

# Colour This

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**Abstract—** This document presents the implementation, explanation and analysis in the use of an Encoder-Decoder Neural Network and its performance in colouring black and white images and the use of parallelization techniques to improve the waiting times during training.

## I. INTRODUCTION

Colorizing images that were taken hundreds of years ago allows us to see distant history in a new light. Colorization of old photographs has been done since the 1800's when images were coloured by hand or through a process called photochrom, which added anywhere from 6 to 15 layers of colour to a photo negative, the problem with these techniques was that the resulting images didn't look as realistic as one could expect.[1] Nowadays, colorization of photographs is done by hand using different software such as photoshop or illustrator, along with a vast number of online resources have led artists to reconstruct images with more accuracy. A picture can take up to one month to colorize and in order to do it requires an extensive research of the time period to find the exact colours that would recreate a moment in time. The process of colouring photographs can take a lot of time because for instance human skin can take up to 20 layers of pinks, yellows, greens, reds and blues.

## II. STATE OF THE ART

The Encoder-Decoder Network is a neural network design pattern, that is partitioned in two parts, the encoder and the decoder. This architecture is the standard neural machine translation method and is the core technology inside Google's translate service.[2] The encoder encodes the inputs into state, which often contains several tensors, this means that

the encoder takes the raw input and then outputs a feature tensor that holds the information of the given input. Then this state is passed into the decoder whose job is to generate the wanted outputs. In machine translation, the encoder transforms a source sentence, e.g. "Hello world" into state, e.g., a vector, that captures its semantic information then the decoder uses this state to generate a translated target sentence, e.g., "Bonjour le monde".[3]. A classic Encoder-Decoder mechanism is the one where an image is fed into an Encoder network which encodes the image forming a representation and passes it to the decoder which tries to reconstruct the original input image. This paper uses a slight modification of this for image reconstruction, the Encoder and Decoder is implemented using Convolutional layers to map images into a function in order to do feature extraction.

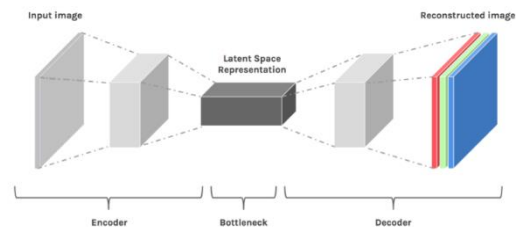


Figure 1. Graphic representation of the Encoder-Decoder

## III. DATA SET

The dataset comes from the Unsplash dataset created by Emil Wallner[4], that contains a database of about 9000 RGB images of 256x256 used for training and about 500 black and white images of 256x256 that are not in the training sample.



Figure 2. Example of the type of images that are present in the dataset.

#### IV. MODEL PROPOSAL

The Encoder-Decoder model proposed to colorize images uses VGG16 as an encoder to do feature extraction with its predetermined weights

Model: "sequential\_2"

Layer (type)	Output Shape	Param #
block1_conv1 (Conv2D)	(None, 224, 224, 64)	1792
block1_conv2 (Conv2D)	(None, 224, 224, 64)	36928
block1_pool (MaxPooling2D)	(None, 112, 112, 64)	0
block2_conv1 (Conv2D)	(None, 112, 112, 128)	73856
block2_conv2 (Conv2D)	(None, 112, 112, 128)	147584
block2_pool (MaxPooling2D)	(None, 56, 56, 128)	0
block3_conv1 (Conv2D)	(None, 56, 56, 256)	295168
block3_conv2 (Conv2D)	(None, 56, 56, 256)	590880
block3_conv3 (Conv2D)	(None, 56, 56, 256)	590880
block3_pool (MaxPooling2D)	(None, 28, 28, 256)	0
block4_conv1 (Conv2D)	(None, 28, 28, 512)	1180160
block4_conv2 (Conv2D)	(None, 28, 28, 512)	2359808
block4_conv3 (Conv2D)	(None, 28, 28, 512)	2359808
block4_pool (MaxPooling2D)	(None, 14, 14, 512)	0
block5_conv1 (Conv2D)	(None, 14, 14, 512)	2359808
block5_conv2 (Conv2D)	(None, 14, 14, 512)	2359808
block5_conv3 (Conv2D)	(None, 14, 14, 512)	2359808
block5_pool (MaxPooling2D)	(None, 7, 7, 512)	0
Total params: 14,714,688		
Trainable params: 14,714,688		
Non-trainable params: 0		

Figure 3. Summary of VGG16 (Encoder) without pooling layers.

The Decoder as the Encoder is composed by Conv2D and Up Sampling layers.

Layer (type)	Output Shape	Param #
input_14 (InputLayer)	(None, 7, 7, 512)	0
conv2d_7 (Conv2D)	(None, 7, 7, 256)	1179904
conv2d_8 (Conv2D)	(None, 7, 7, 128)	295040
up_sampling2d_6 (UpSampling2D)	(None, 14, 14, 128)	0
conv2d_9 (Conv2D)	(None, 14, 14, 64)	73792
up_sampling2d_7 (UpSampling2D)	(None, 28, 28, 64)	0
conv2d_10 (Conv2D)	(None, 28, 28, 32)	18464
up_sampling2d_8 (UpSampling2D)	(None, 56, 56, 32)	0
conv2d_11 (Conv2D)	(None, 56, 56, 16)	4624
up_sampling2d_9 (UpSampling2D)	(None, 112, 112, 16)	0
conv2d_12 (Conv2D)	(None, 112, 112, 2)	290
up_sampling2d_10 (UpSampling2D)	(None, 224, 224, 2)	0
Total params: 1,572,114		
Trainable params: 1,572,114		
Non-trainable params: 0		

Figure 4. Summary of Decoder.

In order to predict the colour of the images the input images need to be pre-processed before entering the model. The pre-processing consists first on applying some transformations to the images in order to do data augmentation.

After applying the transformations, the input images are changed into LAB images, which are an image format that separates the lighting from the RGB images.



Figure 6. Example of a LAB image (left) with its RGB counterpart (right)

After transforming the image the layers of the LAB photograph are separated into two arrays, an X array containing the L layer (luminosity) and a Y array containing the A and B layer (red/green and yellow/blue)

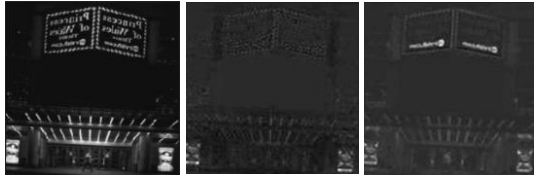


Figure 7. Example of L layer (left) and A layer (middle) and B layer (right)

Then the processed image is passed through the Encoder, which in this case is the VGG16 network and it outputs an image of size 7x7 with 512 filters. This image is then used as the input for the Decoder network. The model is compiled using the mean square error as a loss function and an Adam optimizer.

Another objective of this project was to test the viability of parallelizing the training progress of the network. In order to do this, there are approaches that can be implemented. The first one is to replicate the model into all the available GPUs obtaining a single machine multi-GPU parallelism. This approach divides the model inputs into multiple sub-batches and then a copy of the model is applied on each sub-patch, therefore every copy of the model is executed on a dedicated GPU and at the end the results are concatenated into a big batch in the CPU.

```
try:
    model = multi_gpu_model(model, cpu_relocation = True)
    print("Training using multiple GPUs")
except ValueError:
    print("Training using single GPU or CPU")
```

Figure 8. Code of the duplicate of the model per GPU

This method permits that if we have a batch size of  $n$  images and want to use for instance two GPU's to train the network, then the batch size will be divided into the number of GPU's and create  $x$  number of sub-batches where  $x$  is the number of GPU's. Then each GPU process each sub-batch on its corresponding GPU and at the end it will return a full batch of 64 processes samples.[5]

The other method is to make use of the `use_multiprocessing`, and `workers` that are implemented in the `fit_generator` function. The

`workers` parameter which takes as input an integer will spawn threads or processes when ingesting data batches. This if not done properly, meaning that the way of fetching the data is not thread safe could lead to some problems such as data duplication, this is only done when the `use_multiprocessing` is equal to false.

When the parameter `use_multiprocessing` is set to true, the parallelism changes a bit and now the training uses two or more central processing units also called CPUs and allocate the corresponding number of workers (processes) to each CPU.

```
history = model.fit_generator(train_datagen.flow(vggfeatures, Y, batch_size = BATCH_SIZE),
    epochs = NO_EPOCHS,
    steps_per_epoch = NO_IMAGES // BATCH_SIZE,
    workers=6, use_multiprocessing=False
)
```

Figure 9. Code of multiprocessing and multi-threading

## V. TEST AND VALIDATION

After running the training for 1000 epochs, using 7000 images to train to prevent the RAM depleted, with a batch size of 64, and 109 steps per epoch, had the following performance.

On the following graph it can be appreciated that during training at approximately at epoch 600 or 700 the model starts to overfit to the training data. The model during the resting epochs remain constant with an accuracy of around 80%.

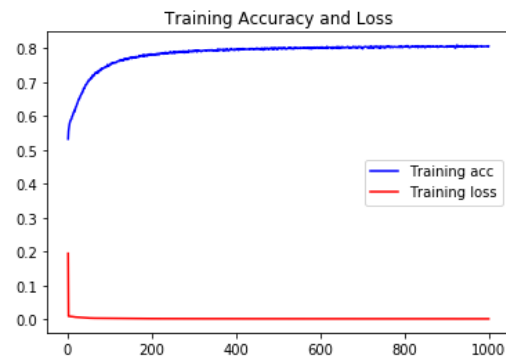


Figure 10. Graph of the training accuracy and loss over 1000 epochs

With the obtained weights after the training of the model, 500 black and white images were predicted. Some of the resulting images did

not end up with colour, but there were some photographs that ended up with a nice result. The images shown below are some samples of the generated images alongside the original black and white photograph. The complete list of generated images can be found in the corresponding link. [6]



Figure 10. Comparison between black and white images and their corresponding colorization.

The resulting images tended to be well colorized, but the colour is not very bright or well defined, sometimes it is possible to see patches of colour in areas where another is presented.

Regarding the parallelization of the training the project was tested with multi-threading and multi GPU parallelization.

No. of GPUs	No. of Threads	Seconds
1	1	11351.00
1	2	8481.83
1	4	5542.05
2	1	4860.35

Figure 11. Table of comparison between different settings of parallelization

It is possible to observe in the previous table that in this specific model the use of threads and the use of GPU parallelization improves the performance during training without affecting the accuracy of the model. It is stated that in this specific model parallelizing improves because not all models benefit from using multi-threading or multi GPU parallelization, this is because in the case of multi-threading parallelism has a runtime cost, in cases where the datasets are too small and quick to read from disk it is faster to access them sequentially than in parallel ingestion, such as it is the case of the MNIST dataset. [7].

In the case of multi GPU parallelism, different models have different scalability due to the overhead of weight synchronization. There is a balance between training one mini-batch and weights synchronization, however any model with large Dense layers usually contributes to a bad scalability like it is the case of the mnist\_mlp model. This model has a light computational cost on training one mini batch while its weights are too large to synchronize efficiently, therefore the time spent in doing one weight synchronization is the same time or even more of what the model spends in training many batches on a single GPU. [8]

Parallelization improves the performance of this specific model and dataset, because as



mention before the dataset images are bigger than 16x16 images making it slower to read each image, therefore gaining an improvement over sequential data feed. On the other hand, the model did not contain Dense layers which are a common problem in the scalability of networks, making this model to have an even better performance with multi GPU parallelization.

In the case of using two threads instead of one the model achieved a speedup of 1.33, when using 4 threads the speedup increased to 2.04 and when using multi GPU parallelization the speedup increased to 2.33. Therefore, the best performance was gained using multi GPU parallelization. The computational resources used for this project did not have the computational power to test when using multi GPU parallelization with multi-threading.

## VI. CONCLUSIONS

Image colorization can lead to see history in a new perspective, it helps to stop looking at it as a linear timeline but rather as a tapestry of all the moments that were lived by all the people.

Colorization of images to make them look as realistic as possible is complicated, one way in improving the performance of the network to get better colours could be changing the Encoder VGG16 to a newer and more accurate model such as the Inception-v4. Other way of improving the performance could be by changing the whole model from an Encoder-Decoder into a Generative Adversarial Network that uses Inception-v4 to generate more accurate images.

Parallelizing the training of the model can look really simple, such as just writing 4 lines of code, but it is more complicated than that, because you need to consider how the data is being fetched in order to prevent an out of memory from the RAM, and not only that depending on the model sometimes multi-threading can become really expensive

making it faster to run the model as a sequential model instead of using threads. Also, the computational resources needed to improve drastically the performance of the network can be very expensive and difficult to get access to, as in the case of using multi-GPU parallelism.

One possible way to improve performance in training could be using multi GPU parallelization along multi-threading, although very costly in terms of computation power and resources, it could improve greatly the time spent in training.

## VII. REFERENCES

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The implemented code used as a base the following codes:

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