

IIAI30013

Computer Vision

HW1: Image Sensing Pipeline

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Image Sensing Pipeline

- Homework due: 3/19
- Late submissions will incur a penalty of one point for each day overdue.
- The assignment allows a maximum extension of 3 days (it will not be accepted if submitted later than 3 days).
- Submit files: code and report (4 questions), and submit them in both **.ipynb** and **PDF** file formats respectively.
- This assignment can be carried out using [Colab](#) or completed on your PC.
- Please refer to the questions on page 18 of HW1.pdf for the four questions in the report.

Image Sensing Pipeline

- Digital Camera

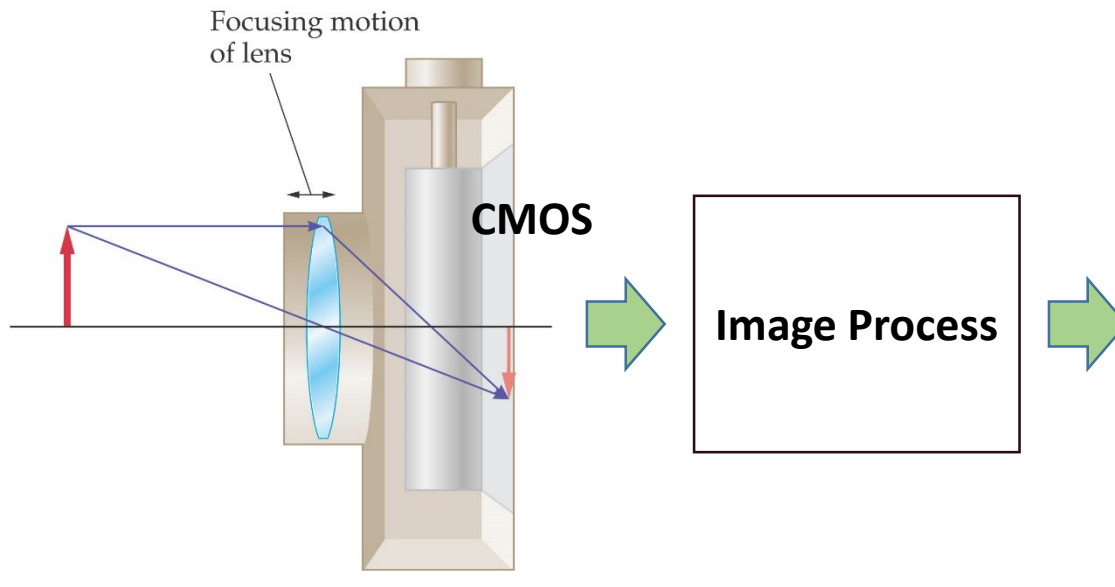


Image Sensing Pipeline

- Image Sensing Pipeline

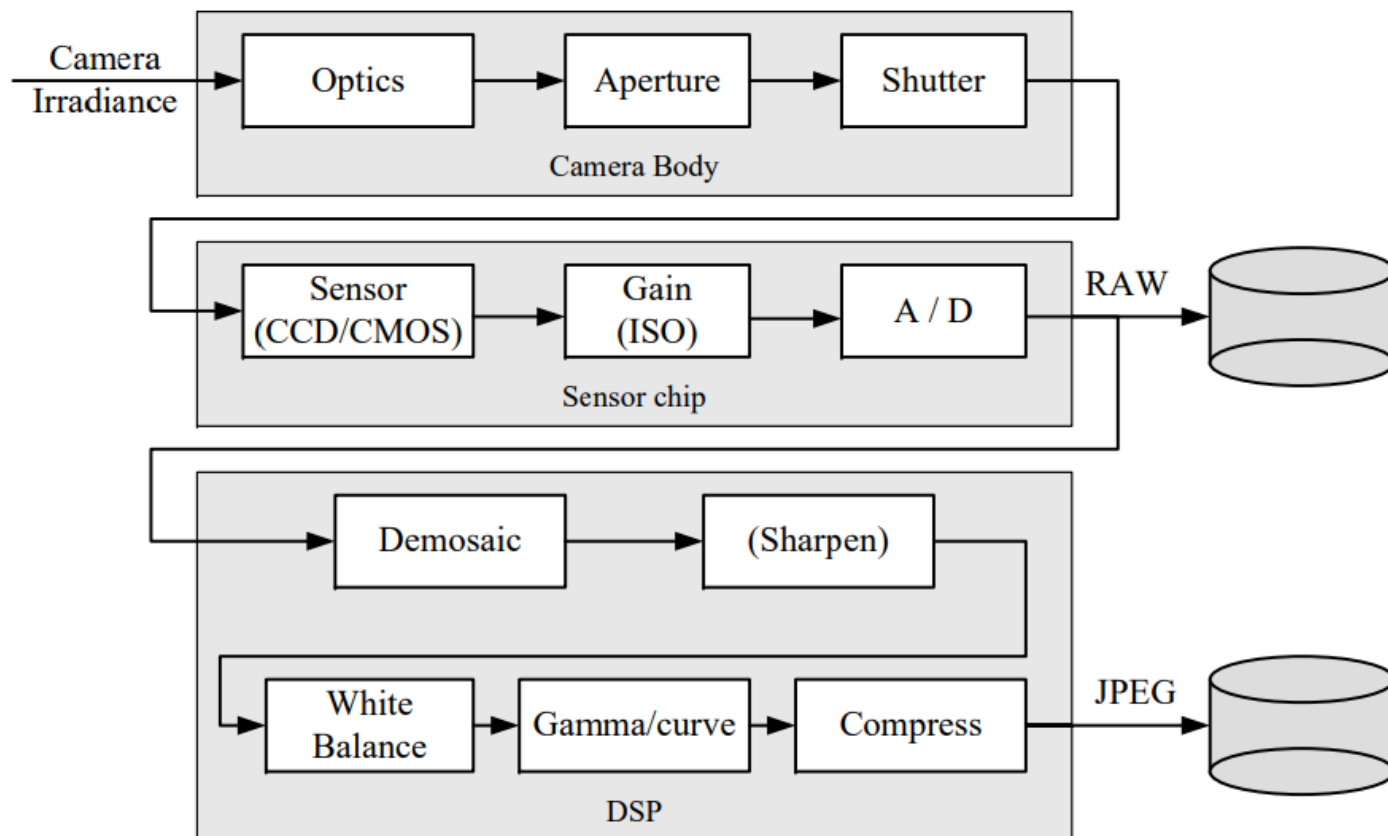


Image Sensing Pipeline

- This homework:

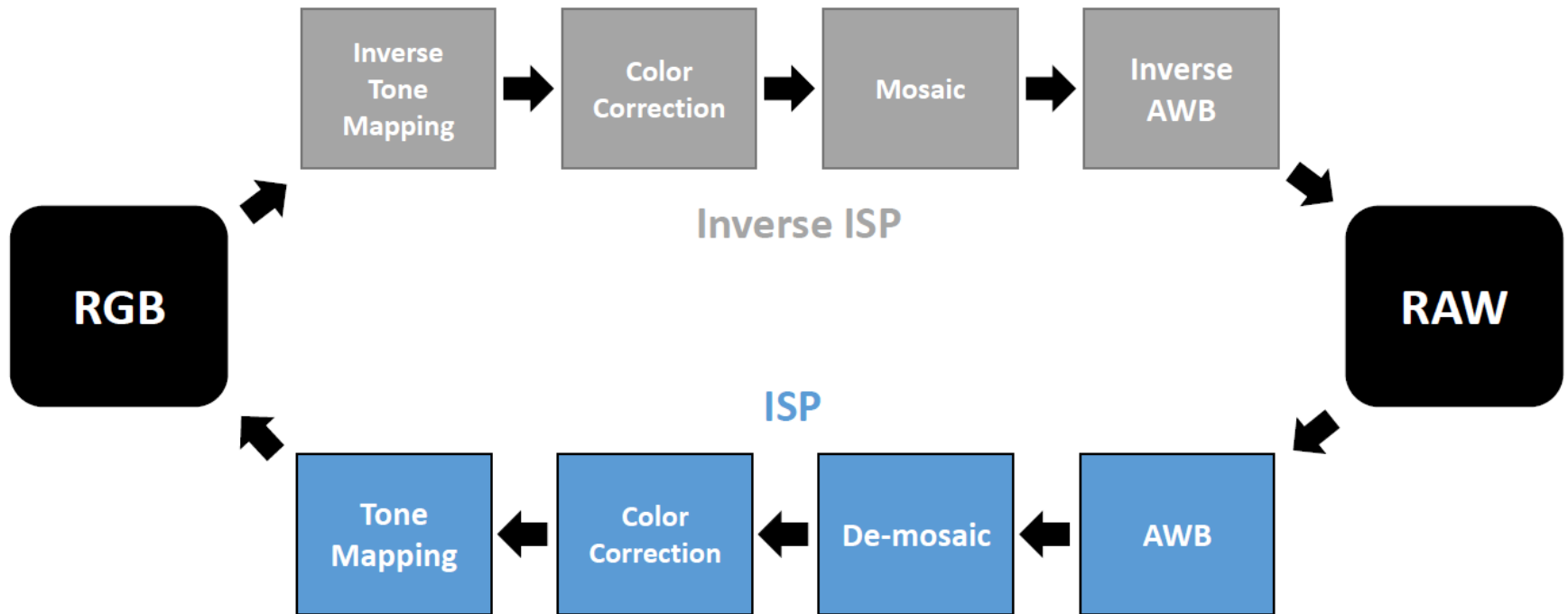


Image Sensing Pipeline

- Example: Inverse ISP

Original Image



Image after inverse tone



Image after CIE



Image after CCM



Image after mosaic



Image Sensing Pipeline

- Example: ISP

Image after WG



Image after demosaic



Image after Color Correction



Image after XYZ2RGB

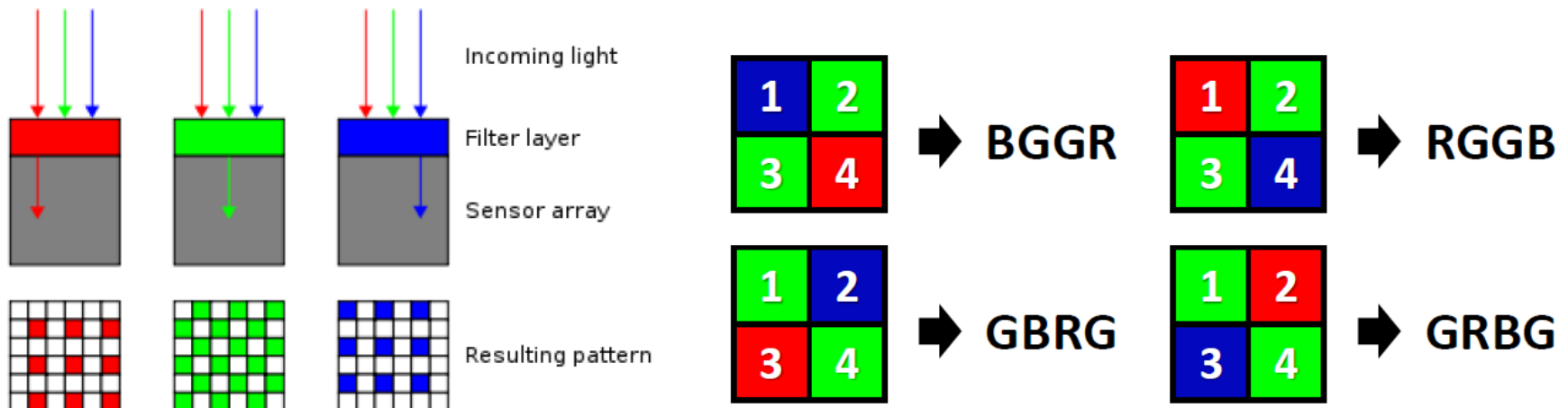


Image after tone mapping



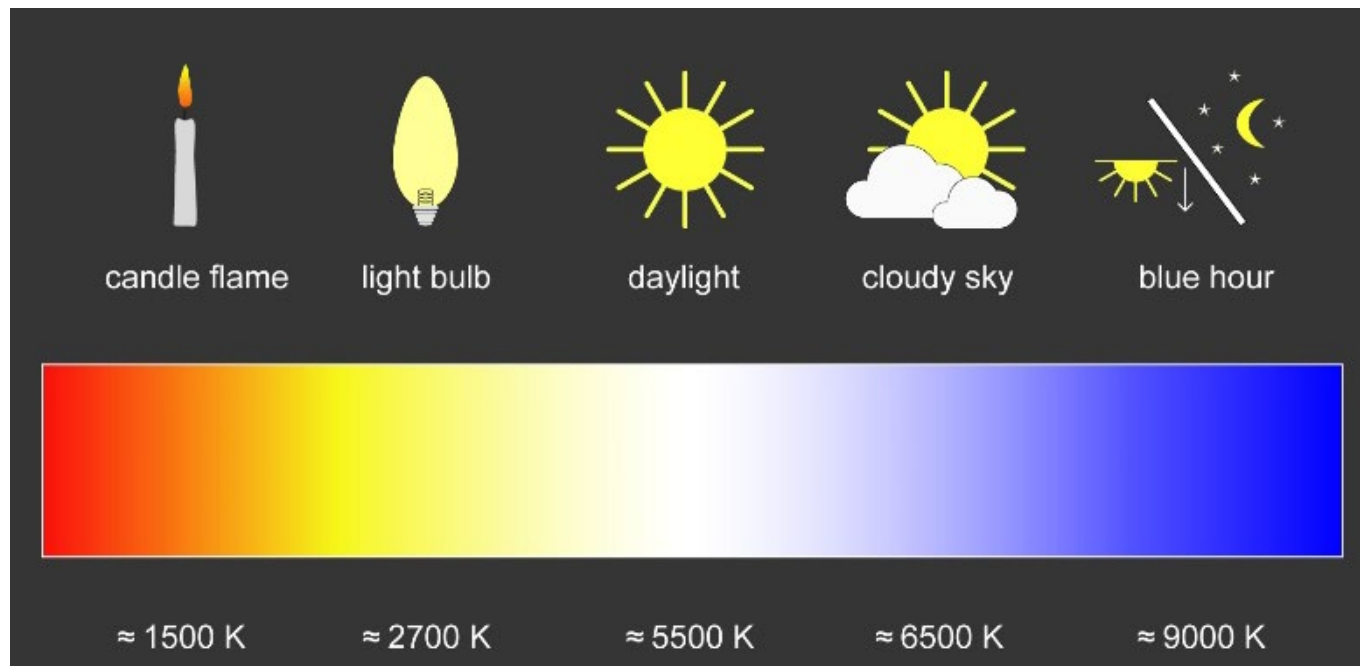
Raw Data (rawRGB)

- Bayer pattern (CFA, Color Filter Arrays)
 - Green photo sensors: luminance sensitive elements
 - Red and blue photo sensors: chrominance sensitive elements
 - Twice as many green elements as red or blue to mimic the physiology of the human eye
 - Four patterns: BGGR, RGGB, GBRG, GRBG



AWB (Auto White Balance)

- WB: mimics chromatic adaptation of the eye
 - Can be manual settings
 - Stored in metadata



AWB (Auto White Balance)

- AWB: attempts to make what is assumed to be white map to “pure white”
 - Two classical methods: gray world algorithm and white patch algorithm
 - In this homework, you only need to implement easiest AWB method (plz refer to TODO)

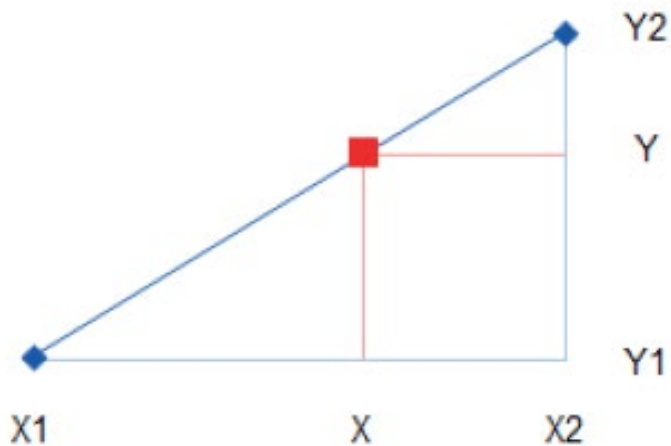
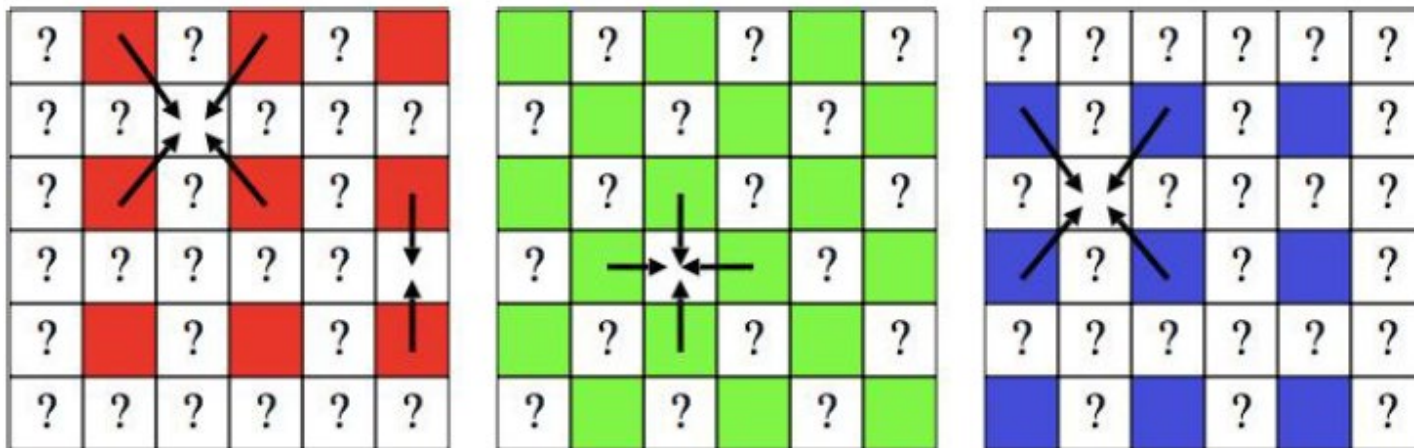
```
def generate_wb_mask(img, pattern, fr, fb):
    ...

    Input:
        img: H*W numpy array, RAW image
        pattern: string, 4 different Bayer patterns (GRBG, RGGB, GBRG, BGGR)
        fr: float, white balance factor of red channel
        fb: float, white balance factor of blue channel
    Output:
        mask: H*W numpy array, white balance mask
    ...

    #####
    # TODO:                                     #
    # 1. Create a numpy array with shape of input RAW image.                         #
    # 2. According to the given Bayer pattern, fill the fr into                       #
    #    corresponding red channel position and fb into corresponding                 #
    #    blue channel position. Fill 1 into green channel position                   #
    #    otherwise.                                                                    #
    #####
```

Demosaic

- Easiest method Linear Interpolation



$$\frac{(X - X1)}{(X2 - X1)} = \frac{(Y - Y1)}{(Y2 - Y1)}$$

$$Y = Y1 + (X - X1) \frac{(Y2 - Y1)}{(X2 - X1)}$$

Demosaic

- Python Library colour_demosaicing

- demosaicing_CFA_Bayer_bilinear
- demosaicing_CFA_Bayer_Malvar2004

[MHCW04] Henrique S Malvar , Li Wei He, Ross Cutler, and One Microsoft Way. High Quality Linear Interpolation for Demosaicing of Bayer Patterned Color Images. In International Conference of Acoustic, Speech and Signal Processing, 5 8. Institute of Electrical and Electronics Engineers, Inc., May 2004.

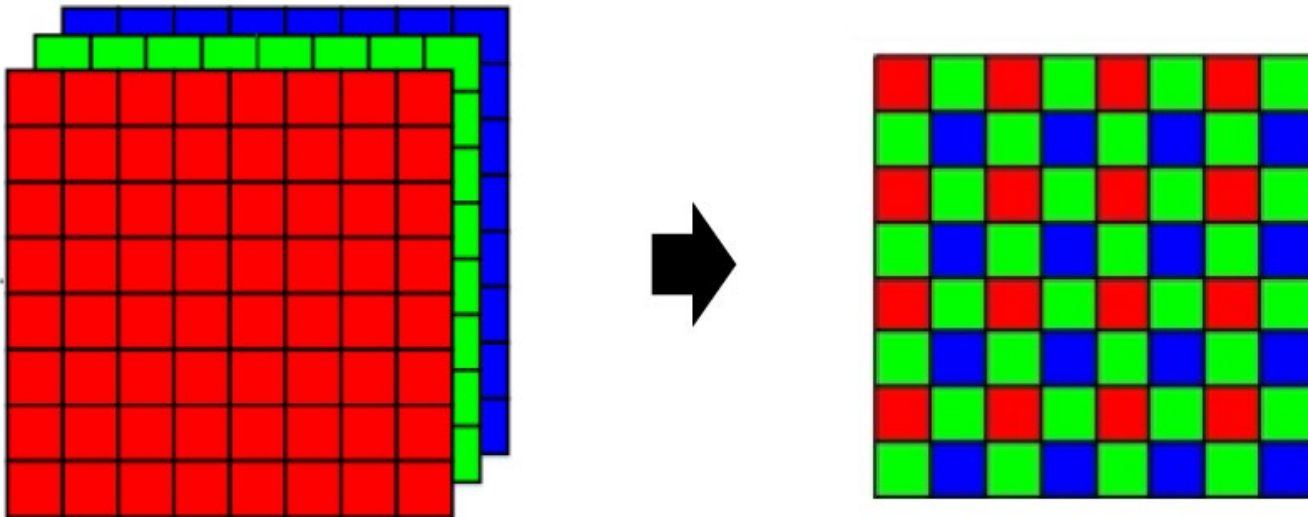
- demosaicing_CFA_Bayer_Menon2007

[MAC07] Daniele Menon, Stefano Andriani , and Giancarlo Calvagno . Demosaicing With Directional Filtering and a posteriori Decision. IEEE Transactions on Image Processing, 16(1):132 141, January 2007.

```
from colour_demosaicing import (  
    EXAMPLES_RESOURCES_DIRECTORY,  
    demosaicing_CFA_Bayer_bilinear,  
    demosaicing_CFA_Bayer_Malvar2004,  
    demosaicing_CFA_Bayer_Menon2007,  
    mosaicing_CFA_Bayer)
```

Mosaic

- Discard the value of other 2 channels
 - $H*W*3 \rightarrow H*W$
- Python Library `colour_demosaicing`
 - `mosaicing_CFA_Bayer`



Mosaic

```
def mosaic(img, pattern):
    ...
    Input:
        img: H*W*3 numpy array, input image.
        pattern: string, 4 different Bayer patterns (GRBG, RGGB, GBRG, BGGR)
    Output:
        output: H*W numpy array, output image after mosaic.
    ...

#####
# TODO:
# 1. Create the H*W output numpy array.
# 2. Discard other two channels from input 3-channel image according to
#    given Bayer pattern.
#
# e.g. If Bayer pattern now is BGGR, for the upper left pixel from
#       each four-pixel square, we should discard R and G channel
#       and keep B channel of input image.
#       (since upper left pixel is B in BGGR bayer pattern)
#####

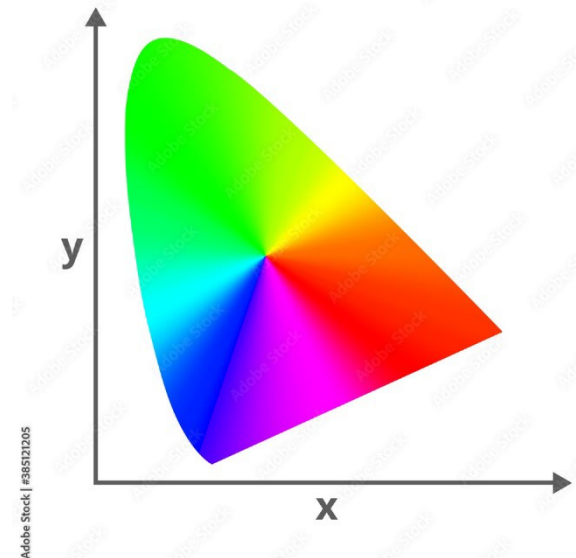
#####
#
#                               End of your code
#
#####

return output
```

Color Collection

- CCM (Color Correction Matrix)
 - Transforms sensor native **RGB** values into **CIE XYZ** color space.
 - It is important that the white balance has been performed correctly.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.4887180 & 0.3106803 & 0.2006017 \\ 0.1762044 & 0.8129847 & 0.0108109 \\ 0.0000000 & 0.0102048 & 0.9897952 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$



Color Collection

- CCM (Color Correction Matrix)
 - Transforms sensor native **RGB** values into **CIE XYZ** color space
 - It is important that the white balance has been performed correctly

```
def color_correction(img, ccm):
    ...
    Input:
        img: H*W*3 numpy array, input image
        ccm: 3*3 numpy array, color correction matrix
    Output:
        output: H*W*3 numpy array, output image after color correction
    ...

#####
# TODO:                                     #
#   Following above instruction to get color correction result   #
#                                                                 #
#####
```

CCM Matrix = `array([[2.04720944, -0.54963846, -0.08908884],`
 `[-0.59391878, 1.59546609, 0.27727791],`
 `[-0.45329066, -0.04582763, 0.81181092]])`

Tone Mapping

- Display cannot afford the brightness in real world
 - use more sensor bits to store
- High Dynamic Range (HDR) => Low Dynamic Range (LDR)
 - compress sensor bits into 8 bit (RGB24)
 - makes images suitable to be viewed on a digital screen
- Tone curve: Non linear mapping of RGB tones

Original Image



Image after inverse tone



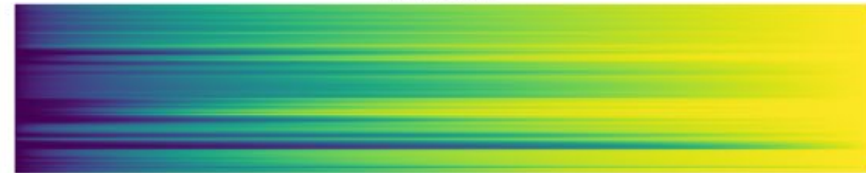
Tone Mapping

```
curve_name = os.path.join(curve_path, 'tone_curves.mat')
curve_inv_name = os.path.join(curve_path, 'tone_curves_inv.mat')
```

Irradiance



Brightness



```
import numpy as np
import math

def tone_mapping(img, I, B, index=0, inv=False):
    """
    Input:
        img: H*W*3 numpy array, input image.
        I: 201*1024 array, represents 201 tone curves for Irradiance.
        B: 201*1024 array, represents 201 tone curves for Brightness.
        index: int, choose which curve to use, default is 0
        inv: bool, judge whether tone mapping (False) or inverse tone mapping (True), default is False
    Output:
        output: H*W*3 numpy array, output image afte (inverse) tone mapping.
    """
    #####
    # TODO:
    # Following above instruction to get tone mapping as output.
    # and inverse tone mapping result as output
    #####
```

End Result

- Calculate the PSNR of the original image and the restored image generated after the Inverse ISP and ISP process.

Original Image



Image after inverse process



```
def calculate_psnr(img1, img2):
    """
    Input:
        img1, img2: H*W*3 numpy array
    Output:
        ... psnr: the peak signal-to-noise ratio value
    """
    #####
    # TODO:
    # Following above instruction to get PSNR as output.
    #
    #####

    #####
    #
    # End of your code
    #
    #####
    return psnr
```

```
calculate_psnr(img, img_tm)
```

```
81.43537077717903
```

Image Sensing Pipeline

- Homework Question:

- a. Discuss different treatments of different Bayer patterns when: i. applying white balance mask into original image. ii. doing mosaic algorithm.
- b. Show the image results of each step as p.6/7 in HW1.pdf.
- c. Show the image results of inverse ISP and ISP as p.16 in HW1.pdf. Additionally, compare the performance results of this task using PSNR.
- d. In recent AI de-noising methods, in order to generate paired data for training, we will add synthetic noise to clean image on RAW domain instead of RGB domain. Explain the reason.

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Image Formation

Q & A

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