GAN for CVD

Introduction

A light of a specific range of wavelengths in the visible spectrum is called colour. It is an intrinsic property and objects only reflect the light falling on them in order for us to see and perceive colour. Fundamentally, the frequency of light waves and the manner in which they combine before they reach the eye is what one perceives as colour.
The human retina consists of photoreceptors called cones, which may be of three types- blue, green and red cones, also referred to as S (for small wavelengths), M (for medium wavelengths) and L (for long wavelengths) cones respectively. Each of these cones are capable of distinguishing light of a fixed range of wavelengths. When the light falling on each of these cones combine to form a single signal, an object is seen as a certain colour. Owing mostly to genetic alterations, one or more of these cells fail to function; the result of which is colour vision deficiency (CVD). Based on the number of types of impaired cones, CVD may be broadly classified as anomalous trichromacy, dichromacy and monochromacy.
In an anomalous trichromat, the number of functioning photoreceptors are the same as someone with normal vision. However, the sensitivity of one or more cones to a wavelength shifts from its regular position and a colour is perceived differently. Depending on the type of cones that are anomalous, there may be three types of anomalous trichromacy- Protanomaly, Deuteranomaly and Tritanomaly, i.e, anomalous L, M and S cones respectively.
In a dichromat, one set of cones is dysfunctional, resulting in the inability of the person to perceive a whole range of colours. Again, depending on the type of affected cones, dichromacy may be of three types- Protanopia, Deuteranopia and Tritanopia, i.e, absent L, M and S cones respectively.
In monochromats, two sets of cone cells are absent, owing to which, the range of their colour perception is very small and they are capable of perceiving colours of one shade only.
The ambit of the project deals mainly with dichromacy. More specifically, we consider protanopia and deuteranopia, more commonly known as red blindness and green blindness respectively. Usually, people with either of these deficiencies find it difficult to distinguish between reds, greens, browns and oranges. Thus, they are studied as one classification of CVD called red-green colorblindness. People with this type of CVD usually have issues with reading maps and medical images.

Abstract

The three main types of colorblindness are as follows:

- Red blindness- The range of wavelengths are perceived such that shades of green may not be distinguished.
- Green blindness- The range of wavelengths are perceived such that shades of red may not be distinguished.
- Yellow-blue blindness- The range of wavelengths are perceived such that blue shades are perceived as green and yellow shades, as pink.

There are tons of digital solutions to allow the colour deficient to distinguish between the problematic colours. There are also multiple tools that simulate how a colourblind person views an image. Some of these solutions are-

- The confusion colours are clustered and recolored. For example: red may be recolored with another colour, say, navy blue.
- Greyscaling- This reduces the number of grey levels in order to make the images monochromatic. This enables the affected person to distinguish between multiple objects in an image. However, this method is not efficient since the naturalness of objects is lost
- Sonification- In this method, the user is told what colour they are looking at, by means of an audio.
- Other solutions are smart wearables and web plugins to simulate and recolor the confusion colours.

Problem Statement

People with colour vision deficiency face many problems in day-to-day life, which go unacknowledged by people with normal vision. In most cases of colour blindness, children from the age of 4 find it difficult to distinguish between reds, greens, browns and oranges. Many affected people aren't even aware of the deficiency until their adulthood. Colour vision deficiency limits the number of job opportunities as pilots, as scientists, in the Army or in any field which requires impeccable vision. Furthermore, simple tasks such as distinguishing lights of a traffic signal, assessing the ripeness of a fruit, noticing when a device has finished charging etc. become perplexing.

Objective

The primary objective of this project is the methodology for identifying the shades of colours. Study says that a normal human is able to clearly identify nearly 1 million shades of colours. But in the case of humans having “enchroma”, they would be able to see only 1% (i.e.10,000 colours) from the normal humans. While painting pictures, a painter needs to identify the colour patterns exactly or else the reality of the image is not clear.
Colour vision deficiency(CVD) is a form of colour blindness where the patients are unable to perceive certain colours. The data sets for CVD are very limited. This project involves creation of a data set for CVD and setting up a cycle GAN for recoloring images for the colorblind in an optimised manner. Optimization function would involve identification of the confusion colours, identification of the replacement colour and colour compensation in an efficient manner.

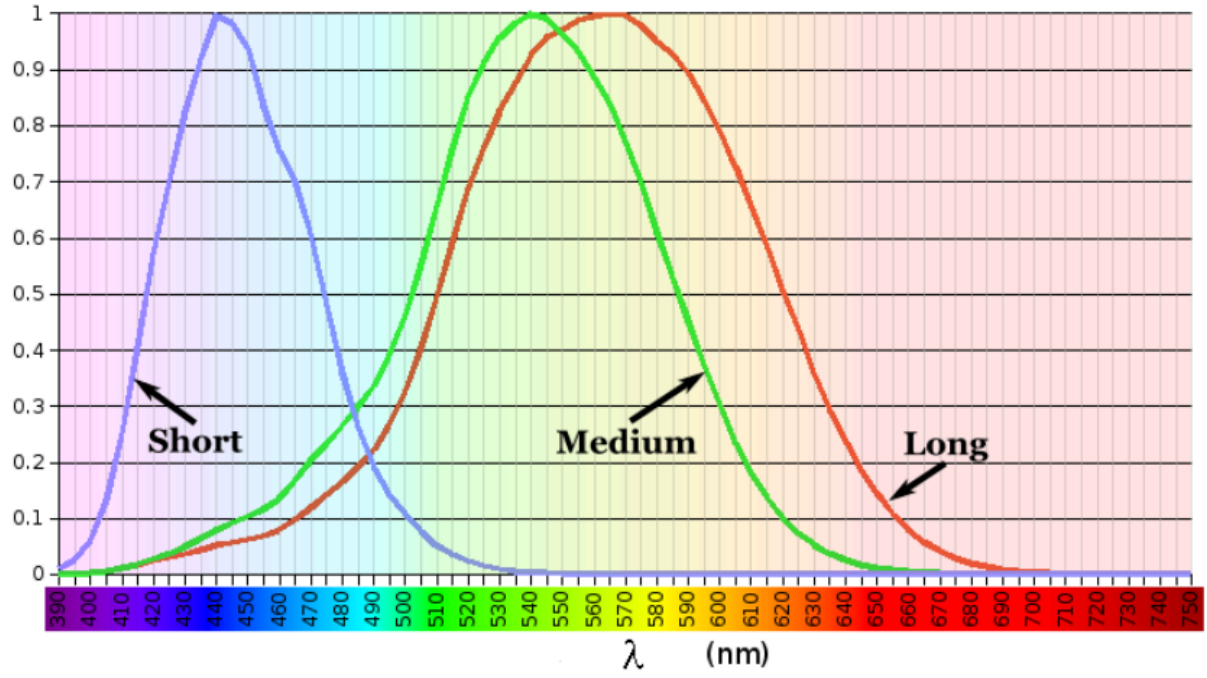
Motivation

Colour vision is a part of the human central nervous system which interprets information from the visible light to form the visual colour perception of the surrounding world. Individuals with normal colour vision or trichromats have three independent channels to convey information of colours. These three independent channels are namely cone cells sensitive in the red, green and blue spectral range in human eyes and they are generally represented by the long, medium, and short cone respectively.
About eight percent of the male population have some kind of colour vision deficiency. Dichromacy is one of the colour vision deficiencies, and it occurs when one of the cones is absent or not functioning. Thus, individuals with dichromacy or dichromats have a colour perception in two-dimensional colour space. Dichromacy can be classified into three categories; protanopia, deuteranopia, or tritanopia depending on whether the missing cone is the L-cone, Mcone, or S-cone respectively. Protanopia and deuteranopia are called red-green deficiency, and are common types of dichromacy. Individuals with red-deficiency are called protanopes while individuals with green-deficiency are called deuteranopes. Red-green deficients have difficulty in distinguishing between red and green. They view red and green as yellow, orange, and beige colours. Thus, they experience great difficulties with color discrimination that not only affect their social life but may also affect their careers.

Experiment

Creating the Simulated Images Dataset

A human trichromat's eyes contain 3 types of cone cells, each of which has a unique sensitivity to different wavelengths of light.



We process the images by transforming RGB to LSM space, where LSM stands for Long-Short-Medium (wavelengths).
First step is to remove the gamma correction. This converts RGB to linear RGB space, where the numbers representing colours transform into colour intensities such that it appears more uniform to humans.
Removing Gamma correction :

$$v' = \begin{cases} \left(\frac{\frac{v}{255}}{12.92}\right) & v <= 0.04045 \times 255 \\ \left(\frac{\frac{v}{255} + 0.055}{1.055}\right)^{2.4} & v > 0.04045 \times 255 \end{cases}$$

After removing gamma correction, each of the resulting Linear RGB values are floats in the range [0,1]. We can apply this formula to the red, green and blue values of an arbitrary processing colour ***C*** and put the result in a vector, like so:

$$\begin{bmatrix} r_c \\ g_c \\ b_c \end{bmatrix}$$

Convert the Linear RGB values to XYZ using a transformation matrix M_sRGB obtained from www.brucelindbloom.com. This sRGB matrix is calculated from the XYZ values of the 3 primaries used in this colour space.

$$M_{sRGB} = \begin{bmatrix} 0.4124564 & 0.3575761 & 0.1804375 \\ 0.2126729 & 0.7151522 & 0.0721750 \\ 0.0193339 & 0.1191920 & 0.9503041 \end{bmatrix}$$

$$M_{sRGB} \begin{bmatrix} r_c \\ g_c \\ b_c \end{bmatrix} = \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix}$$

This can then be converted from the XYZ colour space to the LMS colour space using the Hunt-Pointer-Estevez transformation matrix M_HPE:

$$M_{HPE} = \begin{bmatrix} 0.4002 & 0.7076 & -0.0808 \\ -0.2263 & 1.1653 & 0.0457 \\ 0 & 0 & 0.9182 \end{bmatrix}$$

$$M_{HPE} \begin{bmatrix} x_c \\ y_c \\ z_c \end{bmatrix} = \begin{bmatrix} l_c \\ m_c \\ s_c \end{bmatrix}$$

For simplicity we can multiply M_sRGB and M_LMS to calculate one transformation matrix T for converting colours from the Linear RGB colour space to the LMS colour space.

$$T = M_{HPE} M_{sRGB} = \begin{bmatrix} 0.31399022 & 0.63951294 & 0.04649755 \\ 0.15537241 & 0.75789446 & 0.08670142 \\ 0.01775239 & 0.10944209 & 0.87256922 \end{bmatrix}$$

$$T \begin{bmatrix} r_c \\ g_c \\ b_c \end{bmatrix} = \begin{bmatrix} l_c \\ m_c \\ s_c \end{bmatrix}$$

We shall simulate Protanopia in this experiment. Protanopes are missing L cones. We apply the following transformation. Consider a matrix S_p with variables q1, q2 for two of the matrix elements such that:

$$\begin{bmatrix} 0 & q_1 & q_2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} l_c \\ m_c \\ s_c \end{bmatrix} = \begin{bmatrix} q_1 m_c + q_2 s_c \\ m_c \\ s_c \end{bmatrix}$$

Where, q1 and q2 are given by:

$$q_1 = \frac{l_b s_w - l_w s_b}{m_b s_w - m_w s_b}$$

$$q_2 = \frac{l_b m_w - l_w m_b}{s_b m_w - s_w m_b}$$

Using the above method, Protanopia Simulation Matrix is obtained which is given by:

$$S_p = \begin{bmatrix} 0 & 1.05118294 & -0.05116099 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Hassan - Paramesran Colour Compensation Method

The above method has the following pipeline :
(R, G, B) → (X, Y, Z) → (X', Y', Z') → (R', G', B')
The leading idea of this method is to perform a non-uniform rotation of the colours in the chromaticity XZ plane, so changing the colour chromaticity but preserving the original luminance (i.e., the Y parameter remains unchanged).

The recoloring procedure underlying the Hassan-Paramesran method takes place in the CIE XYZ space and consists of three main steps: (i) colour normalisation, (ii) angular colour correction, and (iii) colour un-normalization.

In the first step, each colour c_i and its homologous dichromat colour d_i (as seen by a dichromat person) are both normalised by the value of luminance Y so that the normalised luminance takes on the value 1.
Assume that the normalised colours are denoted by

$$\dot{c}_i = (\dot{X}_i, \dot{Y}_i, \dot{Z}_i) \text{ and } \dot{d}_i = (\dot{x}_i, \dot{y}_i, \dot{z}_i)$$

In the second step, we computed the error parameters

$$\epsilon_x = |\dot{X}_i - \dot{x}_i| \text{ and } \epsilon_z = |\dot{Z}_i - \dot{z}_i|$$

The error in parameter y is zero.
We also calculate the angles corresponding to normalised colours c'_i and d'_i given by:

$$\alpha = \tan^{-1}(\dot{Z}_i/\dot{X}_i) \text{ and } \beta = \tan^{-1}(\dot{z}_i/\dot{x}_i)$$ respectively.

The correction angle is given by θ = |α − β | so that the corresponding rotation matrix applies then to the vector $[\epsilon_x \ \epsilon_z]^T$ to correction vector $[\varepsilon_x \ \varepsilon_z]^T$.

Colour correction in then performed in terms of the normalised colour-normal trichromat space coordinates as follows:

$$\dot{X}_i' = \dot{X}_i + \varepsilon_x,\ \dot{Y}_i' = \dot{Y}_i, \text{ and } \dot{Z}_i' = \dot{Z}_i + (\varepsilon_x + \varepsilon_z)$$

Adding both ε_x and ε_z into Z'_i increases the stimulation of blues of the recolored image, and, consequently, the colour perception of the red-green dichromats.

Third, one performs the inverse of the first step, i.e., the un-normalization of the colour

$$\dot{c}_i' = (\dot{X}_i', \dot{Y}_i', \dot{Z}_i') \text{ into } c_i' = (X_i', Y_i', Z_i')$$

which is then converted into (R ,G, B).

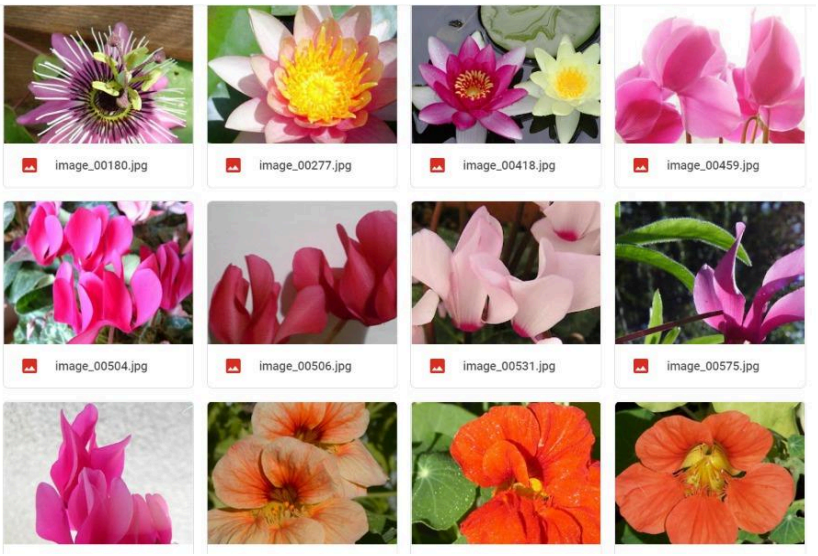
Now we have with us the original image dataset, simulated images dataset and colour compensated/recoloured images dataset. We use the original image dataset and the recoloured dataset to train a CycleGan.

Results and Discussion

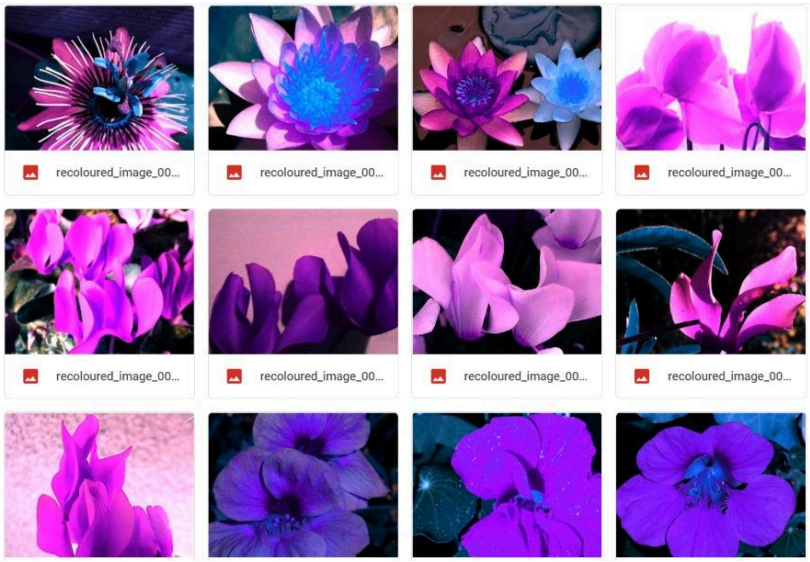
Part 1-

In the first phase of our project, we applied the Hassan-Paramesran Colour Compensation Method in order to generate 3 datasets- original images, simulated images and recolored images.

The results of the application of the colour compensation algorithm are as follows:



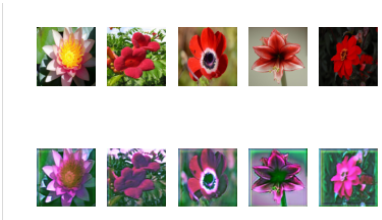
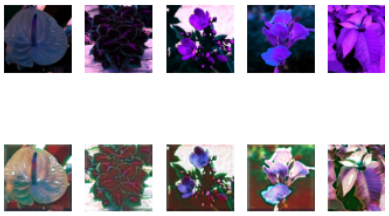
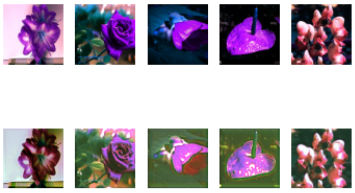
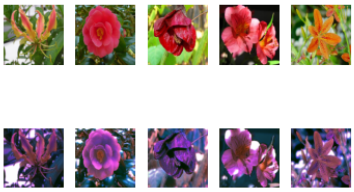
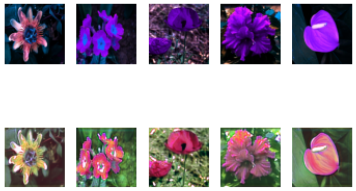
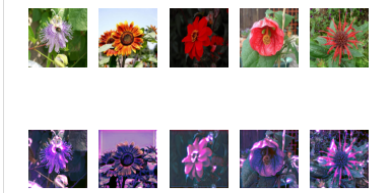
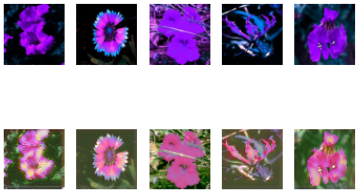
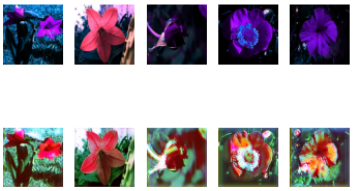
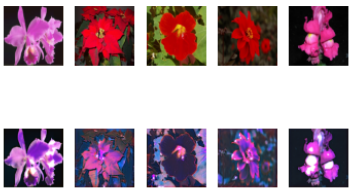
Original Images- Sample

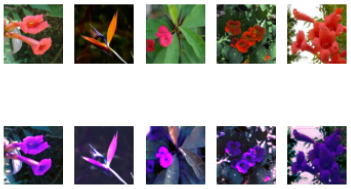
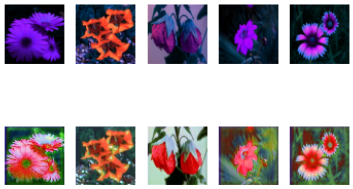


Recolored Images- Sample

Part 2-

In the second phase, we trained a Generative Adversarial Network and executed it through 7 epochs in order to recolor the images. The results of this phase are as follows:

Epoch No.	Original to Recolored	Recolored to Original
1		
2		
3		
4		
5		
6		

7		

- As seen from the results, the initial epochs show the images to be blurry and identification of objects is difficult.
- As the GAN is trained further, we see, around epoch 5, that the noise in the images begins to reduce and the generated images are smooth. The objects in the images may also be distinguishable from one another.
- By the 7th epoch, we observe very close similarities between the algorithm generated images and the images generated by the GAN.
- Considering the limited computational capabilities of the working environment and technical difficulties faced, it was decided to stop the execution at 7 epochs. However, sharper and ideal results may be observed at over 15 epochs.

Conclusion:

This project has achieved all its objectives since the GAN was successfully set up. A dataset for the CVD was created and using the Hassan-Paramesran method,recolored images were simulated that enables the protanopes to distinguish between red related colours that they are normally unable to perceive.The Hassan-Paramesran method preserves colour naturalness as much as possible, as well as colour consistency.

Limitations:

Although the GAN was able to successfully recolor the images for the protanopes,it cannot be used by them in real time.Naturalness of the object is also lost since the recoloring is done to provide contrast such that the protanopes can distinguish between red and the other colours and the true colour of the object is unknown to the colorblind.

Future Work:

A similar GAN can be set up to help the Deuteranopes and the Tritanopes to distinguish between green and blue respectively. The GAN can be implemented in websites as a browser plug-in to translate the images for a colorblind user such that they are able to distinguish between the colours and perceive the image better. In the current algorithm,

we parse all the pixels and their recoloring is done one by one. In future, we can explore parallel computing to reduce computation time, making it a better candidate for browser plug-in. This can make surfing through the web more interesting for the protanopes, who usually find it hard to tell between red related colours. We can also extend our modification to the GAN in a manner such that it can be implanted into an eyewear in the future which can be used on a regular basis by the colorblind helping them to see a more colourful world.

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Code:

.ipynb file for colour compensation
https://colab.research.google.com/drive/14zn59kVFZQi1_eHTaYaCo24qduP1zbmT#scrollTo=-Gj096LF8v9U

.ipynb file for GAN
https://colab.research.google.com/drive/1xHvIZRblZwuiiFOqzZUaUwEgMDG5SxAm?authuser=1#scrollTo=WE6xLqPZfSqW

Drive link for dataset

https://drive.google.com/drive/folders/1PqvHG3cktCVCujDPhwie2eQqhEwvRpqE?usp=sharing

References:

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7. https://machinelearningmastery.com/how-to-develop-a-pix2pix-gan-for-image-to-image-translation/