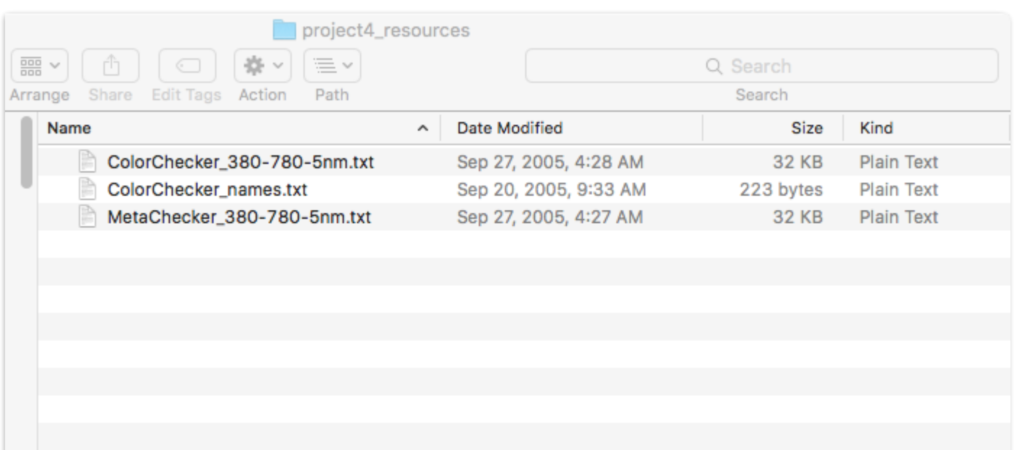
Project 4: color differences

In this project you will first develop functions to calculate CIELab values from XYZ tristimulus values, and ΔE_{ab} color differences from pairs of CIELab values. You will then calculate CIELab values for the real, imaged, and matching color patches you measured in previous projects, and calculate ΔE_{ab} color differences between pairs of patches. Finally you will tabulate the values and plot the differences.

1) Download the project resources provided in myCourses to your working directory.



2) a) Modify the ref2XYZ function you created in Project 3 so that it can simultaneously process multiple reflectance spectra (ref(s)). Depending on how you originally implemented your function, it may already be able to do this. If not, an example of how to implement this capability is shown below. b) Include a listing of the code for your ref2XYZ function in your report by using the comment syntax shown below.

```
function XYZ = ref2XYZ(ref,cmfs,ill)

    % compute XYZ from surface reflectance factor(s), color matching functions,
    % and illuminant spectral power distribution
    % can handle multiple ref(s) simultaneously
    % 3/9/16 jaf

    %compute normalizing constant for each illuminant
    k = 100./(cmfs(:,2)'*ill);

    %compute XYZ
    XYZ = k.*cmfs'*diag(ill)*ref;

end
```

```
%%
% include a listing of the indicated function in a published report
% (note that the "include" markup syntax must be part of a
% contiguous comment block that starts with a section marker %%)
%
% <include>ref2XYZ.m</include>
```

3) a) Test your modified ref2XYZ function using the code provided below. b) Confirm that your results are the same to within rounding error. c) Include the output in your report.

```
CC_spectra = load('ColorChecker_380-780-5nm.txt');
CC_XYZs = ref2XYZ(CC_spectra(:,2:25),cie.cmf2deg,cie.illD65)
```

```
CC_XYZs =

  Columns 1 through 7

   11.5145   39.1346   18.3488   11.1492   25.8437   31.7110   37.1457
   10.3819   36.5981   19.6332   13.8551   24.3868   43.8600   29.5592
    7.1502   27.0564   35.6470    7.4267   45.6142   44.8778    6.5006

  Columns 8 through 14

   13.8627   29.1328    8.5889   33.9174   46.1864    8.9183   15.0353
   12.3179   19.8475    6.4569   44.1533   42.4957    6.4177   24.1079
   39.3093   14.9941   15.4745   11.4297    8.6771   32.2736    9.6379

  Columns 15 through 21

   19.3447   55.8457   29.6768   14.4138   87.8402   57.9621   35.2286
   11.3576   58.9726   19.3515   19.9750   92.3781   61.0426   37.0414
    5.5526    9.6411   32.2626   39.0008   95.6125   65.4909   40.2256

  Columns 22 through 24

   19.3492    8.7646    3.2111
   20.4708    9.2915    3.3763
   22.1545   10.3188    3.9312
```

4) a) Create a function **Lab = XYZ2Lab(XYZ, XYZn)** based on the equations given below. The function should take as input, XYZ (a 3xn array of tristimulus values) and XYZn (a 3x1 vector of tristimulus values of the reference illuminant (e.g. D50, D65, A, …), and return Lab (a 3xn array of CIELab values). Note the conditional function f(x) used in the calculations. b) Include a listing of the code for your function in your report.

$$L^* = 116 f\left(Y/Y_n\right) - 16$$

$$a^* = 500\left[f\left(X/X_n\right) - f\left(Y/Y_n\right)\right]$$

$$b^* = 200\left[f\left(Y/Y_n\right) - f\left(Z/Z_n\right)\right]$$

$$f(x) = \begin{Bmatrix} x^{1/3} & x > 0.008856 \\ 7.787x + 16/116 & x \le 0.008856 \end{Bmatrix}$$

5) a) Test your XYZ2Lab function by modifying the script shown below to calculate the CIELab values of the patches in the ColorChecker chart from the XYZ values you calculated in step 3. The script uses ref2XYZ to calculate XYZn for the D65 illuminant, XYZ2Lab to compute the CIELab values, textread to read in the names of the ColorChecker patches, and fprintf to produce the formatted output. Textread produces a cell array of the names so you will need to use the {} rather than the () syntax to access the actual text strings. b) Use this script to reproduce the table shown below. c) Confirm that your results are the same to within rounding

```
% load the CIE data into a structure
cie = loadCIEdata;

% compute the XYZ values of D65 for XYZn in XYZ2Lab
XYZn_D65 = ref2XYZ(cie.illE,cie.cmf2deg,cie.illD65);

% calculate the Lab values
CC_Labs = XYZ2Lab(…);

% read in the names of the ColorChecker patches
names = textread('ColorChecker_names.txt','%s','delimiter','|');

% print the formatted table
% header
fprintf(…);
fprintf(…);
% loop to print the patch values
for i=1:size(CC_Labs,2)
   fprintf(…);
end
```

ColorChecker XYZ and Lab values (D65 illuminant and 2 deg. observer)

Patch #	X	Y	Z	L*	a*	b*	Patch Name
1	11.515	10.382	7.150	38.519	12.410	13.309	Dark Skin
2	39.135	36.598	27.056	66.974	14.329	17.320	Light Skin
3	18.349	19.633	35.647	51.420	-1.624	-21.603	Blue Sky
4	11.149	13.855	7.427	44.024	-13.963	21.774	Foliage
5	25.844	24.387	45.614	56.473	11.544	-24.698	Blue Flower
6	31.711	43.860	44.878	72.135	-33.101	3.115	Bluish Green
7	37.146	29.559	6.501	61.272	32.497	55.059	Orange
8	13.863	12.318	39.309	41.717	14.416	-42.900	Purplish Blue
9	29.133	19.847	14.994	51.664	45.468	13.382	Moderate Red
10	8.589	6.457	15.474	30.537	23.785	-24.136	Purple
11	33.917	44.153	11.430	72.331	-26.083	57.948	Yellow Green
12	46.186	42.496	8.677	71.211	17.187	64.297	Orange Yellow
13	8.918	6.418	32.274	30.443	27.024	-53.277	Blue
14	15.035	24.108	9.638	56.196	-40.771	35.342	Green
15	19.345	11.358	5.553	40.176	51.976	22.689	Red
16	55.846	58.973	9.641	81.277	-0.508	78.575	Yellow
17	29.677	19.352	32.263	51.096	50.004	-17.653	Magenta
18	14.414	19.975	39.001	51.809	-25.642	-25.126	Cyan
19	87.840	92.378	95.613	96.975	0.076	3.262	White
20	57.962	61.043	65.491	82.402	-0.133	0.831	Neutral 8
21	35.229	37.041	40.226	67.308	0.079	0.125	Neutral 6.5
22	19.349	20.471	22.154	52.365	-0.541	0.237	Neutral 5
23	8.765	9.291	10.319	36.540	-0.568	-0.600	Neutral 3.5
24	3.211	3.376	3.931	21.492	0.035	-1.462	Black

6) Since none of the ColorChecker patches is dark enough to drive the Y/Yn < 0.008856 clause in the CIELab equations, you will need to modify the data to test the XYZ2Lab function for dark colors. To do this write a script that a) multiplies all the ColorChecker spectra by 0.02 then b) adapt the code you wrote in step 5 to produce the formatted table shown below. c) Confirm that your results are the same to within rounding error. d) Include the table in your report.

ColorChecker(Dark) XYZ and Lab values (D65 illuminant and 2 deg. observer)

Patch #	X	Y	Z	L*	a*	b*	Patch Name
1	0.230	0.208	0.143	1.876	1.350	1.188	Dark Skin
2	0.783	0.732	0.541	6.612	3.565	3.659	Light Skin
3	0.367	0.393	0.713	3.547	-0.255	-4.082	Blue Sky
4	0.223	0.277	0.149	2.503	-1.654	2.191	Foliage
5	0.517	0.488	0.912	4.406	2.184	-5.453	Blue Flower
6	0.634	0.877	0.898	7.924	-8.173	0.823	Bluish Green
7	0.743	0.591	0.130	5.340	7.416	7.347	Orange
8	0.277	0.246	0.786	2.225	1.766	-7.409	Purplish Blue
9	0.583	0.397	0.300	3.586	8.414	1.893	Moderate Red
10	0.172	0.129	0.309	1.166	2.009	-2.416	Purple
11	0.678	0.883	0.229	7.977	-6.593	10.483	Yellow Green
12	0.924	0.850	0.174	7.677	4.646	10.754	Orange Yellow
13	0.178	0.128	0.645	1.159	2.309	-7.234	Blue
14	0.301	0.482	0.193	4.355	-6.454	4.752	Green
15	0.387	0.227	0.111	2.052	7.005	1.949	Red
16	1.117	1.179	0.193	10.405	-0.138	15.181	Yellow
17	0.594	0.387	0.645	3.496	9.246	-3.202	Magenta
18	0.288	0.399	0.780	3.609	-3.745	-4.935	Cyan
19	1.757	1.848	1.912	14.666	0.021	0.885	White
20	1.159	1.221	1.310	10.710	-0.036	0.226	Neutral 8
21	0.705	0.741	0.805	6.692	0.019	0.030	Neutral 6.5
22	0.387	0.409	0.443	3.698	-0.088	0.038	Neutral 5
23	0.175	0.186	0.206	1.679	-0.054	-0.058	Neutral 3.5
24	0.064	0.068	0.079	0.610	0.002	-0.073	Black

7) a) Create a function ***DEab = deltaEab (Lab1, Lab2)*** that implements the ΔE_{ab} color difference metric shown below. Your function should take as input Lab1 and Lab2 (two 3-by-n matrices of CIELAB values) and return DEab (a 1-by-n matrix of ΔE_{ab} color differences). b) Include a listing of the code for your function in your report.

$$\Delta E_{ab} = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$

8) Test your deltaEab function by calculating the ΔE_{ab} color differences between two sets of spectral data. The spectra in the files “ColorChecker_380-780-5nm.txt” and “MetaChecker_380-780-5nm.txt” have been designed to be metameric (small color differences) under D65 but not under other sources. a) Write a script that calculates the ΔE_{ab} color differences between these two datasets under illuminant D65 and under illuminant A. b) Use the results to reproduce the formatted table shown below. c) Confirm that your results are the same to within rounding error. d) Include the table in your report.

ColorChecker and MetaChecker color differences

patch #	DEab(D65)	DEab(illA)
1	2.597e-07	22.636
2	1.136e-07	22.178
3	1.056e-07	32.275
4	1.905e-07	28.232
5	3.980e-07	25.937
6	1.326e-07	29.487
7	8.581e-08	17.309
8	1.454e-07	27.241
9	1.665e-07	12.210
10	2.907e-07	19.509
11	1.561e-07	22.623
12	1.305e-07	16.970
13	1.083e-07	20.083
14	1.193e-07	26.099
15	6.708e-08	7.053
16	1.330e-07	11.532
17	6.468e-09	10.690
18	8.581e-08	31.619
19	2.661e-07	2.545
20	6.948e-08	15.940
21	1.846e-07	28.926
22	8.337e-08	26.751
23	3.668e-07	20.574
24	1.022e-07	18.567

9) Now use your XYZ2Lab and deltaEab functions to calculate CIELab values and color differences for your real, imaged and matching color patches. a) First, use your XYZ2Lab function to calculate the CIELab values of your patches from the XYZ values you ***calculated*** in Project 3. The reference illuminant XYZn should be D50. b) Then use your deltaEab function to calculate color differences between the each of the real patches and their corresponding imaged and matched patches. c) Produce a formatted table like the one shown below that summarizes the ***calculated*** XYZ and Lab values for your patches and the ΔEab color differences between the real patches and the corresponding imaged and matched patches. Your numbers will be different depending on your patches, but their magnitudes should be roughly the same as those shown below. c) Include the table in your report.

Calculated XYZ, Lab, and deltaE values (w.r.t. real patches)

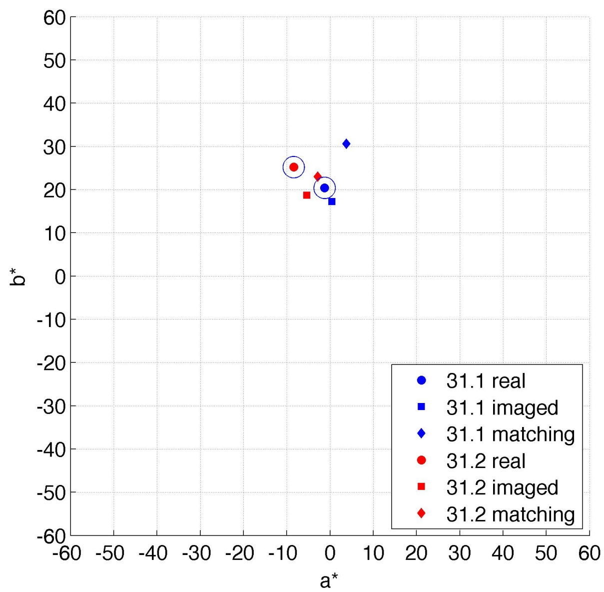
patch 31.1

	X	Y	Z	L	a	b	dEab
real	27.6207	28.9776	14.4681	60.7618	-1.2646	20.4128	
imaged	14.6796	15.1416	7.3660	45.8276	0.4872	17.2195	15.3720
matching	15.9317	15.8463	4.8306	46.7722	3.8006	30.5741	18.0172

patch 31.2

	X	Y	Z	L	a	b	dEab
real	17.9607	20.3217	8.1352	52.1990	-8.4058	25.1960	
imaged	6.5927	7.3908	2.8639	32.6805	-5.3716	18.6969	20.7947
matching	7.4239	8.0139	2.6067	34.0119	-2.8559	23.0065	19.1407

10) Use MATLAB to visualize the color differences between your real, imaged, and matching patches. a) Write code to create a graph like the one shown below, that plots the a*,b* values of each of the patches. b) Include code in the script to draw two circles (there is a Matlab function “viscircles” to do this) with radii 2.5 centered at the a*,b* values of your real patches to determine if your imaged and matching patches are within 2.5 ΔE^*_{ab} of your real patch (i.e. below the typical JND threshold). Use the command “axis(‘square’);” so the circles plot as circles.



11) a) Use the “publish” menu/function in Matlab to document all the code, results, and figures you generated in steps 2-10. b) Include your names and team number at the beginning of the report. c) Include a feedback section at the end of the report that briefly discusses i) who did what parts of the project, ii) any problems you had with the project, iii) any parts of the project you thought were valuable, and iv) any improvements you’d like to see. d) Submit this document as a single PDF named “teamX_project4_report.pdf” to the dropbox on myCourses.