Using Convolutional Neural Networks to Identify Dog Breeds

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I. Definition

Project Overview

Nowadays, AI and computer vision play an important role in detecting objects [1]. There are many models pretrained with a big dataset for this task. For example, there are models that can identify objects in the ImageNet dataset which have 1000 classes [2].

However, there are limitations that these pretrained models can identify only the classes that appear in the trained dataset. For example, in order to specifically identify unseen classes like some dog breeds, the models need to be newly created. Also, there may be situations where there are only a few dog images that have the breed labels because it requires a lot of effort to label images [3]. Thus, the model must use only a few images to train.

Problem Statement

With only a few dog images with breed labels, it is challenging to create a model that does not overfit the training set and give high accuracy on the test set.

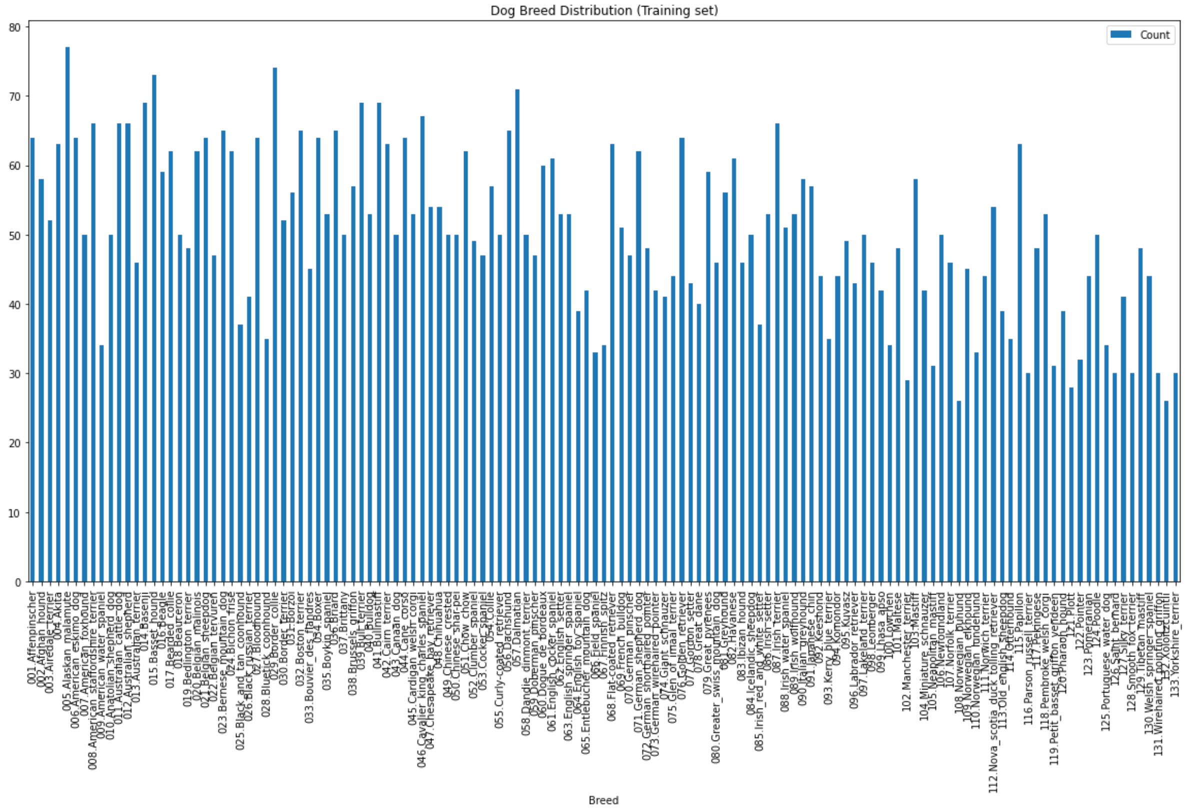
Metrics

Accuracy is the acceptable and selected metric because classes are not extremely unbalanced. However, one may also look at precision and recall of each classes to see performance of each class separately.

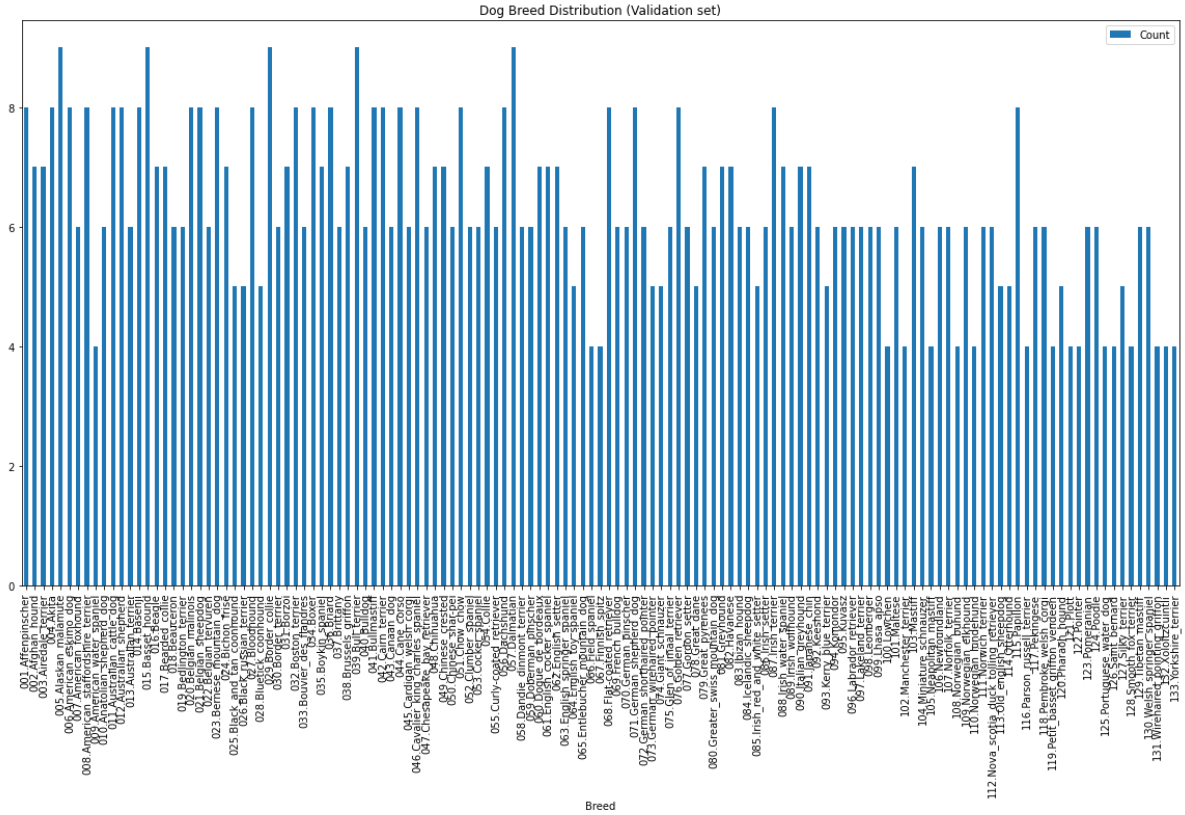
II. Analysis

Data Exploration

Dog dataset: (https://s3-us-west-1.amazonaws.com/udacity-aind/dog-project/dogImages.zip) This is the main dataset for developing a CNN model to identify dog breeds. The dataset contains dog images with 133 breed labels. The dataset consist of training (6680 images), validation (835 images), and test (836 images) sets. The classes are just slightly imbalanced.



Dog Breed Distribution (Training set)
Count
0
10
20
30
40
50
60
70
80
Breed
001.Affenpinscher
002.Afghan_hound
003.Airedale_terrier
004.Akita
005.Alaskan_malamute
006.American_eskimo_dog
007.American_foxhound
008.American_staffordshire_terrier
009.American_water_spaniel
010.Anatolian_shepherd_dog
011.Australian_cattle_dog
012.Australian_shepherd
013.Australian_terrier
014.Basenji
015.Basset_hound
016.Beagle
017.Bearded_collie
018.Beauceron
019.Bedlington_terrier
020.Belgian_malinois
021.Belgian_sheepdog
022.Belgian_tervuren
023.Bernese_mountain_dog
024.Bichon_frise
025.Black_and_tan_coonhound
026.Black_russian_terrier
027.Bloodhound
028.Bluetick_coonhound
029.Border_collie
030.Border_terrier
031.Borzoi
032.Boston_terrier
033.Bouvier_des_flandres
034.Boxer
035.Boykin_spaniel
036.Briard
037.Brittany
038.Brussels_griffon
039.Bull_terrier
040.Bulldog
041.Bullmastiff
042.Cairn_terrier
043.Canaan_dog
044.Cane_corso
045.Cardigan_welsh_corgi
046.Cavalier_king_charles_spaniel
047.Chesapeake_bay_retriever
048.Chihuahua
049.Chinese_crested
050.Chinese_shar-pei
051.Chow_chow
052.Clumber_spaniel
053.Cocker_spaniel
054.Collie
055.Curly-coated_retriever
056.Dachshund
057.Dalmatian
058.Dandie_dinmont_terrier
059.Doberman_pinscher
060.Dogue_de_bordeaux
061.English_cocker_spaniel
062.English_setter
063.English_springer_spaniel
064.English_toy_spaniel
065.Entlebucher_mountain_dog
066.Field_spaniel
067.Finnish_spitz
068.Flat-coated_retriever
069.French_bulldog
070.German_pinscher
071.German_shepherd_dog
072.German_shorthaired_pointer
073.German_wirehaired_pointer
074.Giant_schnauzer
075.Glen_of_imaal_terrier
076.Golden_retriever
077.Gordon_setter
078.Great_dane
079.Great_pyrenees
080.Greater_swiss_mountain_dog
081.Greyhound
082.Havanese
083.Ibizan_hound
084.Icelandic_sheepdog
085.Irish_red_and_white_setter
086.Irish_setter
087.Irish_terrier
088.Irish_water_spaniel
089.Irish_wolfhound
090.Italian_greyhound
091.Japanese_chin
092.Keeshond
093.Kerry_blue_terrier
094.Komondor
095.Kuvasz
096.Labrador_retriever
097.Lakeland_terrier
098.Leonberger
099.Lhasa_apso
100.Lowchen
101.Maltese
102.Manchester_terrier
103.Mastiff
104.Miniature_schnauzer
105.Neapolitan_mastiff
106.Newfoundland
107.Norfolk_terrier
108.Norwegian_buhund
109.Norwegian_elkhound
110.Norwegian_lundehund
111.Norwich_terrier
112.Nova_scotia_duck_tolling_retriever
113.Old_english_sheepdog
114.Otterhound
115.Papillon
116.Parson_russell_terrier
117.Pekingese
118.Pembroke_welsh_corgi
119.Petit_basset_griffon_vendeen
120.Pharaoh_hound
121.Plott
122.Pointer
123.Pomeranian
124.Poodle
125.Portuguese_water_dog
126.Saint_bernard
127.Silky_terrier
128.Smooth_fox_terrier
129.Tibetan_mastiff
130.Welsh_springer_spaniel
131.Wirehaired_pointing_griffon
132.Xoloitzcuintli
133.Yorkshire_terrier



Dog Breed Distribution (Validation set)
Count
0
2
4
6
8
Breed
001.Affenpinscher
002.Afghan_hound
003.Airedale_terrier
004.Akita
005.Alaskan_malamute
006.American_eskimo_dog
007.American_foxhound
008.American_staffordshire_terrier
009.American_water_spaniel
010.Anatolian_shepherd_dog
011.Australian_cattle_dog
012.Australian_shepherd
013.Australian_terrier
014.Basenji
015.Basset_hound
016.Beagle
017.Bearded_collie
018.Beauceron
019.Bedlington_terrier
020.Belgian_malinois
021.Belgian_sheepdog
022.Belgian_tervuren
023.Bernese_mountain_dog
024.Bichon_frise
025.Black_and_tan_coonhound
026.Black_russian_terrier
027.Bloodhound
028.Bluetick_coonhound
029.Border_collie
030.Border_terrier
031.Borzoi
032.Boston_terrier
033.Bouvier_des_flandres
034.Boxer
035.Boykin_spaniel
036.Briard
037.Brittany
038.Brussels_griffon
039.Bull_terrier
040.Bulldog
041.Bullmastiff
042.Cairn_terrier
043.Canaan_dog
044.Cane_corso
045.Cardigan_welsh_corgi
046.Cavalier_king_charles_spaniel
047.Chesapeake_bay_retriever
048.Chihuahua
049.Chinese_crested
050.Chinese_shar-pei
051.Chow_chow
052.Clumber_spaniel
053.Cocker_spaniel
054.Collie
055.Curly-coated_retriever
056.Dachshund
057.Dalmatian
058.Dandie_dinmont_terrier
059.Doberman_pinscher
060.Dogue_de_bordeaux
061.English_cocker_spaniel
062.English_setter
063.English_springer_spaniel
064.English_toy_spaniel
065.Entlebucher_mountain_dog
066.Field_spaniel
067.Finnish_spitz
068.Flat-coated_retriever
069.French_bulldog
070.German_pinscher
071.German_shepherd_dog
072.German_shorthaired_pointer
073.German_wirehaired_pointer
074.Giant_schnauzer
075.Glen_of_imaal_terrier
076.Golden_retriever
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079.Great_pyrenees
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081.Greyhound
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088.Irish_water_spaniel
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125.Portuguese_water_dog
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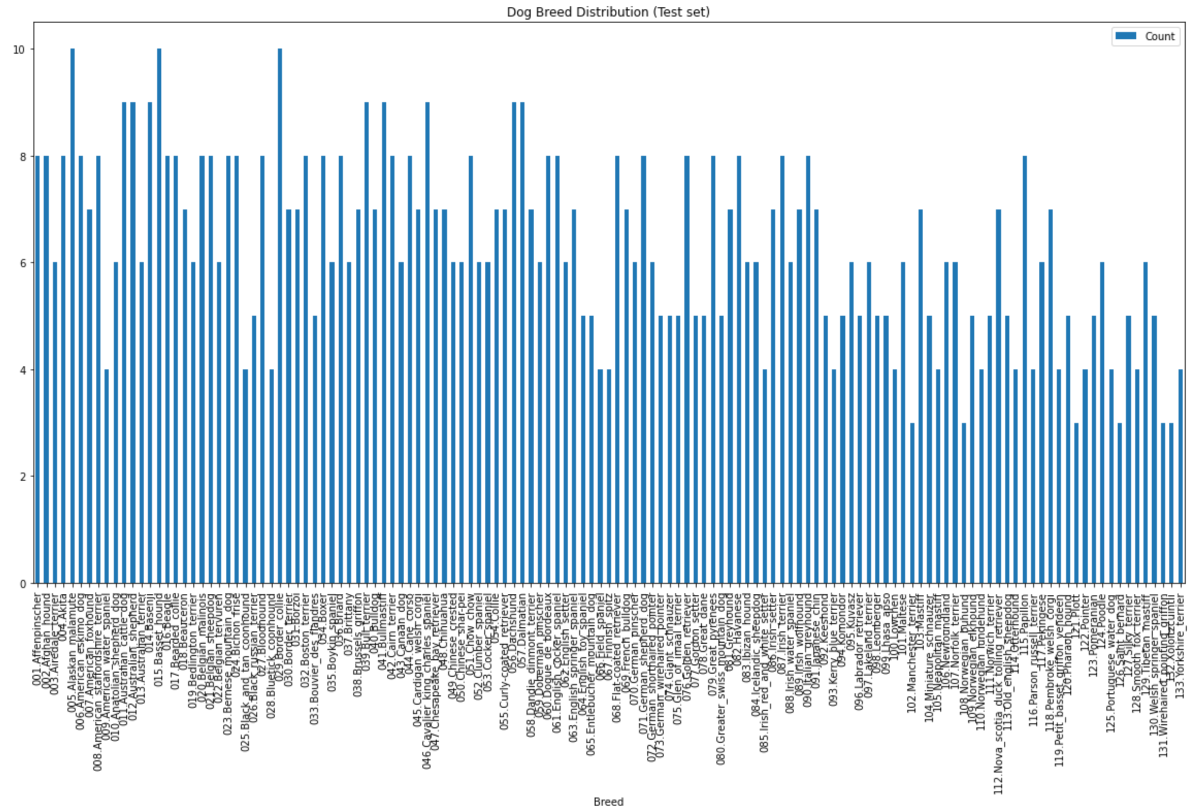
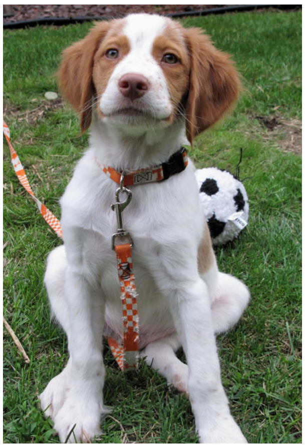
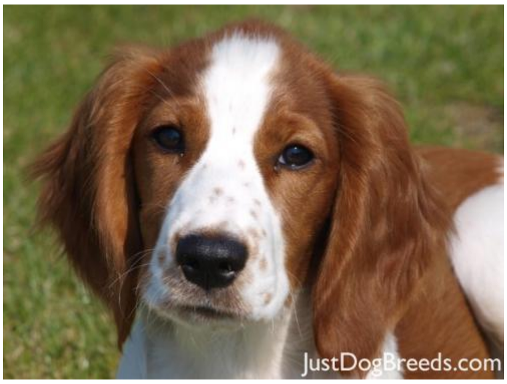


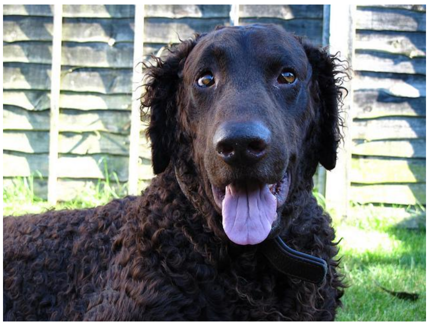
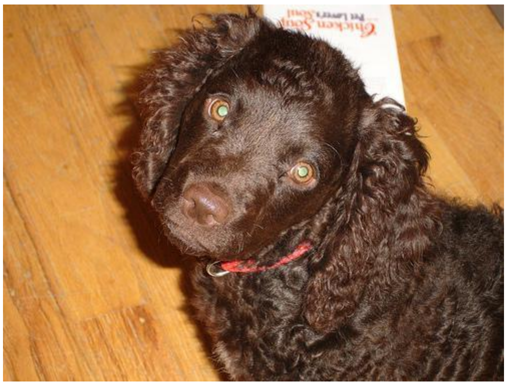
Exploratory Visualization

The feature required for training the model is the image itself. Due to the nature of deep learning models that will be used in this project, the features will be extracted automatically by the models. Images just need some preprocessing steps such as resize, flip, and a little rotation to have correct format and have variety of inputs for the models.

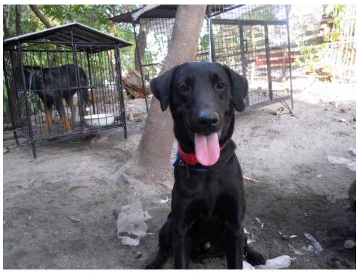
However, there is some challenge to assign breed to dogs if the dogs look very similar to each other. For example, distinguishing between a Brittany and a Welsh Springer Spaniel is hard even by a human.

Brittany	Welsh Springer Spaniel
	

Curly-Coated Retrievers and American Water Spaniels also look similar.

Curly-Coated Retriever	American Water Spaniel
	

Likewise, some dogs have more than one color such as Labradors. The can be yellow, chocolate, and black. Thus, the model need to consider both shape and color.

Yellow Labrador	Chocolate Labrador	Black Labrador
		

Algorithms and Techniques

In order to achieve high accuracy from fitting the model with only a few images, transfer learning must be used. Also, the chosen base models should be trained on the dataset that contain some different dog breeds. Fortunately, all base models from torchvision are trained on the ImageNet dataset which contains some image categories corresponding to dogs [2]. Thus, one of these base models will be chosen for transfer learning in this project.

Benchmark

There are some works that use the same datasets to create and test the models [4, 5] and give the similar benchmark results. For example, Maanav Shah created 4 models including VGG-49, ResNet-50, Inception V3, and Xception [4]. The model performance comparisons of his work are as follows.

Model	Acc	Training Time in seconds (20 epochs, batch size = 32)
VGG-19	46%	24.16
ResNet-50	82%	18.41
Inception v3	81%	31.83
Xception	85%	49.07

III. Methodology

Data Preprocessing

Image transformations for training set

1. Resize an image to have size (244, 244)
2. Random flip the image horizontally
3. Apply small rotation in the range -10 to 10 degree to the image
4. Convert the image to the tensor that is the data type for the model
5. Normalize images to have the mean =[0.485, 0.456, 0.406] and std = [0.229, 0.224, 0.225] so that the model can learn from the image easier

Random flip and rotation provide variety to the training sets and can help model to avoid overfitting issue.

Image transformations for evaluation and test sets

1. Resize an image to have size (244, 244)
2. Convert the image to the tensor that is the data type for the model
3. Normalize images to have the mean =[0.485, 0.456, 0.406] and std = [0.229, 0.224, 0.225] so that the test image has the same mean and std as the trained ones.

Implementation

ResNet-50 from torchvision.models are chosen as a pretrained model. The strong point of this model is that it can avoid vanishing gradient even for quite deep model architectures. The way to use transferred model with the new dataset is to freeze all feature layers and only allow classification layer to be trained. The steps are as follows.

1. Load the pretrained model "ResNet-50 " for the ImageNet dataset from torchvision
2. Freeze all features layers not to be trained
3. Create new classification layer to have the number of output nodes equal to the number of dog breeds which is 133
4. Train the parameters of the classification layer

After 19 epochs of training, the best model with lowest loss in validation set provides 82% of accuracy in the test set. Later iterations give insignificant improvement in the validation loss. Thus, some hyperparameter may be changed before continue training the model. One possible parameter that can affect the training performance after training for some epochs is the learning rate. Eventually, model will require lower learning rate to converge to the lower training loss.

Refinement

Model refinement is made by reducing the learning rate from 0.001 to 0.0001. The steps are as follows.

1. Load the best trained model
2. Continue training with lower learning rate (lr = 0.0001) for 25 epochs

After 25 epochs of refinement training, the best model with lowest loss in validation set provides 86% of accuracy in the test set. The accuracy increases 4% from the model without refinement.

IV. Results

Model Evaluation and Validation

The best model provide the 86% of the accuracy in test set. There are 720 correct identification samples from the total 836 samples in the test set. Precision and recall for each classes are also reported as follows.

```
                                         precision    recall  f1-score   support

                      001.Affenpinscher       1.00      0.88      0.93         8
                       002.Afghan_hound       1.00      1.00      1.00         8
                   003.Airedale_terrier       0.86      1.00      0.92         6
                              004.Akita       1.00      0.88      0.93         8
                   005.Alaskan_malamute       0.83      1.00      0.91        10
                006.American_eskimo_dog       1.00      1.00      1.00         8
                  007.American_foxhound       0.75      0.86      0.80         7
     008.American_staffordshire_terrier       0.89      1.00      0.94         8
             009.American_water_spaniel       0.67      0.50      0.57         4
             010.Anatolian_shepherd_dog       0.83      0.83      0.83         6
              011.Australian_cattle_dog       1.00      0.89      0.94         9
                012.Australian_shepherd       0.90      1.00      0.95         9
                 013.Australian_terrier       1.00      0.83      0.91         6
                            014.Basenji       0.82      1.00      0.90         9
                       015.Basset_hound       1.00      1.00      1.00        10
                             016.Beagle       0.83      0.62      0.71         8
                     017.Bearded_collie       0.70      0.88      0.78         8
                          018.Beauceron       1.00      1.00      1.00         7
                 019.Bedlington_terrier       1.00      1.00      1.00         6
                   020.Belgian_malinois       0.78      0.88      0.82         8
                   021.Belgian_sheepdog       1.00      1.00      1.00         8
                   022.Belgian_tervuren       1.00      1.00      1.00         6
               023.Bernese_mountain_dog       1.00      1.00      1.00         8
                       024.Bichon_frise       1.00      1.00      1.00         8
            025.Black_and_tan_coonhound       1.00      1.00      1.00         4
              026.Black_russian_terrier       0.80      0.80      0.80         5
                         027.Bloodhound       1.00      1.00      1.00         8
                 028.Bluetick_coonhound       1.00      1.00      1.00         4
                      029.Border_collie       1.00      1.00      1.00        10
                     030.Border_terrier       1.00      0.86      0.92         7
                             031.Borzoi       1.00      0.86      0.92         7
                     032.Boston_terrier       1.00      1.00      1.00         8
               033.Bouvier_des_flandres       0.80      0.80      0.80         5
                              034.Boxer       1.00      0.88      0.93         8
                     035.Boykin_spaniel       1.00      1.00      1.00         6
                             036.Briard       1.00      1.00      1.00         8
                           037.Brittany       1.00      0.67      0.80         6
                   038.Brussels_griffon       0.88      1.00      0.93         7
                       039.Bull_terrier       1.00      1.00      1.00         9
                            040.Bulldog       1.00      1.00      1.00         7
                        041.Bullmastiff       0.73      0.89      0.80         9
                      042.Cairn_terrier       1.00      0.88      0.93         8
                         043.Canaan_dog       0.75      1.00      0.86         6
                         044.Cane_corso       0.83      0.62      0.71         8
               045.Cardigan_welsh_corgi       0.67      0.86      0.75         7
      046.Cavalier_king_charles_spaniel       0.75      0.67      0.71         9
           047.Chesapeake_bay_retriever       0.88      1.00      0.93         7
                          048.Chihuahua       1.00      0.71      0.83         7
                    049.Chinese_crested       0.75      1.00      0.86         6
           050.Chinese_shar-pei       1.00      1.00      1.00         6
                 051.Chow_chow       1.00      0.88      0.93         8
           052.Clumber_spaniel       1.00      1.00      1.00         6
            053.Cocker_spaniel       0.71      0.83      0.77         6
                    054.Collie       1.00      0.86      0.92         7
   055.Curly-coated_retriever       0.88      1.00      0.93         7
                056.Dachshund       0.73      0.89      0.80         9
                057.Dalmatian       1.00      1.00      1.00         9
   058.Dandie_dinmont_terrier       1.00      0.86      0.92         7
        059.Doberman_pinscher       0.83      0.83      0.83         6
        060.Dogue_de_bordeaux       1.00      1.00      1.00         8
   061.English_cocker_spaniel       0.80      0.50      0.62         8
           062.English_setter       1.00      0.83      0.91         6
 063.English_springer_spaniel       0.75      0.86      0.80         7
      064.English_toy_spaniel       0.50      0.60      0.55         5
 065.Entlebucher_mountain_dog       0.83      1.00      0.91         5
            066.Field_spaniel       1.00      0.75      0.86         4
            067.Finnish_spitz       1.00      0.50      0.67         4
   068.Flat-coated_retriever       1.00      0.88      0.93         8
           069.French_bulldog       1.00      1.00      1.00         7
           070.German_pinscher       0.71      0.83      0.77         6
      071.German_shepherd_dog       1.00      1.00      1.00         8
072.German_shorthaired_pointer       0.50      0.50      0.50         6
 073.German_wirehaired_pointer       1.00      0.20      0.33         5
          074.Giant_schnauzer       0.67      0.80      0.73         5
     075.Glen_of_imaal_terrier       0.67      0.80      0.73         5
         076.Golden_retriever       0.80      1.00      0.89         8
            077.Gordon_setter       0.62      1.00      0.77         5
               078.Great_dane       1.00      0.60      0.75         5
           079.Great_pyrenees       0.78      0.88      0.82         8
080.Greater_swiss_mountain_dog       1.00      0.80      0.89         5
                081.Greyhound       0.86      0.86      0.86         7
                 082.Havanese       0.50      0.62      0.56         8
             083.Ibizan_hound       1.00      1.00      1.00         6
       084.Icelandic_sheepdog       0.57      0.67      0.62         6
085.Irish_red_and_white_setter       0.50      0.75      0.60         4
             086.Irish_setter       1.00      0.86      0.92         7
            087.Irish_terrier       1.00      0.88      0.93         8
      088.Irish_water_spaniel       0.71      0.83      0.77         6
          089.Irish_wolfhound       1.00      0.71      0.83         7
        090.Italian_greyhound       0.89      1.00      0.94         8
            091.Japanese_chin       0.88      1.00      0.93         7
                 092.Keeshond       1.00      1.00      1.00         5
       093.Kerry_blue_terrier       1.00      0.75      0.86         4
                 094.Komondor       1.00      1.00      1.00         5
                   095.Kuvasz       0.80      0.67      0.73         6
       096.Labrador_retriever       0.57      0.80      0.67         5
         097.Lakeland_terrier       1.00      0.67      0.80         6
               098.Leonberger       1.00      1.00      1.00         5
               099.Lhasa_apso       0.75      0.60      0.67         5
                  100.Lowchen       0.50      0.25      0.33         4
                  101.Maltese       0.75      0.50      0.60         6
       102.Manchester_terrier       1.00      1.00      1.00         3
                  103.Mastiff       0.71      0.71      0.71         7
      104.Miniature_schnauzer       0.83      1.00      0.91         5
       105.Neapolitan_mastiff       0.80      1.00      0.89         4
             106.Newfoundland       0.75      1.00      0.86         6
          107.Norfolk_terrier       0.75      1.00      0.86         6
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                 108.Norwegian_buhund       0.67      0.67      0.67         3
               109.Norwegian_elkhound       1.00      0.80      0.89         5
              110.Norwegian_lundehund       1.00      0.75      0.86         4
                  111.Norwich_terrier       0.71      1.00      0.83         5
 112.Nova_scotia_duck_tolling_retriever       1.00      1.00      1.00         7
              113.Old_english_sheepdog       0.75      0.60      0.67         5
                      114.Otterhound       1.00      0.75      0.86         4
                        115.Papillon       1.00      0.88      0.93         8
           116.Parson_russell_terrier       1.00      1.00      1.00         4
                       117.Pekingese       1.00      1.00      1.00         6
              118.Pembroke_welsh_corgi       0.80      0.57      0.67         7
      119.Petit_basset_griffon_vendeen       1.00      1.00      1.00         4
                  120.Pharaoh_hound       1.00      1.00      1.00         5
                          121.Plott       1.00      0.67      0.80         3
                        122.Pointer       0.29      0.50      0.36         4
                     123.Pomeranian       0.67      0.80      0.73         5
                         124.Poodle       1.00      0.83      0.91         6
           125.Portuguese_water_dog       0.60      0.75      0.67         4
                  126.Saint_bernard       1.00      1.00      1.00         3
                  127.Silky_terrier       0.75      0.60      0.67         5
             128.Smooth_fox_terrier       1.00      0.50      0.67         4
                129.Tibetan_mastiff       1.00      0.67      0.80         6
           130.Welsh_springer_spaniel       0.75      0.60      0.67         5
      131.Wirehaired_pointing_griffon       0.50      1.00      0.67         3
                   132.Xoloitzcuintli       1.00      1.00      1.00         3
               133.Yorkshire_terrier       0.60      0.75      0.67         4

                      avg / total       0.88      0.86      0.86       836
```
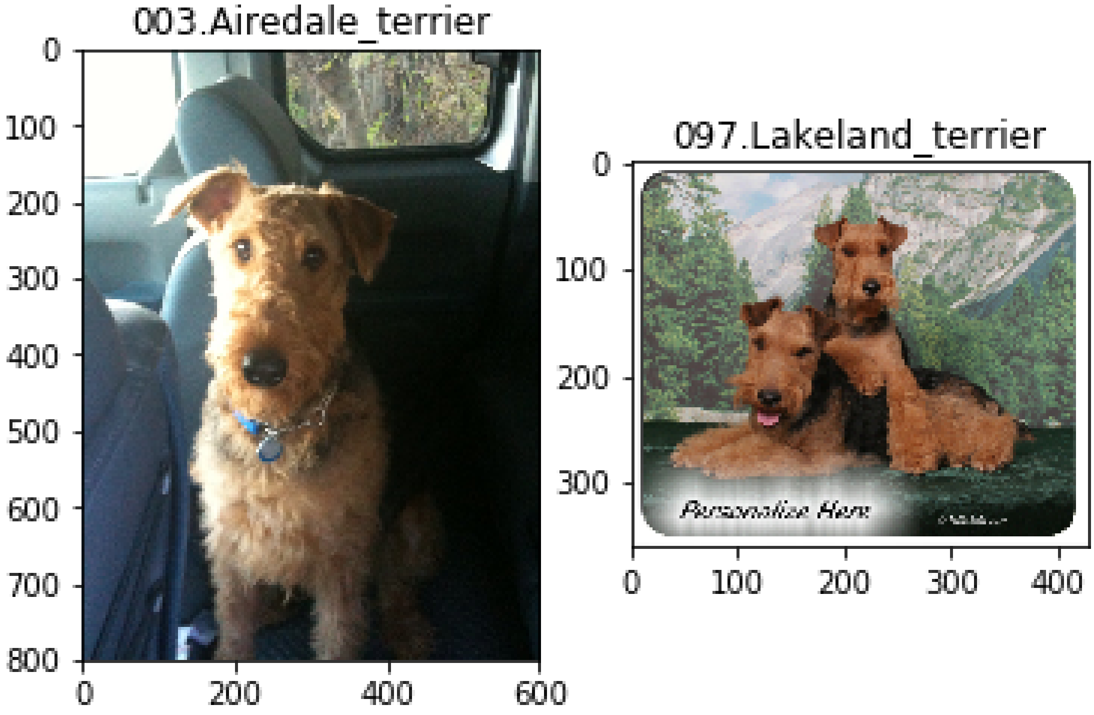

One obvious reason of wrong prediction is the similarity between breeds. For example, some Lakeland_terrier sample is predicted as Airedale_terrier by the model.



Justification

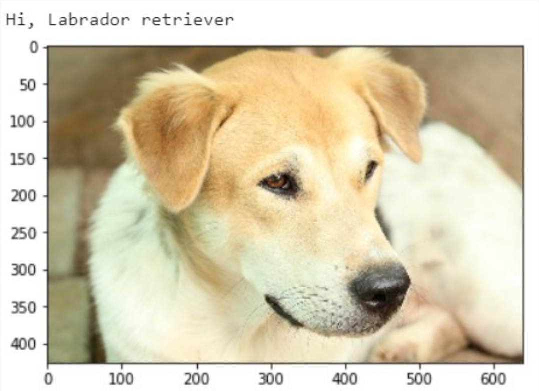
The ResNet-50 model after refinement give higher accuracy (86%) than the accuracy of ResNet-50 (82%) and the accuracy of Xception (85%) provided in the benchmark section. However, if more advance learning rate policy is applied, the model may provide even higher accuracy [4].

V. Conclusion

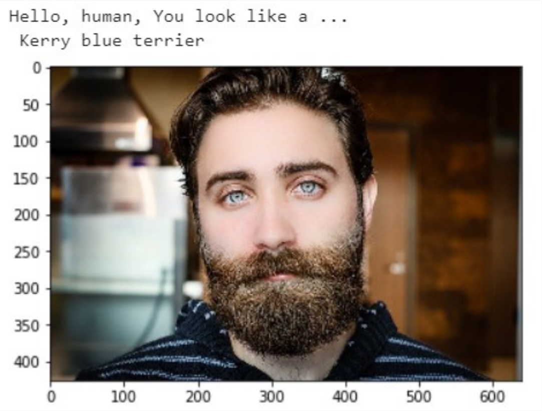
Transfer learning can help identification problems that have only a few image samples to train the new model. In this project, the transferred model provides high accuracy (86%) in the test set.

Example of using the dog breed identification as a part of an aplication

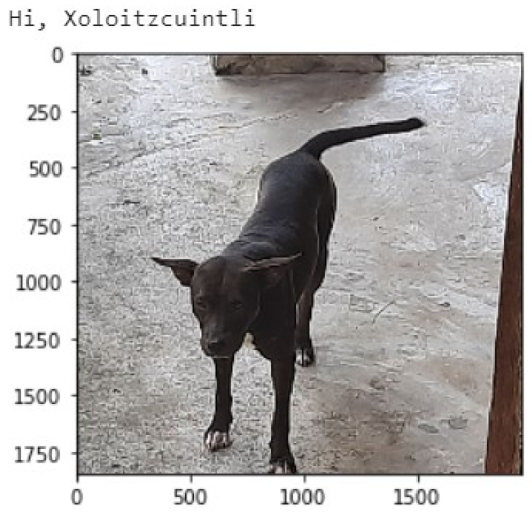
Dog-breed identification can be a part of some application. For example, the application can accepts a file path to an image and first determines whether the image contains a human, dog, or neither based on Haar feature-based cascade classifiers to detect human faces and pretrain VGG16 to detect dogs. Then, if a dog is detected in the image, dog-breed identification can be used to return the predicted breed. if a human is detected in the image, return the resembling dog breed. if neither is detected in the image, provide output that indicates an error. Some results of this application are shown as follows.



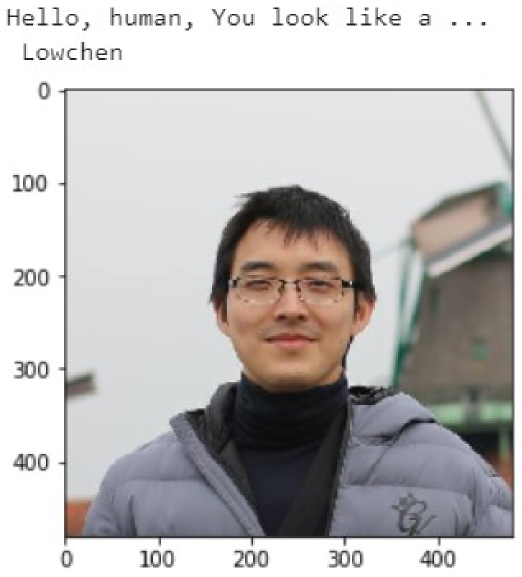
```
Hi, Labrador retriever
```



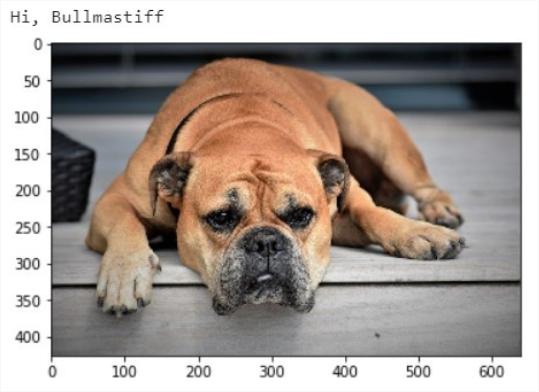
```
Hello, human, You look like a ...
 Kerry blue terrier
```



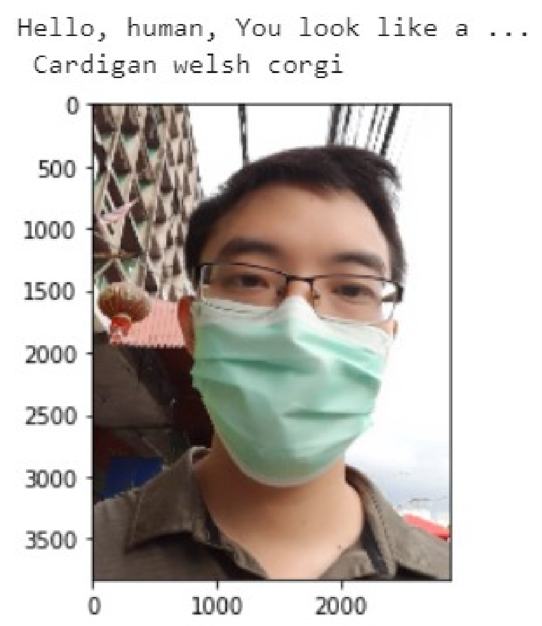
```
Hi, Xoloitzcuintli
```



```
Hello, human, You look like a ...
 Lowchen
```



```
Hi, Bullmastiff
```



```
Hello, human, You look like a ...
 Cardigan welsh corgi
```

Reflection

There are some pitfalls that ones may face. The problem may look very simple but it can take your time to solve if you do not realize it.

- Setting "Shuffle = True" in the data loader for the train set is very important. If we set Shuffle = False, it is possible that the samples in the same batch contains only one class or only a few classes and cause model to not be able to learn much from that batch.

- Even though, some acceptable results are met, we may be able to improve the performance of the result further by adjusting only one parameter or only a few parameters. For example, after the model can achieve 82% of the accuracy it can be improved more by only reducing the learning rate parameter and continuing training.

Improvement

To improve the result, these factors may need to explored further.

- Learning rate policies
- Pretrained model architectures
- Batch size

Reference

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