Create a row vector field in the structure called "lambda" from the first file's wavelength information. <u>The wavelength information for each other datasets should be removed by deleting the first column of each loaded matrix before storing the data in the structure.</u>

        CIE_2Deg_380-780-5nm.txt
        CIE_10Deg_380-780-5nm.txt
        CIE_IllA_380-780-5nm.txt
        CIE_IllD65_380-780-5nm.txt
        CIE_IllF_1-12_380-780-5nm.txt

    b. CIE illuminant E is an equal energy illuminant. Include it in your "cie" structure by creating a vector field "illE" with a length equal to the wavelength range and a constant value of 100.

    c. When called without suppressing output, your structure should look like this:

```
cie = 

      lambda: [1x81 double]
     cmf2deg: [81x3 double]
    cmf10deg: [81x3 double]
        illA: [81x1 double]
      illD65: [81x1 double]
        illE: [81x1 double]
        illF: [81x12 double]
```

    d. save "cie" in your ColorToolbox folder by using the *save* command.

2. Create a function called ref2XYZ that takes as input a vector of reflectance factor data, a set of CIE color matching functions, and the spectral power distribution of a light source, and returns a 3-by-n (n is the number of reflectance samples) vector of CIE tristimulus values (XYZ). Follow the procedure and example shown in this homework's Appendix (PCT, p. 56). **NOTE:** This function should work with either reflectance or transmittance data. You are just calculating the tristimulus values of a reflected/transmitted spectrum, and this example uses reflectance.

    a. Your function should contain just <u>two lines</u> of matrix math, the first to calculate k (the illuminant normalization constant), and the second to calculate the product of k, the transpose of the color matching functions, a diagonal matrix of the illuminant, and the vector of reflectances.

    b. To test your function, run the following code and confirm you get exactly the same output:

```
clear
ref=load('ObjectRef_380-780-5nm.txt');
ref=ref(:,2);
load cie
objXYZ=ref2XYZ(ref, cie.cmf2deg, cie.illD65);
fprintf('X=%5.2f Y=%5.2f Z=%5.2f\n',objXYZ);
```

X=13.47 Y=14.39 Z=47.52

3. Create a function called "XYZ2xyY" that takes as input a 3-by-n vector of tristimulus values and returns a 3-by-n vector of chromaticity coordinates and luminance factor. Save your new function to your *ColorToolbox_Lastname*.

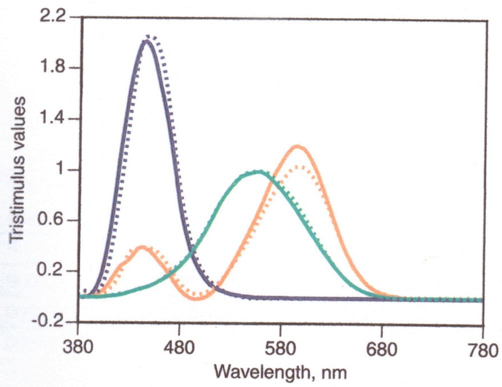
    a. Verify that your function works correctly by testing with the following:

```
>> objXYZ=[13.472;14.385;47.5221];
>> XYZ2xyY(objXYZ)

ans =

    0.1787
    0.1908
   14.3850
```

4. Now create a function called "xyY2XYZ" that does the opposite, goes from Chromaticity Coordinates with Y in a 3-by-n vector (x, y, and Y) and returns a 3-by-n vector of tristimulus values. Use the above numbers to check that your new function works as well. Save your new function to your *ColorToolbox_Lastname*.



Using the CIE standard deviate observer, the effects of age on color matching can be estimated. These are estimated color-matching functions for 20-year-old (solid lines) and 60-year old (dashed lines) observers. However, note that $\bar{y}_{10\lambda}$ appears independent of age, a result of normalization applied to the Stiles and Burch data used to derive the standard deviate observer. As a consequence, we do not recommend its use.

Tristimulus integration for reflecting objects is shown here:

$$X = k\sum_{\lambda} S_\lambda R_\lambda \bar{x}_\lambda \Delta\lambda$$

$$Y = k\sum_{\lambda} S_\lambda R_\lambda \bar{y}_\lambda \Delta\lambda$$

$$Z = k\sum_{\lambda} S_\lambda R_\lambda \bar{z}_\lambda \Delta\lambda$$

$$k = \frac{100}{\sum_{\lambda} S_\lambda \bar{y}_\lambda \Delta\lambda}$$

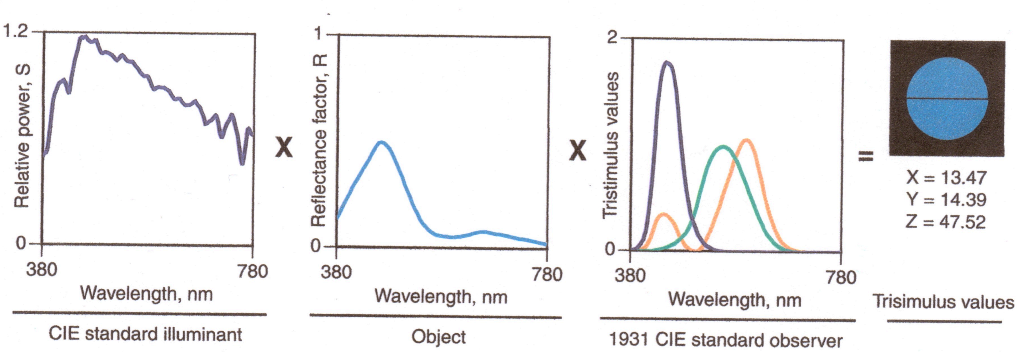
where S_λ is a CIE illuminant, R_λ is the object's spectral reflectance factor, $\bar{x}_\lambda$, $\bar{y}_\lambda$, and $\bar{z}_\lambda$ are the CIE standard observer color-matching functions, Σ_λ represents summation across wavelength, k is a normalizing constant, and $\Delta\lambda$ is the measurement wavelength interval (for objects it is usually either 10 or 20 nm). These equations, in fact, are an approximation of the mathematical operation of integration. See Appendix.

metamerism, known to correlate highly with observer metamerism (Billmeyer 1980, Kaiser 1980). Recognize, also, that for highly metameric matches, any single observer may be poorly represented by any of the CIE standard observers (Thornton 1998). To ensure matches that hold for all observers under all viewing conditions, metamerism must be eliminated or, at the very least, greatly minimized.

Calculating Tristimulus Values for Materials

We now describe how to calculate CIE tristimulus values from spectral data of an object, a CIE standard illuminant, and one of the CIE standard observers. The figures on this and the facing page illustrate the method, and the table on page 58 provides a numerical example. The values of *S*, at each of many equally spaced wavelengths across the spectrum, are multiplied together with *R* and $\bar{x}$, $\bar{y}$, or $\bar{z}$ to give products at each wavelength ($SR\bar{x}$), ($SR\bar{y}$), and ($SR\bar{z}$). These are summed up (mathematically equivalent to finding the areas under the curves) to give the tristimulus values *X*, *Y*, and *Z*.

By definition, CIE color-matching functions are defined from 360 nm to 830 nm in 1-nm increments (ISO/CIE 10527). Ideally, measurements of sources and objects should have the identical wavelength range and increment. In practice, spectrophotometers designed for color measurement have wavelength ranges near 400 nm to 700 nm with increments of either 10 nm or 20 nm. Therefore, in order to calculate tristimulus values accu-



The CIE tristimulus values *X*, *Y*, and *Z* of a color are obtained by multiplying together the relative power S_λ of a CIE standard illuminant, the reflectance factor R_λ (or the transmittance) of the object, and the standard observer functions $\bar{x}_\lambda$, $\bar{y}_\lambda$, or $\bar{z}_\lambda$. The products are summed up for all the wavelengths in the visible spectrum, then their sums are normalized, resulting in CIE tristimulus values, as indicated in the diagrams here and on page 57 and by the mathematical equations shown above.