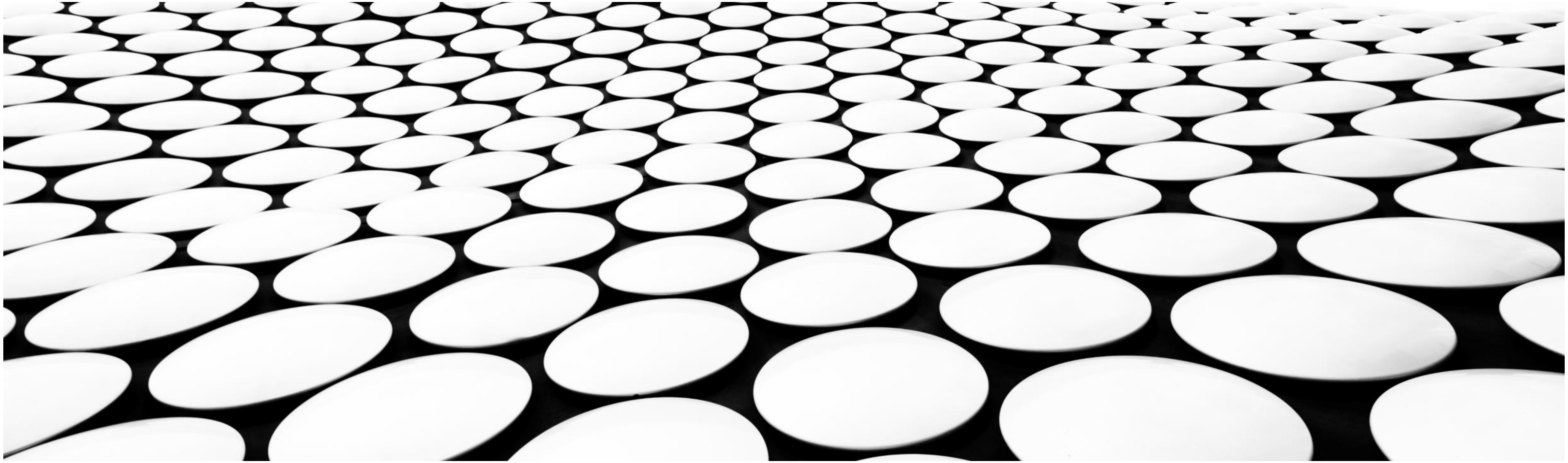
WASTE IMAGE CLASSIFICATION USING CONVOLUTIONAL NEURAL NETWORKS

NAVDEEP RAJ | DATA SCIENCE FINAL CAPSTONE | MENTOR: MAX SOP



ABSTRACT/BUSINESS PROBLEM

- In today's fast-growing economy, rapid advancement and industrialization have led to an enormous generation of waste which has become a matter of great concern resulting in environmental pollution and hazardous health problems.
- It is important to have an advanced waste filtration management system which can separate waste into different categories for better recycling and environmental cleaning.

- Objective of this project is to establish a smart waste classification system which can separate waste from images using CNNs.
- This project uses TrashNet dataset for generating CNN models with six classes to classify the waste into.
- Various transfer learning architectures like VGG, DenseNet, MobileNet, Inception, etc. have been used to train the data and achieve accuracy.

PROJECT GOALS

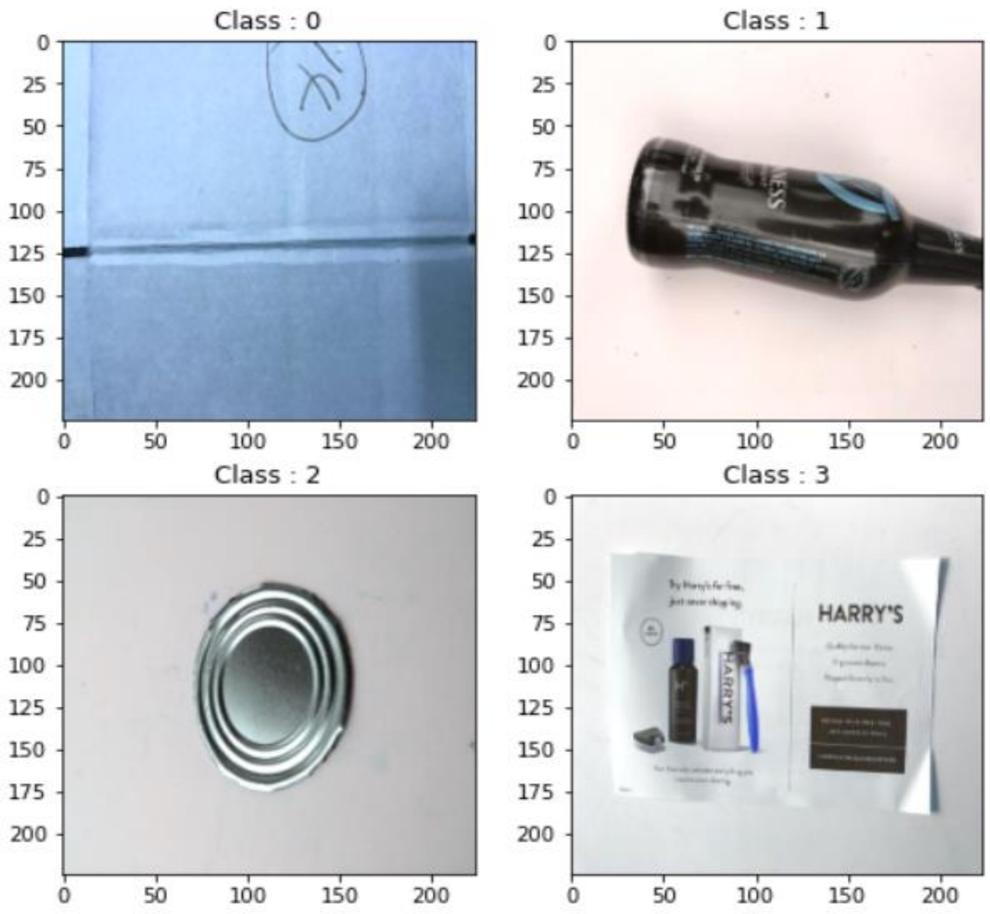
- Data pre-processing of trash images and create augmented data to obtain high classification accuracy.
- To train data on various architectures like VGG-16, ResNet-50, DenseNet, Inception, Custom layering, MobileNet, etc.
- Evaluate models majorly on accuracy metrics and class prediction probability.

DATASET

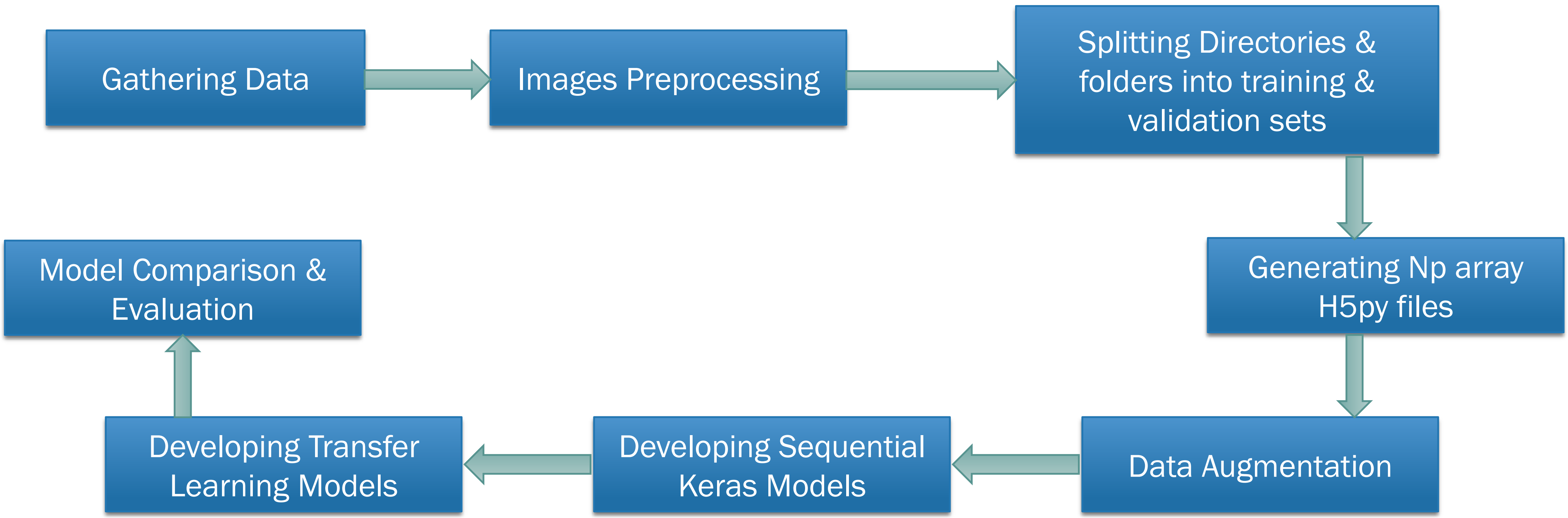
- Dataset was created by Thung and Young.
- This dataset spans six categories and consists of 2527 images in total
- We used approximately 75% from each category as training data, and 25% as development data. Therefore, our training set had 1894 images in total, and our development set had 633 images in total.

- Cardboard – Training – 302, Test – 101, Total – 403
- Glass - Training – 376, Test – 125, Total – 501
- Metal - Training – 307, Test – 103, Total – 410
- Paper - Training – 445, Test – 149, Total – 594
- Plastic - Training – 361, Test – 121, Total – 482
- Trash - Training – 103, Test – 34, Total – 137
- Total - Training – 1894, Test – 633, Total – 2527

SOME IMAGE SAMPLES

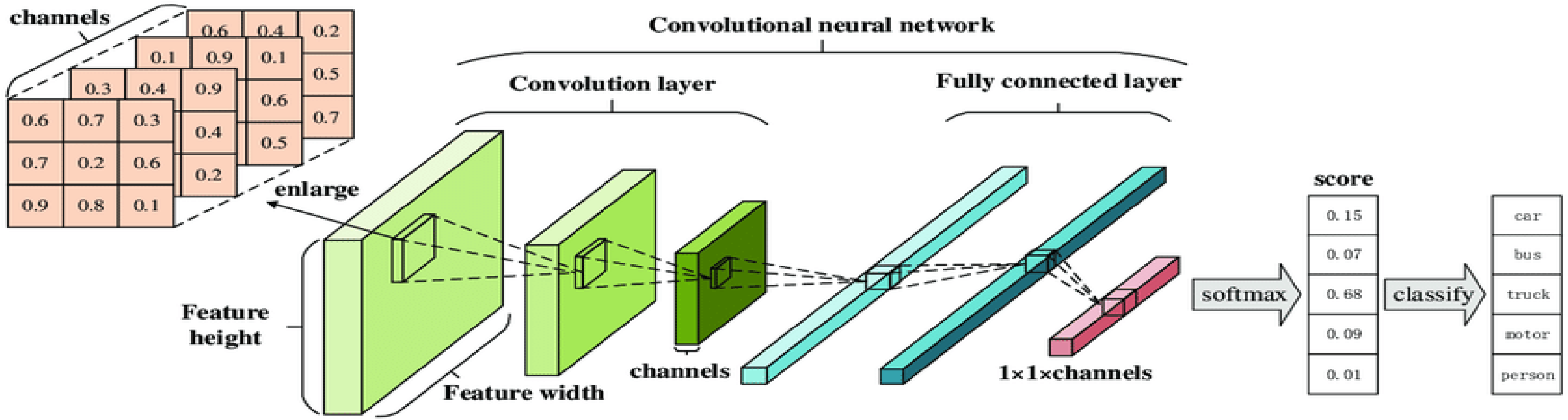


METHODOLOGY/STEPS



CNN – AN INTRODUCTION

- A Convolutional neural network (CNN) is a neural network that has one or more convolutional layers and are used mainly for image processing, classification, segmentation and also for other auto correlated data
- The traditional CNN structure is mainly composed of convolution layers, pooling layers, fully connected layers, and some activation functions.
- Each convolution kernel is connected to the part of feature maps. The input is connected to all of the output elements in the fully connected layer.



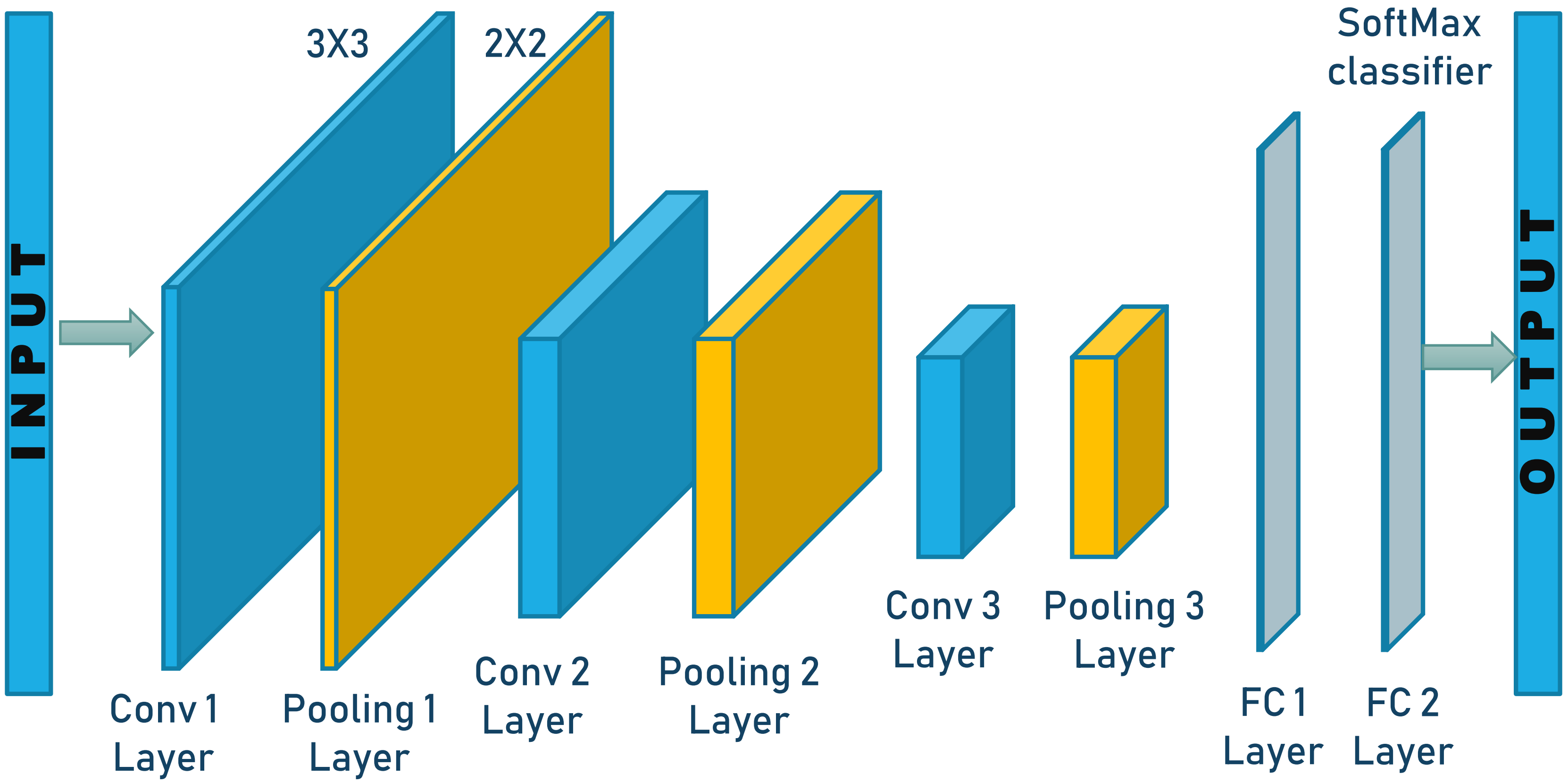
Source: https://www.researchgate.net/figure/Architecture-of-a-Convolutional-Neural-Network-CNN-The-traditional-CNN-structure-is_fig1_330106889

MODELLING

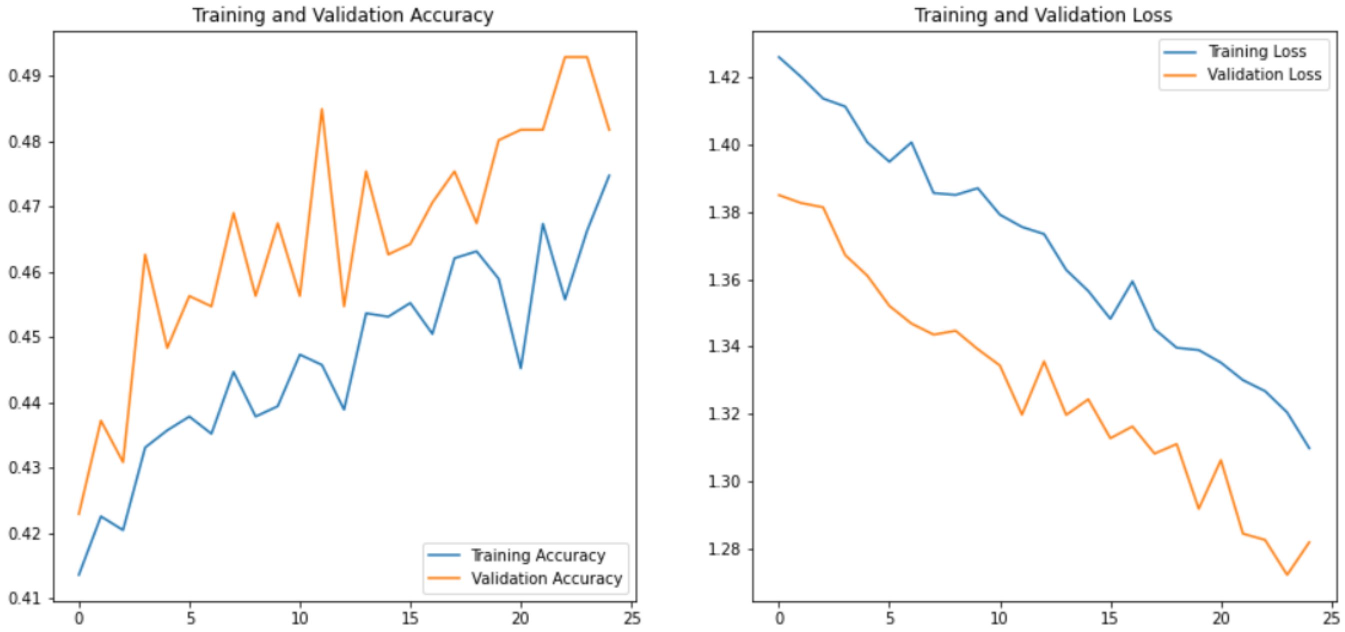
- Note: All transfer Models used pretrained weights i.e layers were frozen with weights from Imagenet data
- For all models
  - a) Output Activation – Softmax
  - b) Layer Activation – Relu
  - c) Learning rate = .00005
  - d) Optimizer – Adam
  - e) Loss – CategoricalCrossentropy
  - f) Epochs – 20-25

MODEL 1/CUSTOME SEQUENTIAL MODEL

- 3 Convolutional Layers & 2 Fully Connected Layers

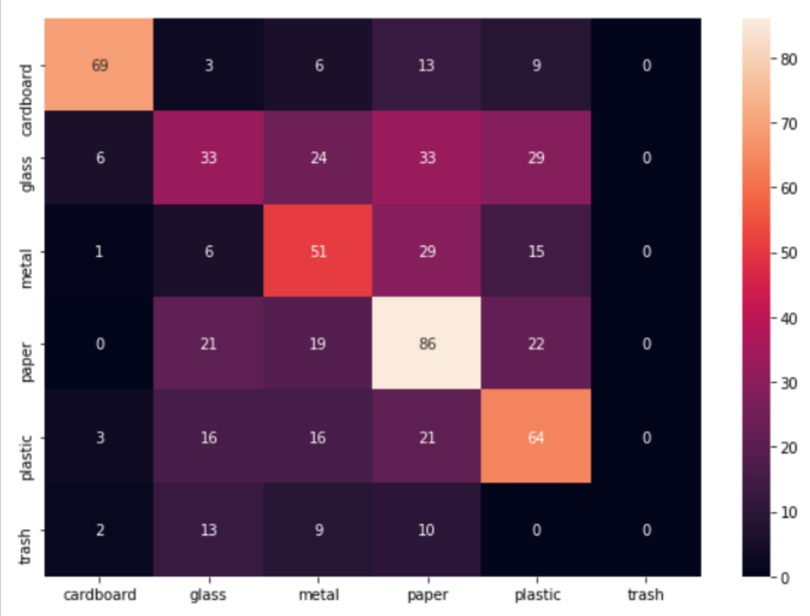


MODEL 1 PERFORMANCE



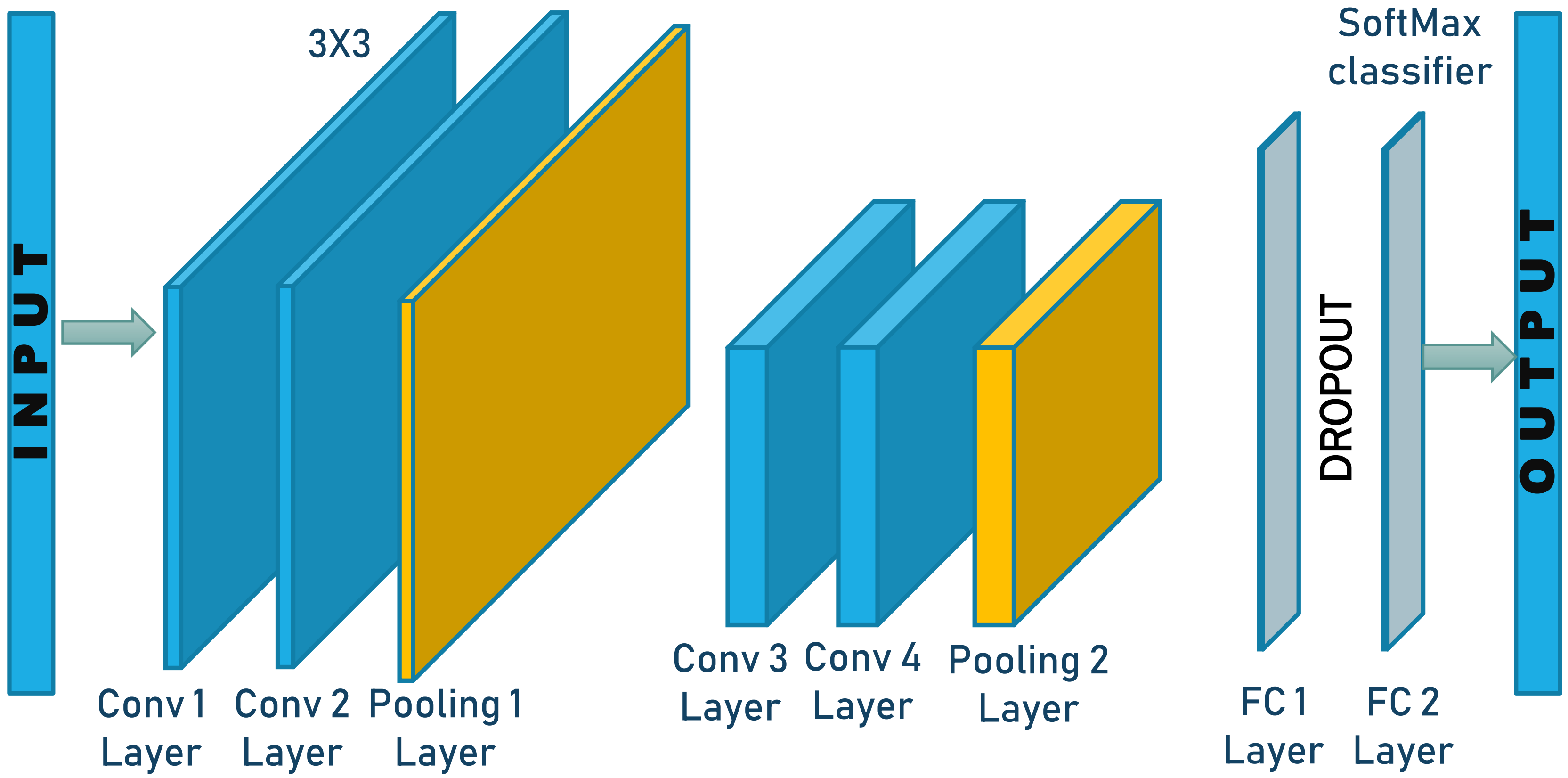
Classification Report

	precision	recall	f1-score	support
cardboard	0.85	0.69	0.76	100
glass	0.36	0.26	0.30	125
metal	0.41	0.50	0.45	102
paper	0.45	0.58	0.51	148
plastic	0.46	0.53	0.49	120
trash	0.00	0.00	0.00	34
accuracy			0.48	629
macro avg	0.42	0.43	0.42	629
weighted avg	0.47	0.48	0.47	629

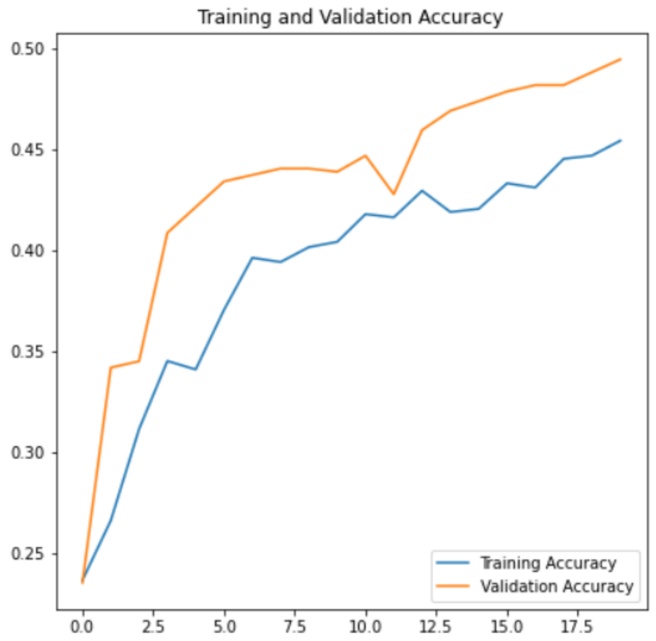


Model's performance – Average with accuracy of 0.48 , predicted Well for carboard, metal & plastic class

MODEL 2 – SEQUENTIAL 4 CONV & 2 FC LAYERS WITH DROPOUT



MODEL 2 PERFORMANCE

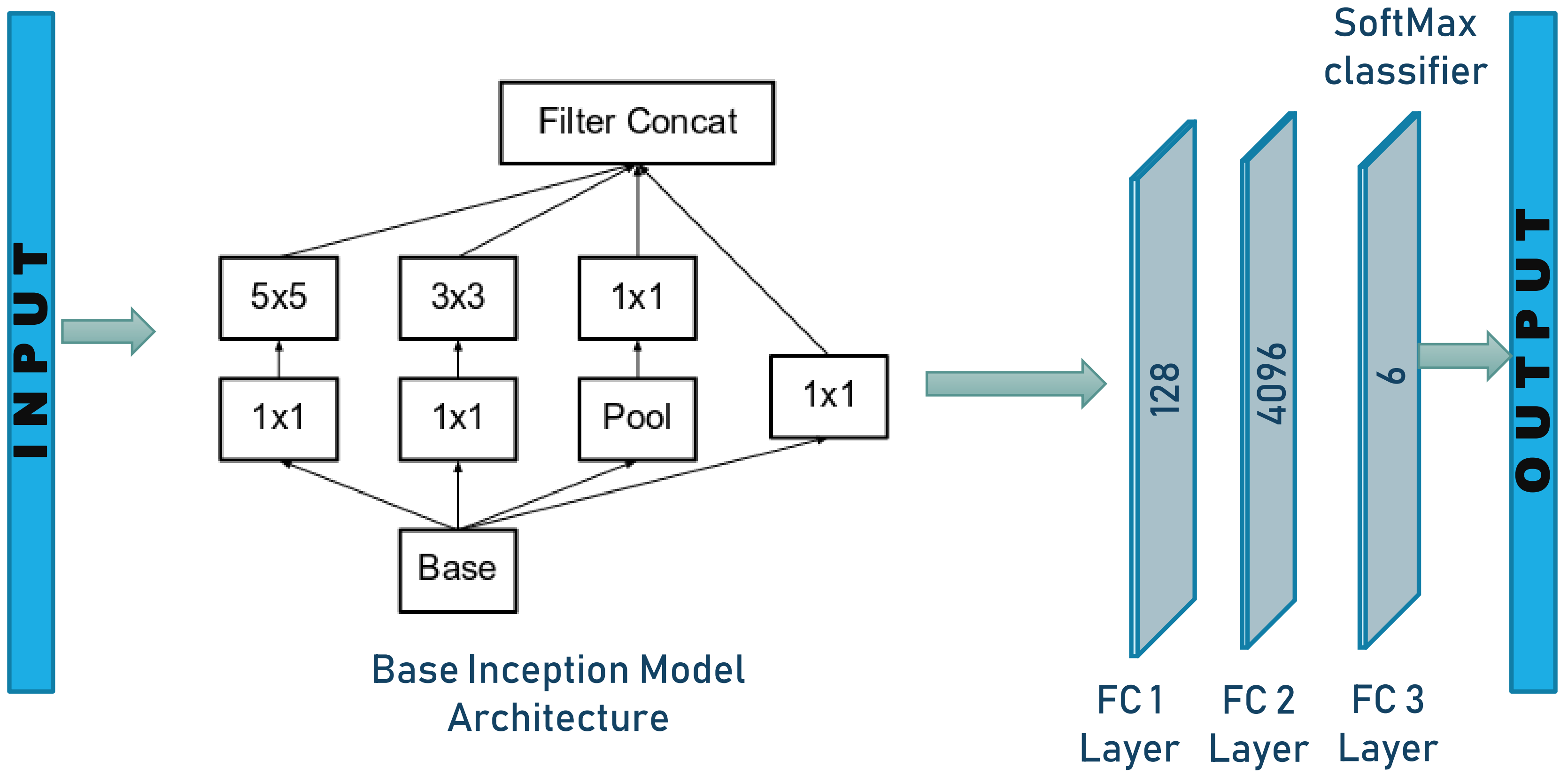


Classification Report

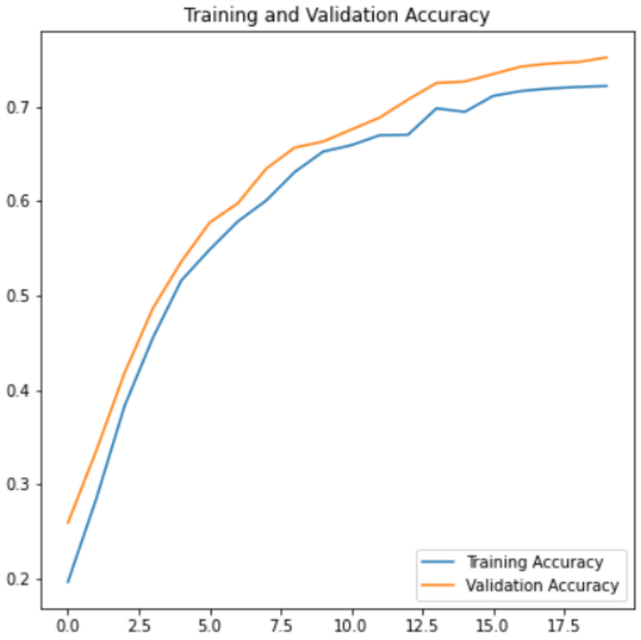
	precision	recall	f1-score	support
cardboard	0.80	0.78	0.79	100
glass	0.45	0.34	0.39	125
metal	0.63	0.25	0.36	102
paper	0.43	0.58	0.50	148
plastic	0.40	0.65	0.49	120
trash	0.00	0.00	0.00	34
accuracy			0.49	629
macro avg	0.45	0.43	0.42	629
weighted avg	0.50	0.49	0.47	629

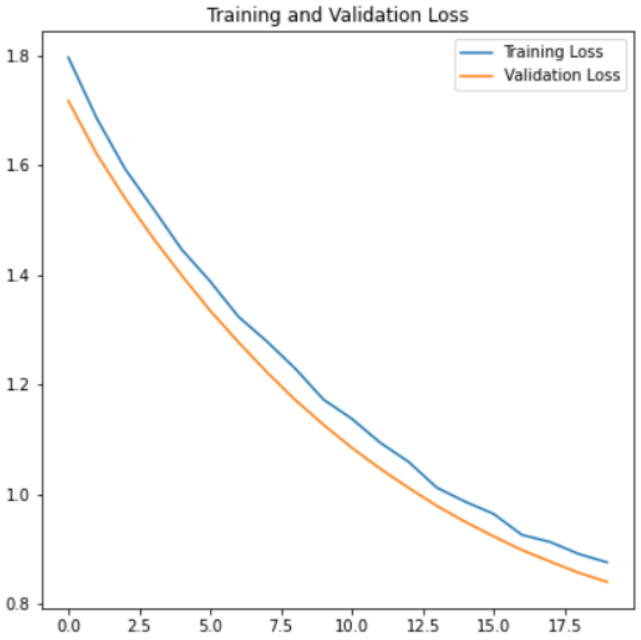
Model's performance – Average with accuracy of 0.49 , predicted
Well for carboard and paper

MODEL 3 – INCEPTION V3 TRANSFER LEARNING MODEL



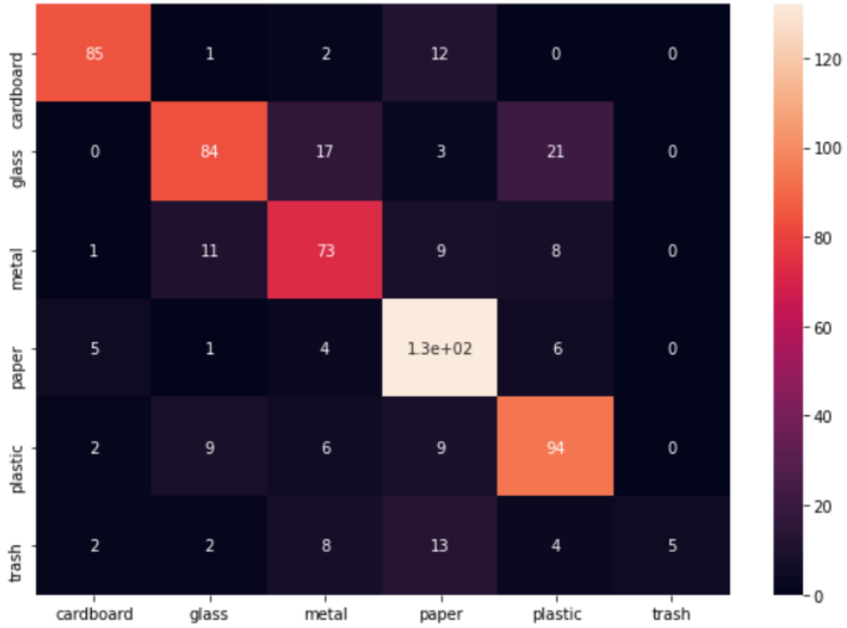
MODEL 3 PERFORMANCE





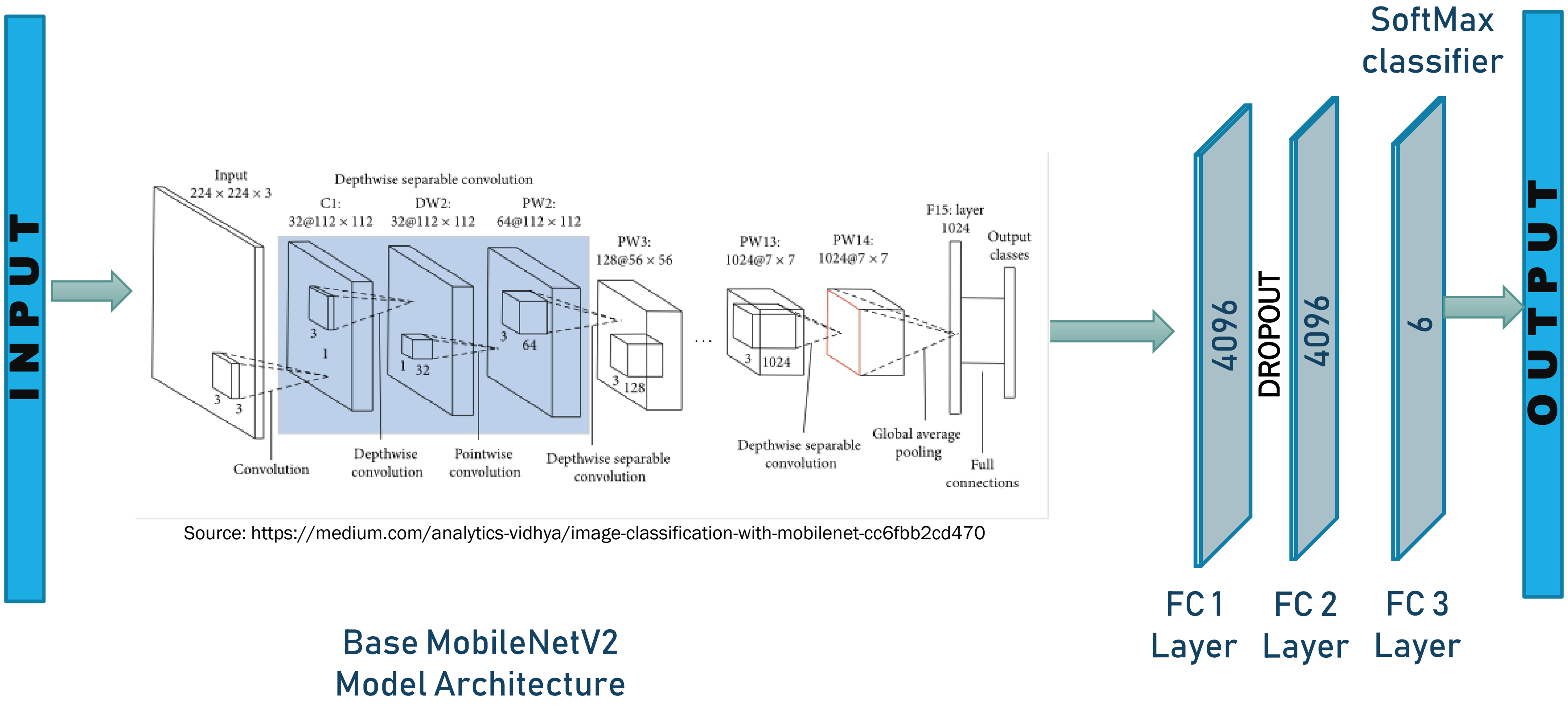
Classification Report

	precision	recall	f1-score	support
cardboard	0.89	0.85	0.87	100
glass	0.78	0.67	0.72	125
metal	0.66	0.72	0.69	102
paper	0.74	0.89	0.81	148
plastic	0.71	0.78	0.74	120
trash	1.00	0.15	0.26	34
accuracy			0.75	629
macro avg	0.80	0.68	0.68	629
weighted avg	0.77	0.75	0.74	629



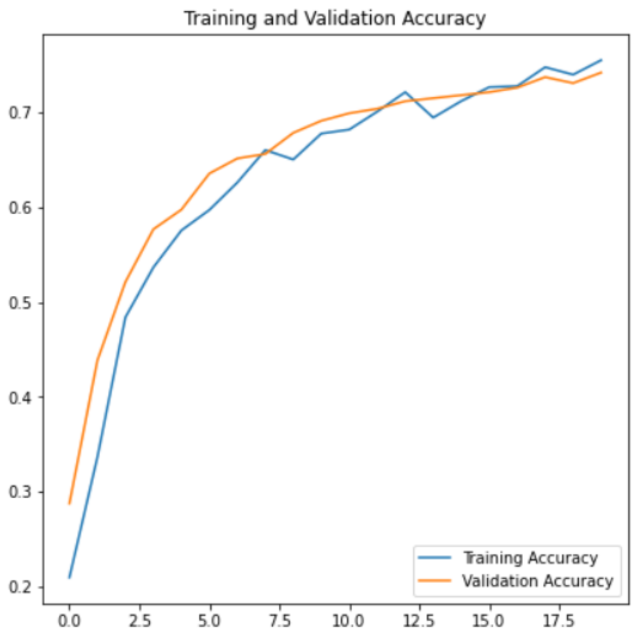
Model's performance – Good with accuracy of 0.75 , predicted Well on most of the classes, even on trash which has very less test samples.

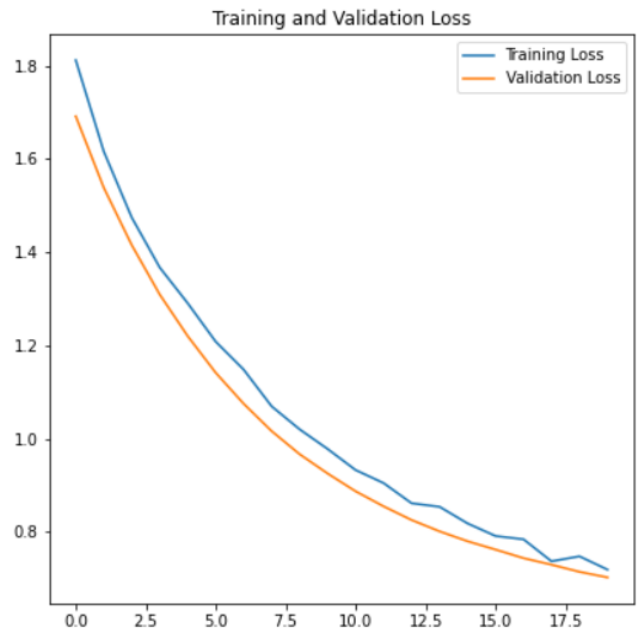
MODEL 4 – MOBILENET TRANSFER LEARNING MODEL



Source: https://medium.com/analytics-vidhya/image-classification-with-mobilenet-cc6fbb2cd470

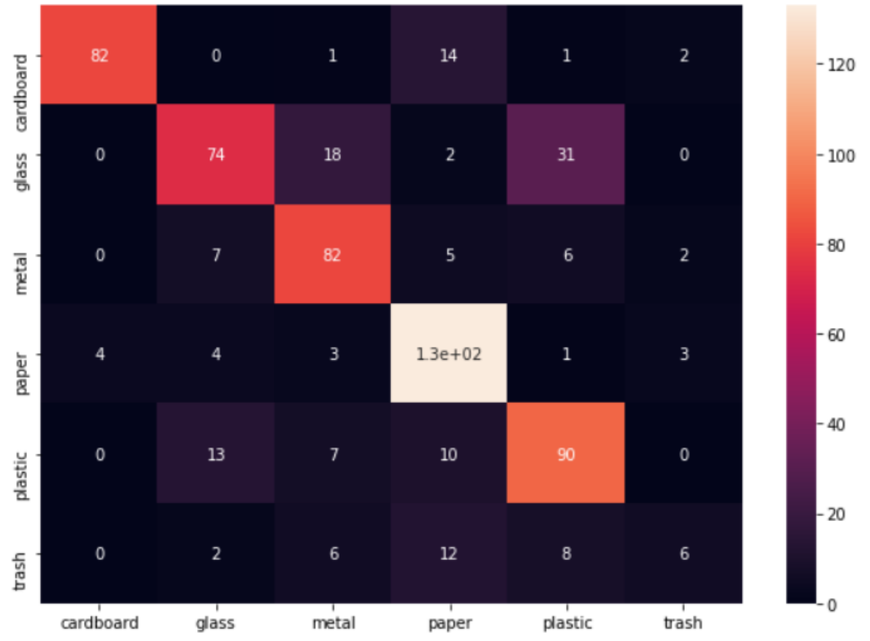
MODEL 4 PERFORMANCE





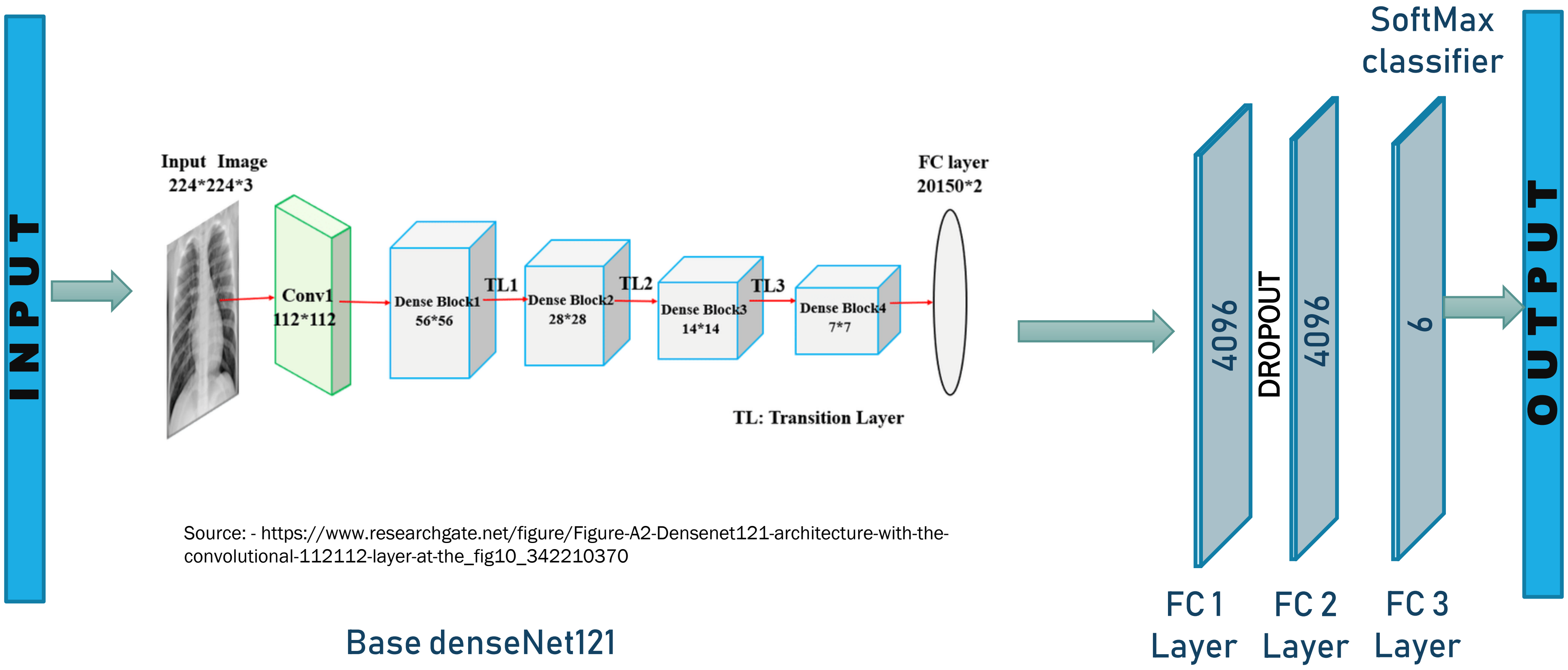
Classification Report

	precision	recall	f1-score	support
cardboard	0.95	0.82	0.88	100
glass	0.74	0.59	0.66	125
metal	0.70	0.80	0.75	102
paper	0.76	0.90	0.82	148
plastic	0.66	0.75	0.70	120
trash	0.46	0.18	0.26	34
accuracy			0.74	629
macro avg	0.71	0.67	0.68	629
weighted avg	0.74	0.74	0.73	629



Model's performance – Good with accuracy of 0.74 , predicted
Well on all classes, pretty good prediction, even recall is high which
means more positive predictions are correct

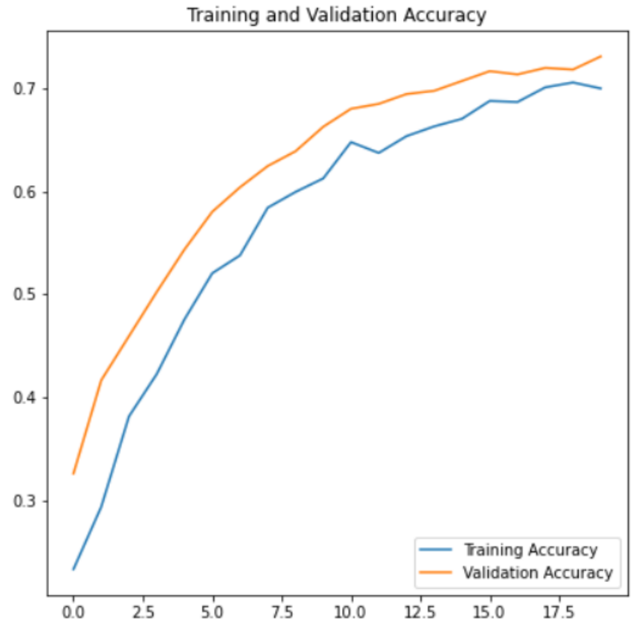
MODEL 5 – DENSENET121 TRANSFER LEARNING MODEL

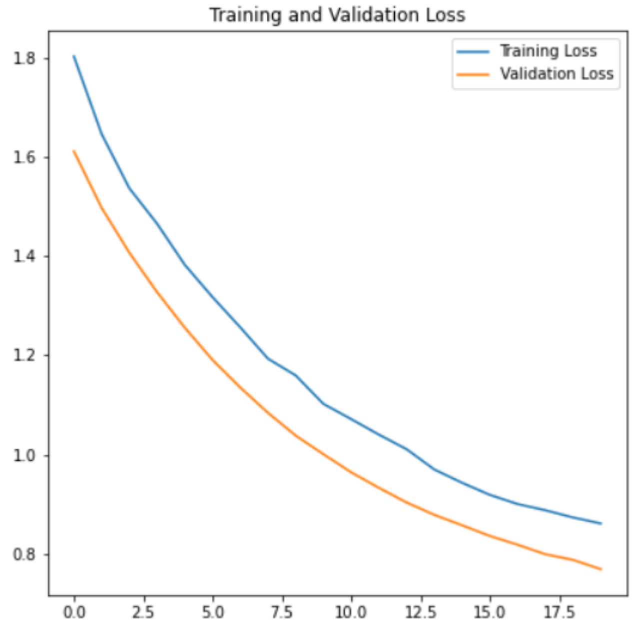


Source: - https://www.researchgate.net/figure/Figure-A2-Densenet121-architecture-with-the-convolutional-112112-layer-at-the_fig10_342210370

Base denseNet121
Model Architecture

MODEL 5 PERFORMANCE



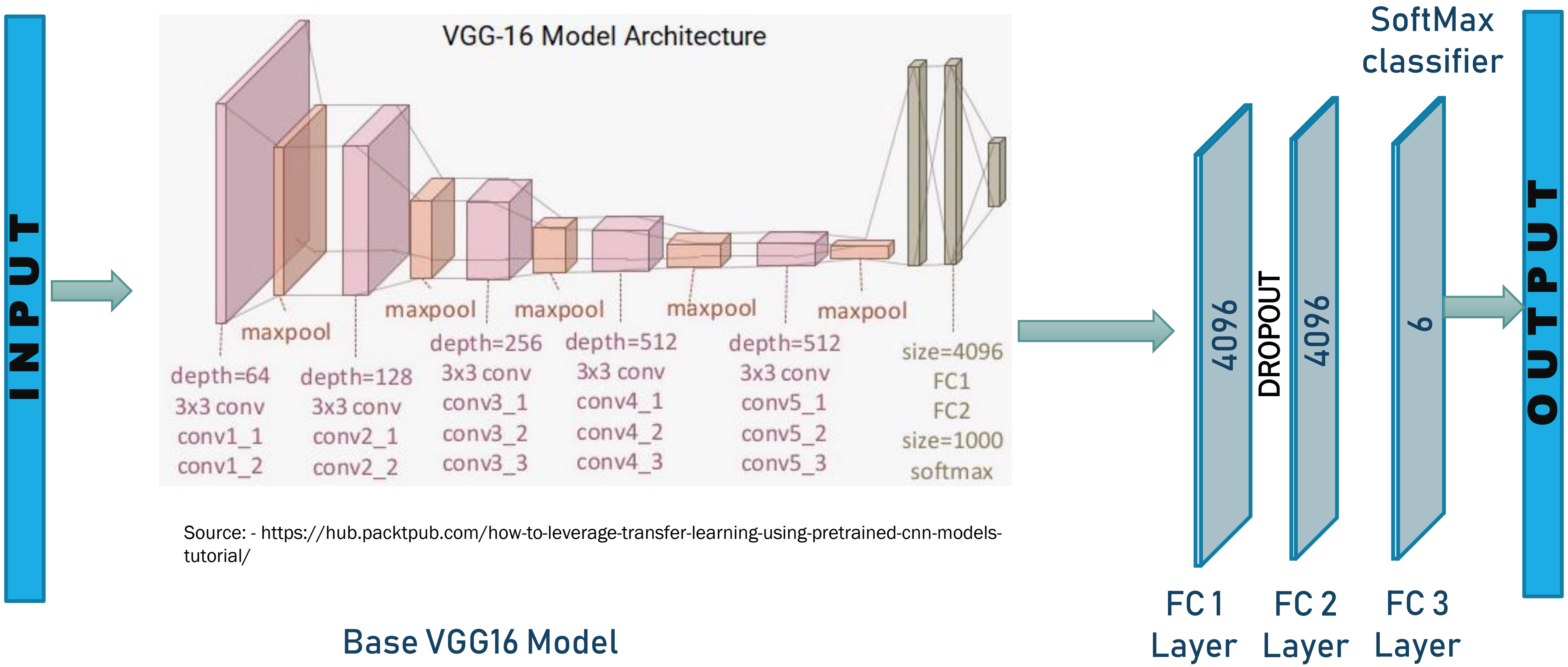


Classification Report

	precision	recall	f1-score	support
cardboard	0.88	0.81	0.84	100
glass	0.68	0.77	0.72	125
metal	0.78	0.73	0.75	102
paper	0.70	0.89	0.78	148
plastic	0.71	0.61	0.65	120
trash	0.56	0.15	0.23	34
accuracy			0.73	629
macro avg	0.72	0.66	0.66	629
weighted avg	0.73	0.73	0.72	629

Model's performance – Good with accuracy of 0.73 , predicted
Well on all classes, pretty good prediction,

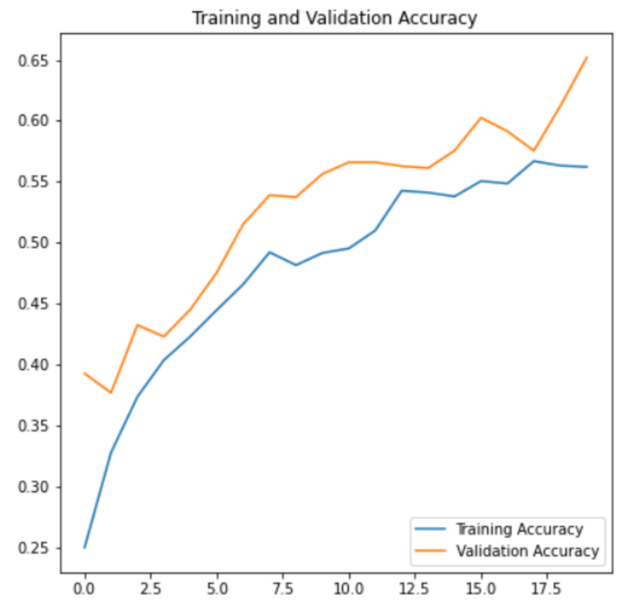
MODEL 6 – VVG16 TRANSFER LEARNING MODEL

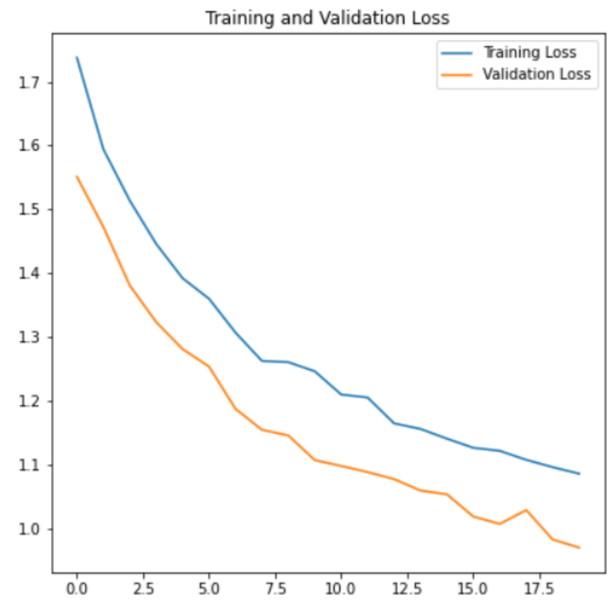


Source: - https://hub.packtpub.com/how-to-leverage-transfer-learning-using-pretrained-cnn-models-tutorial/

Base VGG16 Model Architecture

MODEL 6 PERFORMANCE

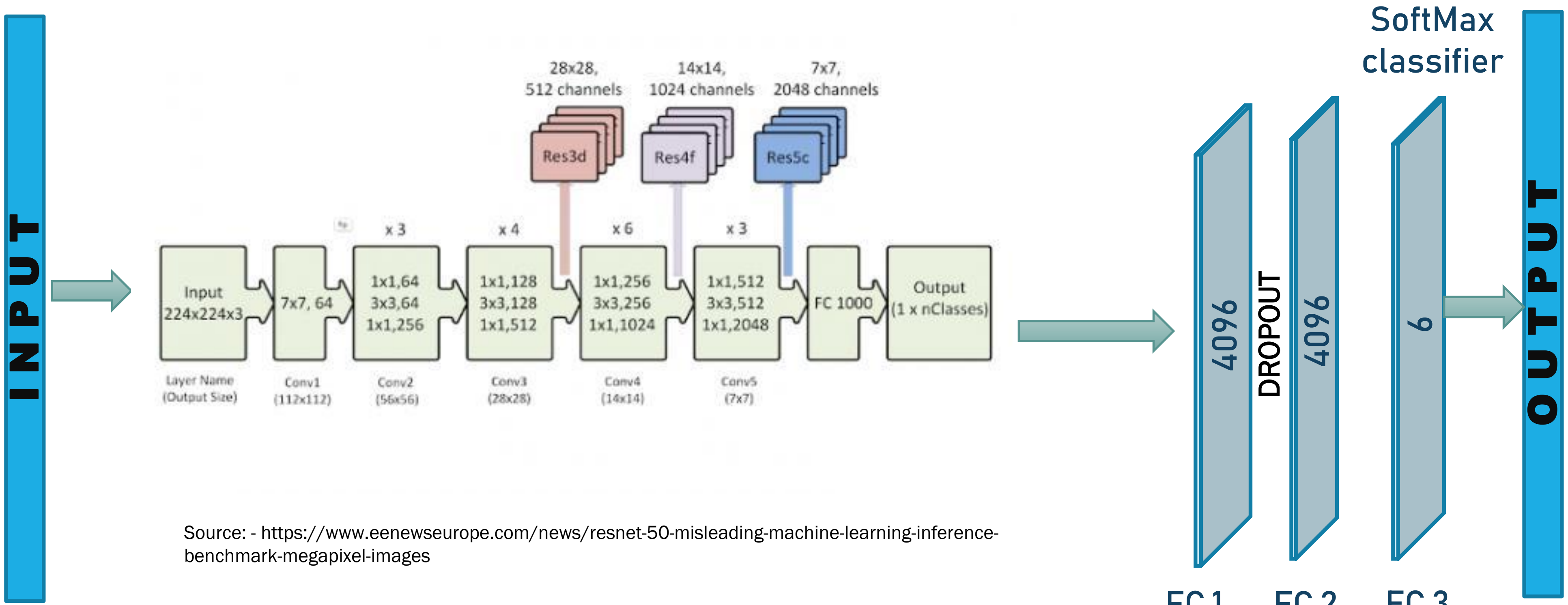




Model's performance – OK with accuracy of 0.65 , predicted Well on paper, plastic & Cardboard,

```
Classification Report
              precision    recall  f1-score   support

   cardboard       0.72      0.69      0.70       100
       glass       0.71      0.54      0.62       125
       metal       0.64      0.69      0.66       102
       paper       0.71      0.78      0.74       148
     plastic       0.55      0.65      0.59       120
       trash       0.45      0.26      0.33        34

    accuracy                           0.65       629
   macro avg       0.63      0.60      0.61       629
weighted avg       0.65      0.65      0.65       629
```

MODEL 7 – RESNET50 TRANSFER LEARNING MODEL



Source: - https://www.eenewseurope.com/news/resnet-50-misleading-machine-learning-inference-benchmark-megapixel-images

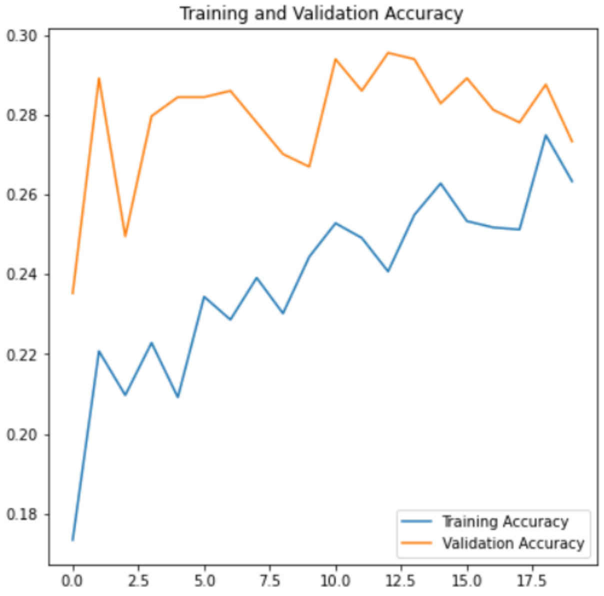
FC 1 Layer

FC 2 Layer

FC 3 Layer

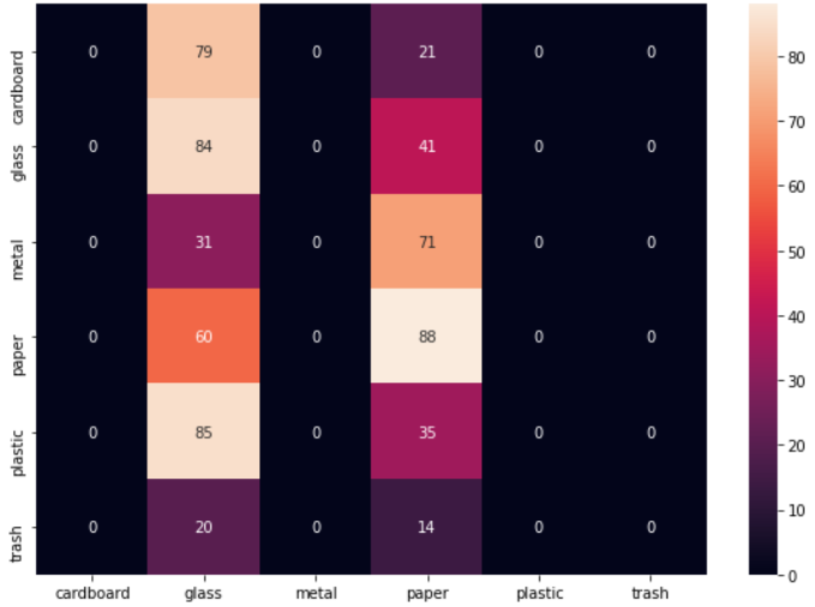
Base RESNET50 Model Architecture

MODEL 7 PERFORMANCE

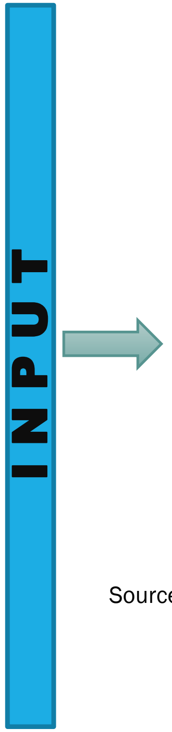


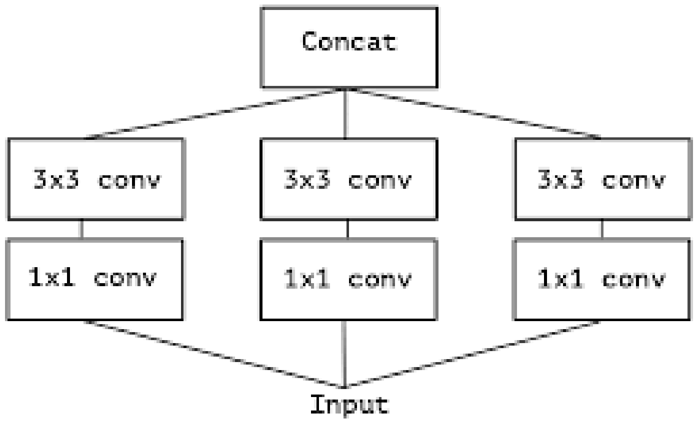
Model’s performance – poor with accuracy of 0.27 , predicted Only glass and paper classes nothing in other classes,

```
Classification Report
              precision    recall  f1-score   support

   cardboard       0.00      0.00      0.00       100
       glass       0.23      0.67      0.35       125
       metal       0.00      0.00      0.00       102
       paper       0.33      0.59      0.42       148
     plastic       0.00      0.00      0.00       120
       trash       0.00      0.00      0.00        34

    accuracy                           0.27       629
   macro avg       0.09      0.21      0.13       629
weighted avg       0.12      0.27      0.17       629
```

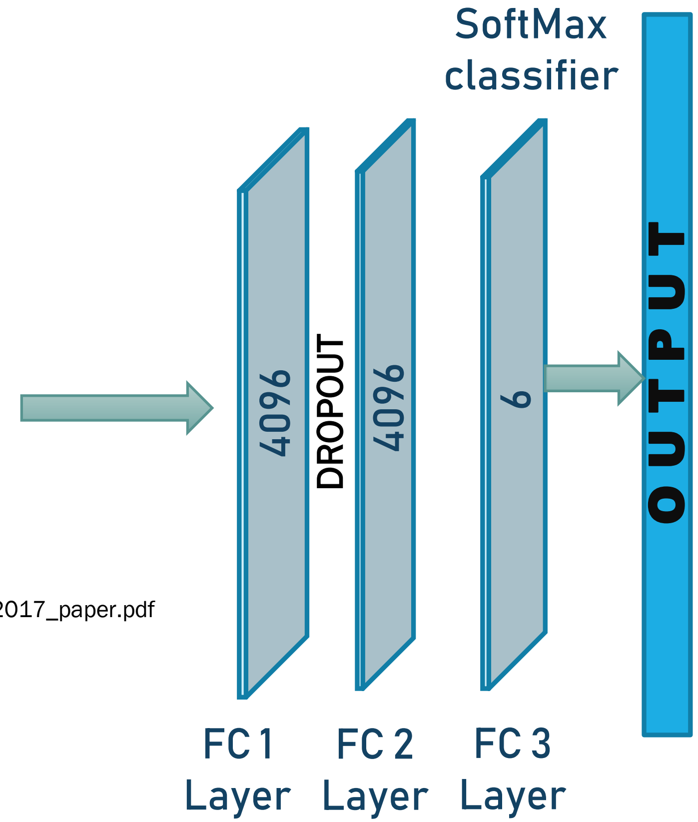


MODEL 8 – XCEPTION TRANSFER LEARNING MODEL



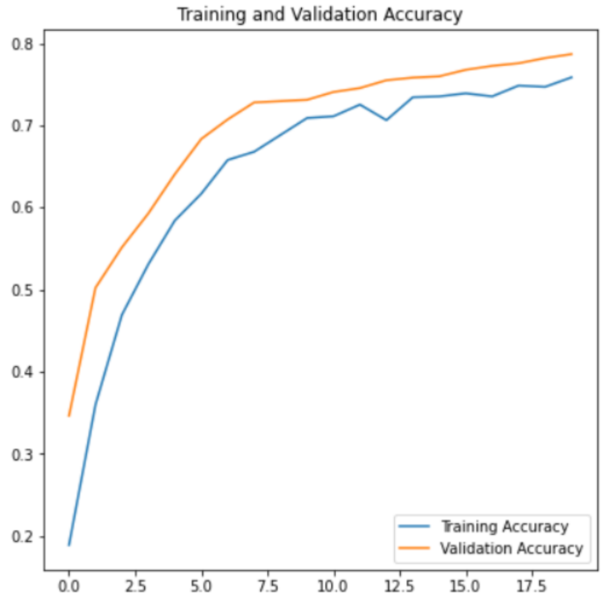


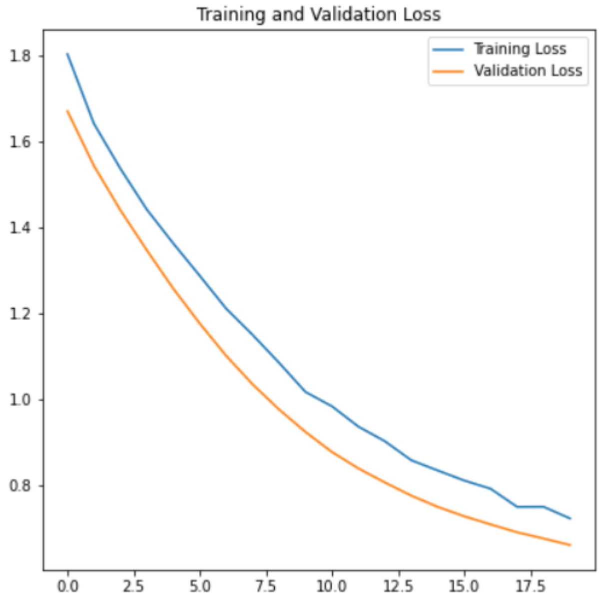
Source: https://openaccess.thecvf.com/content_cvpr_2017/papers/Chollet_Xception_Deep_Learning_CVPR_2017_paper.pdf



Base Xception Model Architecture

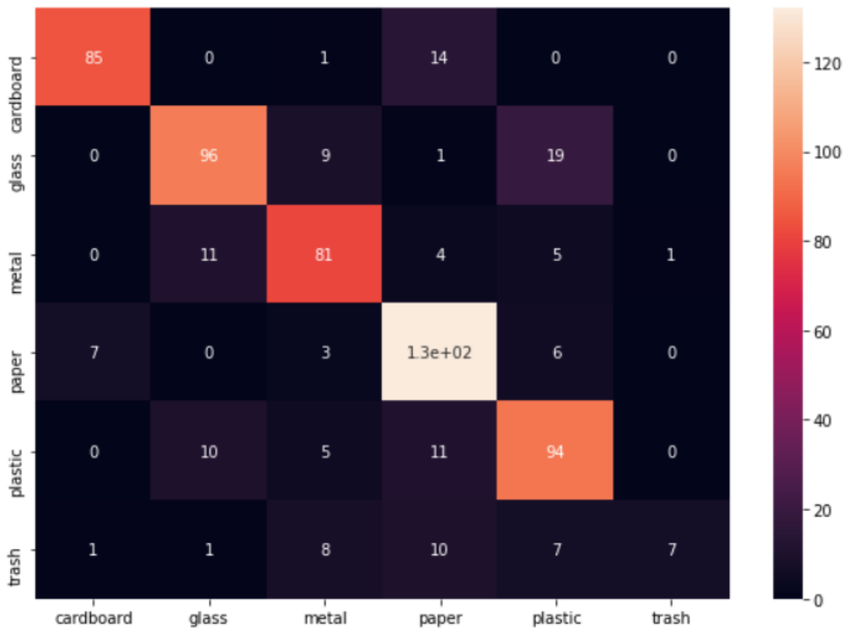
MODEL 8 PERFORMANCE





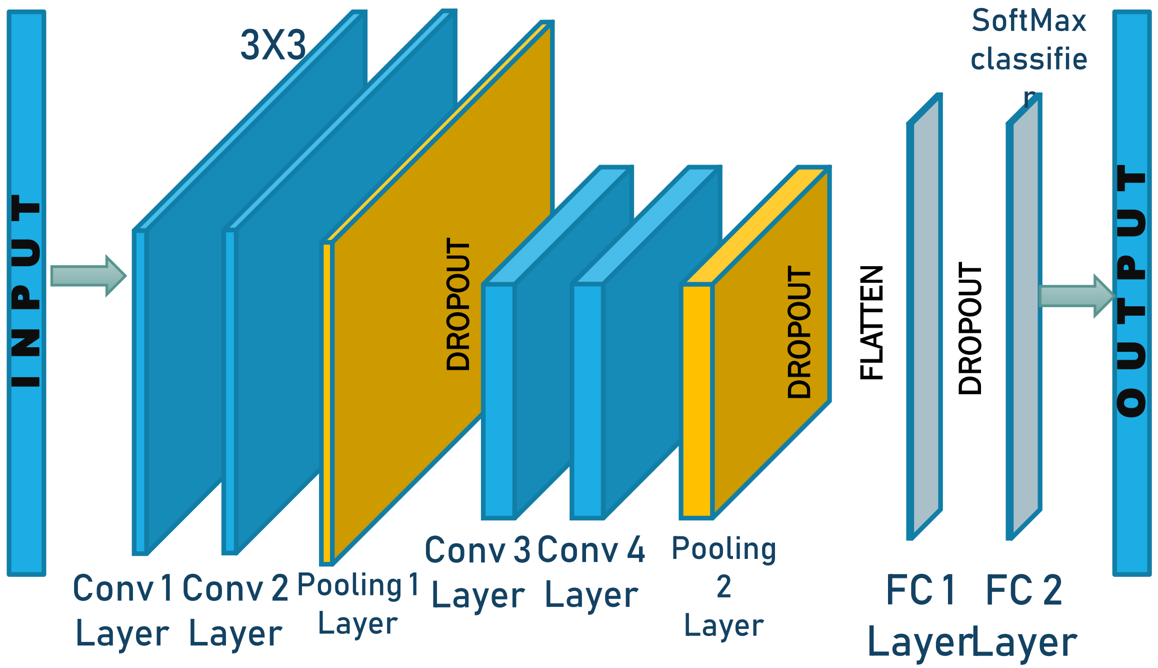
Classification Report

	precision	recall	f1-score	support
cardboard	0.91	0.85	0.88	100
glass	0.81	0.77	0.79	125
metal	0.76	0.79	0.78	102
paper	0.77	0.89	0.82	148
plastic	0.72	0.78	0.75	120
trash	0.88	0.21	0.33	34
accuracy			0.79	629
macro avg	0.81	0.72	0.73	629
weighted avg	0.79	0.79	0.78	629



Model's performance – Best so far with accuracy of 0.79 , predicted most classes with best recall so far,

MODEL 9 – HYPER MODEL USING RANDOM SEARCH WITH MULTIPLE PARMATERS



- 2 TRIALS & 2 EXCUTIONS PER TRIAL WERE RUN
- Range for Dropout – 0.0 to 0.5
- Range for Activation – Relu, Tanh
- Range for learning rate – 0.0001 to 0.01
- Range for filters – 32, 64
- Range for Dense Units – 32 to 256

MODEL 9 PARAMETERS LIST & RESULT

```
Results summary
Results in .\untitled_project
Showing 10 best trials
Objective(name='accuracy', direction='max')
Trial summary
Hyperparameters:
num_filters_1: 32
dropout_1: 0.25
dropout_2: 0.30000000000000004
units: 128
dense_activation: tanh
dropout_3: 0.15000000000000002
learning_rate: 0.00016355245798526342
Score: 0.5640147626399994
Trial summary
Hyperparameters:
num_filters_1: 32
dropout_1: 0.5
dropout_2: 0.1
units: 96
dense_activation: tanh
dropout_3: 0.4
learning_rate: 0.0004442889681244208
Score: 0.3727607876062393
```

```
20/20 [==============================] - 15s 756ms/step - loss: 1.1442 - accuracy: 0.6216
```

- 1st Trial Performance – 0.56 accuracy score
- 2nd Trial Performance – 0.372 accuracy score
- Final Best Model performance on Test set – 62% accuracy score

MODEL COMPARISON

MODEL	Training Accuracy	Validation Accuracy
Custom Model 1 using 3 Conv layers and 2 FC layers	0.475	0.482
Custom Model 2 using 4 Conv and 2 FC layers	0.454	0.494
InceptionV3	0.722	0.752
MobileNetV2	0.756	0.742
DenseNet121	0.700	0.731
VGG16	0.562	0.652
Resnet50	0.263	0.273
Xception	0.759	0.787
HyperModel using Random Search – Best Model	0.564	0.622

CONCLUSION/SUMMARY

- We tried a lot of models to see which models worked best on our data, Xception & Inception proved to be the best, but maybe with more tuning we can achieve an improvement in accuracy by 4-5%.
- We achieved the best accuracy of 79% for validation accuracy with Xception model
- Even with limited challenges, the overall performance of the models is satisfactory and the results obtained are accurate and sufficient enough to use in similar applications.
- Project was conducted with full genuineness and according to the findings it can be seen that the transfer learning models outperformed custom models.
- Scope can be widened by using techniques like object detection algorithm and segmentation for achieving higher accuracy with a balanced dataset and more data size for scalability
- Further data are needed to achieve higher accuracy rates. In the context of our proposed model, we have achieved high classification success.

REFERENCES

- G. Thung and M. Yang. "Dataset of images of trash"
- https://github.com/KhazanahAmericasInc
- https://github.com/frankplus/trash-cnn
- Himanshu Gupta, http://norma.ncirl.ie/
- https://sicara.ai/blog/author/julie-prost