

I. Definition

Image classification has become one of the most important problems nowadays. As computers are getting better at understanding images due to advances in computer vision, solving of image classification problem using Deep learning becoming increasingly realistic.

In This project I will use one of kaggle Competition dataset, this dataset containing images of approximately 960 unique plants belonging to 12 species at several growth stages.

The database have been recorded at Aarhus University Flakkebjerg Research station in a collaboration between University of Southern Denmark and Aarhus University. You can find the dataset [here](#).

The problem here is the weed seedling is much like crop seedling and our goal is to be able to differentiate between them. It will help farmers to automate this task (classify seedling plants).

This project was inspired by [this research center](#).

Problem Statement:

The target of this project is to distinguish between the different weed seeding and crop seeding of 12 different plant species, hence, it's a multi-classification problem. As we take a .png image of a weed or a crop seedling and output the correspondent specie from our 12 classes. I'll be using CNN model to classify the plants. As mentioned below. CNN is widely used in the field of computer vision for doing complicated tasks, hence I'll be using it.

1. Data exploration

- Visualize the distribution of data

2. Data preprocessing

- Check for null and missing values
- resize images
- apply segmentation and sharpening for images
- 5.1 Label encoding
- 6.1 Split training and validation set

2. CNN

- 2.1 Define the model
- 2.2 Set the optimizer and annealer
- 2.3 Data augmentation

4. Evaluate the model

- 3.1 Training and validation curves
- 3.2 Confusion matrix

The final model is expected to be useful for classify the 12 different image species.

Metrics

- Accuracy is a common metric for binary classifiers; it takes into account both true positives and true negatives with equal weight.
- $\text{accuracy} = \frac{\text{true positives} + \text{true negatives}}{\text{dataset size}}$
- **Confusion matrix** can be very helpful to see the model drawbacks.
- a confusion matrix C is such that $C_{i,j}$ is equal to the number of observations known to be in group i but predicted to be in group j .

The most important errors are also the most dangerous.

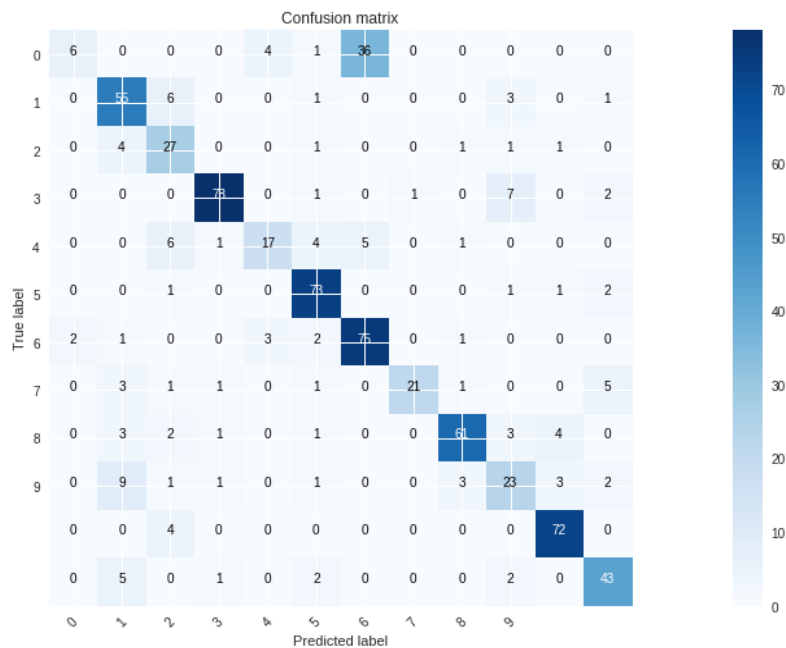
- For CNN I will use the same function provided in Keras API evaluate

Which return the loss value and accuracy matrices for the model in a test mode.

- Accuracy score matrix provided by [confusion matrix sklearn](#)

Compute confusion matrix to evaluate the accuracy of a classification

Here is a plot for confusion matrix of this model:



II. Analysis

Data Exploration:

Plant seedling data set size is 1.6 GB divided into 12 folder in each one it contain number of image belong to certain class. I will split it later into training set and testing set.

- There is 12 types of plant seedling:

- | | |
|--------------------|--------------------|
| 1-Black-grass | 2-Common Chickweed |
| 3-Loose Silky-bent | 4-Shepherd's Purse |
| 5-Charlock | 6-Common wheat |

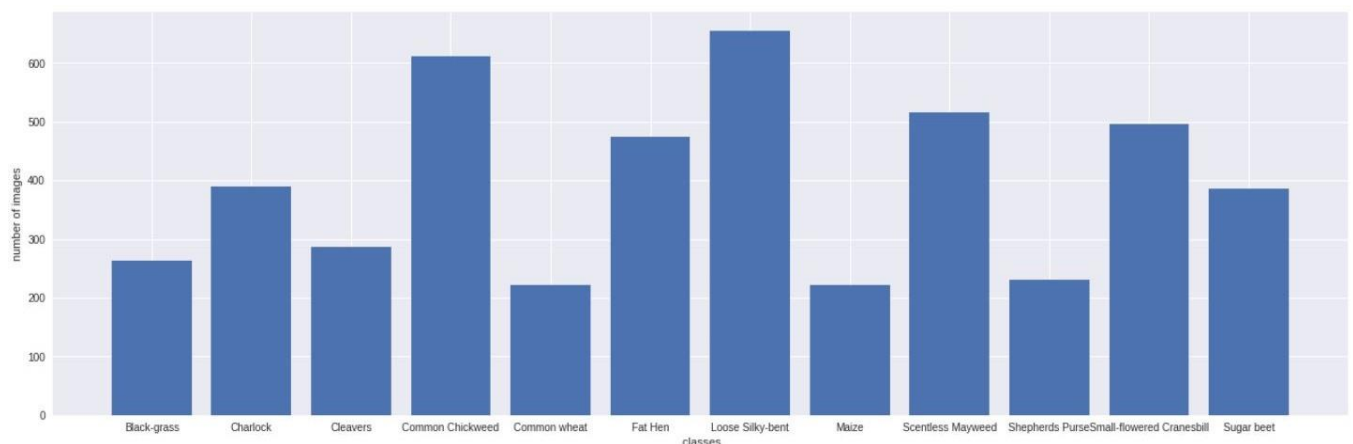
- 7-Maize
- 9-Cleavers
- 11-Scentless Mayweed
- 8-Small-flowered Cranesbill
- 10-Fat Hen
- 12-Sugar beet

- Not all images has the same size (I make resizing to all images in the preprocess stage)

Here is a sample of one of those classes(charlock) :



- The total number of images is **4750** distributed as follows:



Algorithms and Techniques

The classifier is a CNN (Convolutional Neural Network), which is the state-of-the-art algorithm for most image processing tasks, including classification. It needs a large amount of training data compared to other approaches; and this dataset already are big enough to fit this criteria. The algorithm outputs an assigned probability for each class; this can be used to reduce the number of false positive using a threshold . (The tradeoff is that this increases the number of false negatives.)

The following parameters can be tuned to optimize the classifier:

- ❖ Classification threshold (see above)
- ❖ Training parameters
 - Training length (number of epochs)
 - Batch size (how many images to look at once during a single training step)
 - Solver type (what algorithm to use for learning)
 - Learning rate (how fast to learn; this can be dynamic)
 - Weight decay (prevents the model being dominated by a few “neurons”)
- ❖ Neural network architecture
 - Number of layers
 - Layer types (convolutional , fully-connected , or pooling)
 - Layer parameters
- ❖ Preprocessing parameters (see the Data Preprocessing section)

Benchmark:

Plant seedling classification dataset is provided by kaggle I benchmarked my model to another model from kaggle kernels. It has score of 86.3% is a decent score when compared to 60.8% (benchmark model's performance). I believe the final solution will definitely contribute significantly towards solving the current problem.

III. Methodology

Implementation:

The implementation process can be split into two main stages:

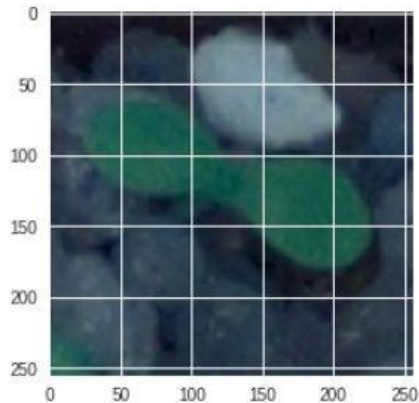
- Preprocessing data stage
- The classifier training stage

Preprocessing:

1- Resizing Images:

Images have not the same size so I have resized the images to 256*256 pixel to feed it later to the neural network

In this figure the image after resize:

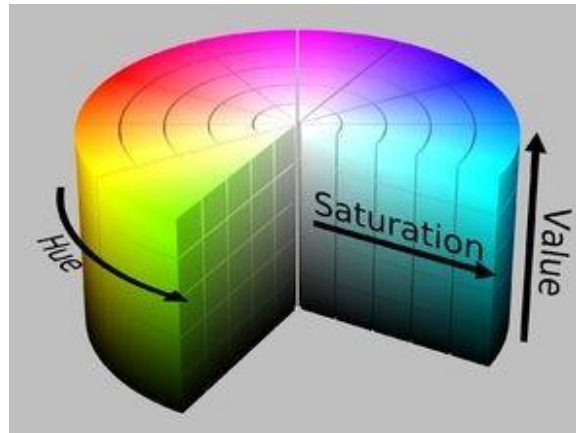


2- Creating mask for the images :

`create_mask_for_plant` function returns an image mask: Matrix with shape (image_height, image_width). In this matrix there are only 0 and 1 values. The 1 values define the interesting part of the original image. I can create this mask using HSV of the image.

The HSV color-space is suitable for color detection because with the Hue we can define the color and the saturation and value will define "different kinds" of the color. (For example it will detect the red, darker red, lighter red too). We cannot do this with the original BGR color space

This figure illustrate HSV space of the image.



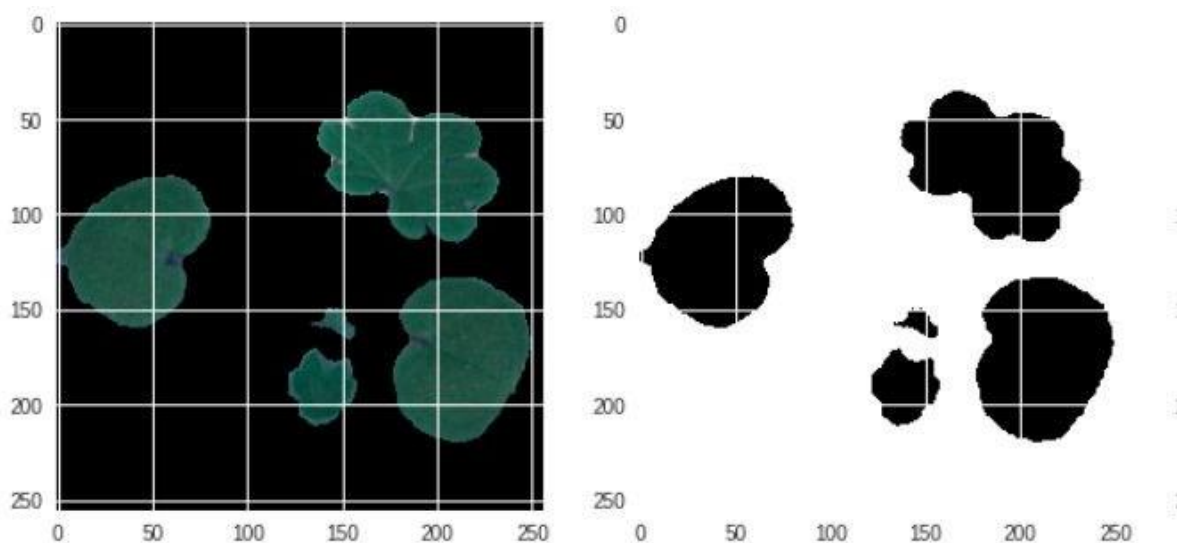
After converting RGB to HSV I started to apply *morphological operations*

3- morphological operations: one of most common morphological operation is **closing** : closing used to close the small halls in the images.

This figure below illustrate the image before and after applying closing:

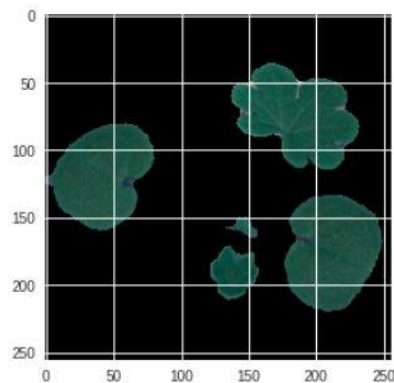


Here is sample after applying the mask on one of images:



4- Segmentation:

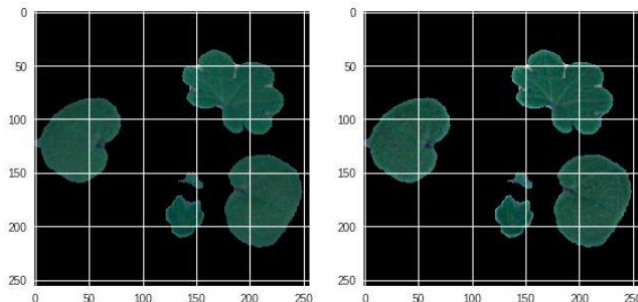
Segmentation is partitioning an image into distinct regions containing each pixels with similar attributes. To be meaningful and useful for image analysis and interpretation, the regions should strongly relate to depicted objects or features of interest. Here is a sample after applying segmentation on one of images:



5- Sharpening:

Sharpening an image increases the contrast between bright and dark regions to bring out features.

Image before and after sharpening:



6- Label encoding:

Using **LabelBinarizer** Binarize labels in a one-vs-all fashion

Input: the label of image and the **output** is vector represent the class in binary form

7- Splitting data into training and testing set:

In this step I used sklearn train_test split 70% for training and 30% for testing Then I split testing data into testing and validation set 50% for testing and 50% for validation. The point of using the validation set is to try to avoid overfitting and check if an overfitting may occur.

The classifier training stage

During the first stage, the classifier was trained on the preprocessed training data. This was done in a Jupyter notebook (titled "FINAL_seedling.ipynp"), and can be further divided into the following steps:

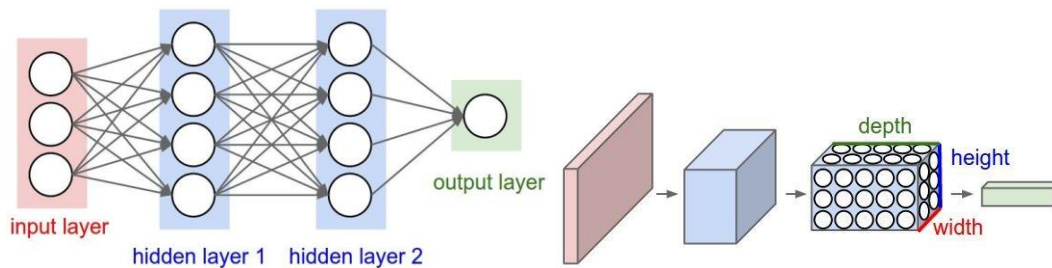
1. Load both the training and validation images into memory, preprocessing them as described in the previous section
the data required for a single training step (a batch of images, their labels, and the learning rate)
2. Define the network architecture and training parameters
3. Define the loss function, accuracy
4. Train the network, logging the validation/training loss and the validation accuracy
5. Plot the logged values
6. If the accuracy is not high enough, return to step 3
7. Save and freeze the trained network

CNN Architecture:

In general, Neural networks accept a single vector as input, transform it to a series of hidden layers, which in turn is made up of set of neurons that are fully connected to all neurons in the previous layer. Neurons of the same layer are independent and do not share any connections. After the hidden layers, is the last fully connected layer which is also called the 'output layer', where each node outputs score for each class. The downside of regular neural network is that they don't scale well to full images. It's mainly because with images of decent size, the number of neurons and weights that the network must accommodate becomes unmanageable. This is where Convolutional Neural Network comes to rescue with its neurons arranged in 3 dimensions (width, height, depth).

Each of the layer in CNN accepts 3D input volume and transforms it into 3D output volume.

Following is a simple visualization of how CNN arranges its neurons in 3 dimensions (width, height, depth):



Following are the layers that are used to build a CNN:

Input layer (w,h,d)

Input layer of shape (w,h,d) represents image of size 'w x h' and 'd' number of color channels. For example, for an image of size (256x256) with 3 color channels (HSV), the input layer will hold raw pixel values of the image as a vector of size [256,256,3]

CONV layer:

The CONV layer will compute the output of neurons that are connected to local regions in the input, each computing a dot product between their weights and a small region they are connected to in the input volume. For eg, if we use 32 filters, CONV layer will output a volume equal to (256x256x3)

Activation functions

Activation layer will apply an element wise activation functions, leaving the volume unchanged.

POOL layer:

Pool layer performs downsampling operation along the spatial dimensions (width, height), outputting a reduced volume than the previous layer. For eg, (128x128x32)

Fully-Connected Layer:

FC layer, also called as the dense layer, each neuron will be connected to all the neurons of the previous layer. FC layer when used as the output layer results in much reduced volume of size [1x1xm], where m is the number of categories that are to be predicted. Each of the nodes of fully connected layer outputs a score corresponding to a class score.

Dropout layer

Dropout layer is used as a method of regularization to combat over-fitting of the training set. It 'drops' neurons at random (depending on the probability mentioned) while calculating the forward prop and backward prop, resulting in

a simpler version of the CNN for each iteration and hence giving the model a hard time to overfit the training set.

Hence for

CNN algorithm consists of several convolution (CNV) operations followed of the image sequentially which is followed by pooling operation (PL) to generate the neurons feed into fully connected (FC) layer.

I used the Keras Sequential API, where you have just to add one layer at a time, starting from the input.

Input: of CNV is typically 2D image data with HSV (hue saturation value)

The first is the convolutional (Conv2D) layer: It is like a set of learnable filters. I chose to set 32 filters for the two firsts conv2D layers and 64 filters for the 2nd convolutional layer and 128 filters for the two last ones.

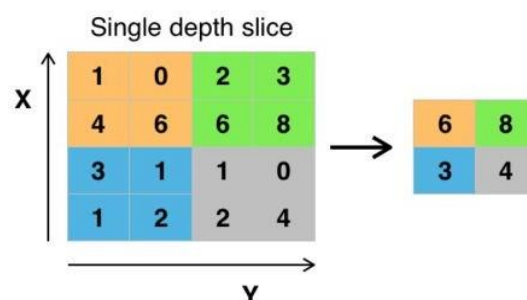
Each filter transforms a part of the image (defined by the kernel size) using the kernel filter. The kernel filter matrix is applied on the whole image. Filters can be seen as a transformation of the image.

The CNN can isolate features that are useful everywhere from these transformed images (feature maps).

The second important layer in CNN is the pooling (MaxPool2D) layer.

This layer simply acts as a downsampling filter. It looks at the 2 neighboring pixels and picks the maximal value. These are used to reduce computational cost, and to some extent also reduce overfitting. We have to choose the pooling size (i.e the area size pooled each time) more the pooling dimension is high, more the downsampling is important.

This figure below illustrate Max pooling with a 2x2 filter and stride = 2:



Combining convolutional and pooling layers, CNN are able to combine local features and learn more global features of the image.

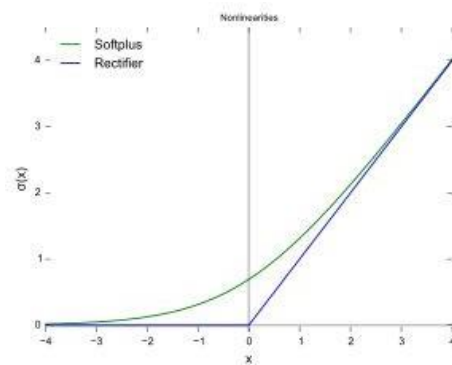
Dropout is a regularization method, where a proportion of nodes in the layer are randomly ignored (setting their weights to zero) for each training sample. This drops randomly a proportion of the network and forces the network to learn features in a distributed way. This technique also improves generalization and reduces the overfitting.

Relu Layer :

ReLU is the abbreviation of Rectified Linear Units. This layer applies the non-saturating activation function. $f(x) = x^+ = \max(0, x)$

It increases the nonlinear properties of the decision function and of the overall network without affecting the receptive fields of the convolution layer.

Figure below illustrate Relu function: Plot of the rectifier (blue) and softplus (green) functions near $x = 0$



The Flatten layer is used to convert the final feature maps into a one single 1D vector. This flattening step is needed so that you can make use of fully connected layers after some convolutional/maxpool layers. It combines all the found local features of the previous convolutional layers.

In the end I used the features in two fully-connected (Dense) layers which is just artificial neural networks (ANN) classifier.

In the last layer (`Dense(10, activation="softmax")`) the net outputs distribution of probability of each class.

Fully Connected (FC) Layer:

This layer will reduce the size of input data to the size of classes that the CNN is trained for by combining output of CNV layer with different weights. Each neuron at the output of the CNV layer will be connected to all other neurons

after weighted properly, Similar to CNV layer, weight of these taps in FC layer is found though backpropagation algorithm.

Classification Layer (CL):

This is the final layer of the CNN that converts the output of FC to probability of each object being in a certain class. Typically soft-max type of algorithms are used in this layer.

The model has the following architecture:

Layer (type)	Output Shape	Param #
conv2d_7 (Conv2D)	(None, 256, 256, 32)	2432
conv2d_8 (Conv2D)	(None, 256, 256, 32)	25632
max_pooling2d_4 (MaxPooling2D)	(None, 128, 128, 32)	0
dropout_5 (Dropout)	(None, 128, 128, 32)	0
conv2d_9 (Conv2D)	(None, 128, 128, 64)	18496
conv2d_10 (Conv2D)	(None, 128, 128, 64)	36928
max_pooling2d_5 (MaxPooling2D)	(None, 64, 64, 64)	0
dropout_6 (Dropout)	(None, 64, 64, 64)	0
conv2d_11 (Conv2D)	(None, 64, 64, 128)	73856
conv2d_12 (Conv2D)	(None, 64, 64, 128)	147584
max_pooling2d_6 (MaxPooling2D)	(None, 32, 32, 128)	0
dropout_7 (Dropout)	(None, 32, 32, 128)	0
global_max_pooling2d_2 (GlobalMaxPooling2D)	(None, 128)	0
dense_25 (Dense)	(None, 256)	33024
dropout_8 (Dropout)	(None, 256)	0
dense_26 (Dense)	(None, 12)	3084
Total params: 341,036		
Trainable params: 341,036		
Non-trainable params: 0		

Complications:

There are some complications that occurred during the code process:

- When the batch_size was 38, it caused an error that I hate the most. Bad Input Shape. I looked in the code and tried to fix it but I couldn't, after some trials and exhausting tracing, I eventually realised that it was the batch_size, hence, I assigned it to none.
- I was considering that all images have the same size but when I feed images to CNN but it also arises some errors, so I did resize images to the same size 256x256x3
- I wasn't able to get higher accuracy at first. However, after applying 128 filters I was able to get better accuracy of 90% which is acceptable for me.

Refinement:

- Decreasing learning rate from .01 to .001 avoid me the overfitting of the model.
- By adding data augmentation accuracy increased to : 91%
- Adding some additional layer also improved the model
- Changing dropout from .25 to .3 improved the accuracy for 86%

IV. Results

Model Evaluation and Validation:

During development, a validation set was used to evaluate the model. The final architecture and hyperparameters were chosen because they performed the best among the tried combinations.

complete description of the final model and the training process:

- The shape of the filters of the 1st and 2nd convolutional layers is 5*5 and 3*3 for the rest of convolutional layers.
- False positives are rare but present

After testing on validation set it give the score in the image:

```
Epoch 36/50
3325/3325 [=====] - 48s 15ms/step - loss: 0.5422 - acc: 0.8135 - val_loss: 0.6605 - val_acc: 0.8008
Epoch 37/50
2368/3325 [=====>.....] - ETA: 12s - loss: 0.4961 - acc: 0.82353325/3325 [=====] - 48s 15ms/step - loss: 0.5170 - acc: 0.8202 - val_loss: 0.6979 - val_acc: 0.8008
Epoch 38/50
3325/3325 [=====] - 48s 15ms/step - loss: 0.5425 - acc: 0.8162 - val_loss: 0.6156 - val_acc: 0.7826
Epoch 39/50
3325/3325 [=====] - 48s 15ms/step - loss: 0.5149 - acc: 0.8235 - val_loss: 0.6210 - val_acc: 0.7994
Epoch 40/50
2368/3325 [=====>.....] - ETA: 12s - loss: 0.5054 - acc: 0.83492624/3325 [=====] - ETA: 9s - loss: 0.5167 - acc: 0.8300
```

With Test loss: 0.48 and Test accuracy: 0.82

And after applying data augmentation

It gives a test score of .91

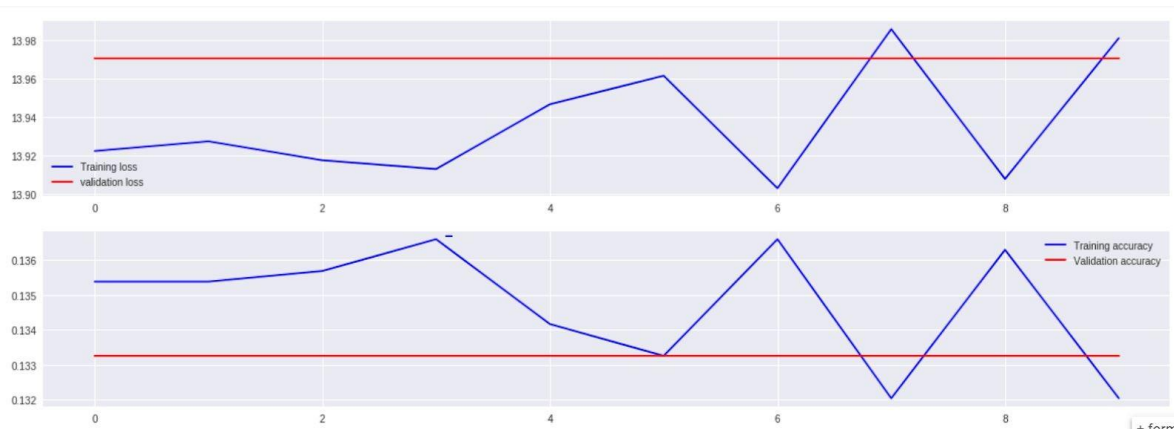
```
Epoch 28/30
- 66s - loss: 0.2357 - acc: 0.9165 - val_loss: 0.5262 - val_acc: 0.8527
Epoch 29/30
- 66s - loss: 0.2480 - acc: 0.9126 - val_loss: 0.5048 - val_acc: 0.8499
Epoch 30/30
- 67s - loss: 0.2324 - acc: 0.9195 - val_loss: 0.5269 - val_acc: 0.8429

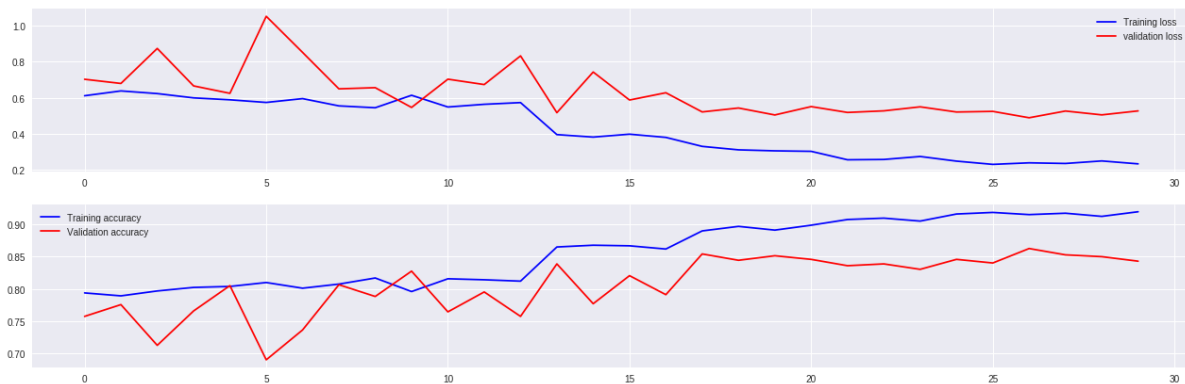
Epoch 00030: ReduceLROnPlateau reducing learning rate to 3.125000148429535e-05.
```

As for the evaluation and validation, I have used 2 main values to check:

Accuracy and validation loss.

Before tuning some parameters (before reducing learning rate)





From the figures I just shared , we can see that with 128 & 64 filters , we have reached a better score at 25 epochs and the validation accuracy is not dropping down

- Having gone through many trials, coding and fixing bugs, and coding again, the current accuracy is more than enough to be trusted. Of course, there'll be an error ratio, but the accuracy is very acceptable and robust enough to be depended on in real life applications.

Justification

The results of the final classifier are much better than that of the benchmark model. It has score of 86.3% is a decent score when compared to 60.8% (benchmark model's performance). I believe the final solution will definitely contribute significantly towards solving the current problem and also with more training data and more preprocessing stages, there are possibilities of improving the model further.

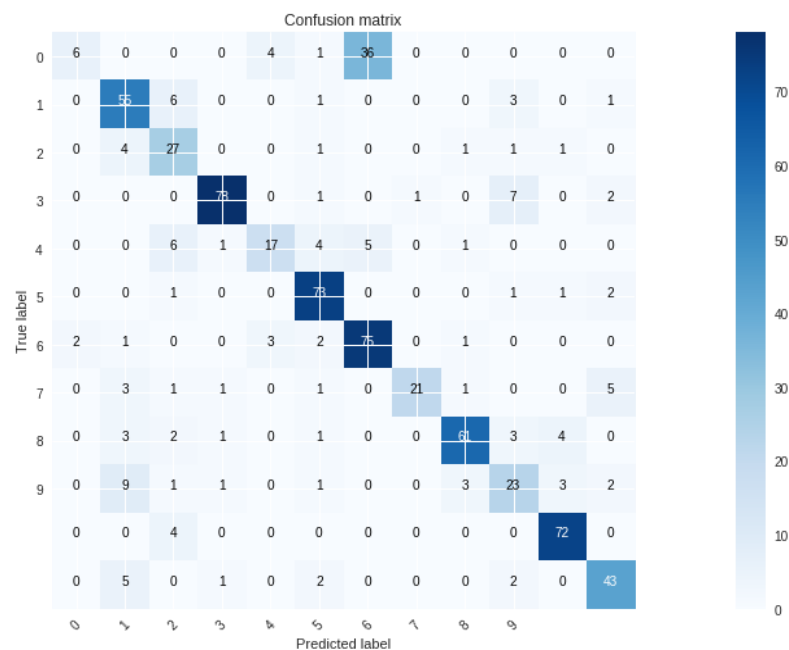
Conclusion:

To show the model quality we get the images which classified incorrectly in the test set this means the images that uncropped correctly can be misclassified

This model can help farmers to automate the task of classifying seedling plants and weed plants.

I plotted the confusion matrix to observe which category is poorly classified by the classifier and observe its performance visually. We can see in the below confusion matrix plot, that the major misclassification happened between

Loose Silky-bent and Black-grass. It looks like the classifier is having difficulty classifying these two categories. I plotted the confusion matrix to observe which category is poorly classified by the classifier and observe its performance visually. We can see in the below confusion matrix plot, that the major misclassification happened between 'Common wheat', 'Fat Hen' It looks like the classifier is having difficulty classifying these two categories. Hence, this is where the classifier needs improvement as these misclassification amount to 50% of the misclassification overall. I believe overcoming this challenge will boost the F1-score significantly.



- My final scores after model tuning is 0.91

Reflection:

I wanted to pick a problem that would give me much more clarity and exposure on how to deal with image classification problems, and I believe that choice of this problem has justified that need.

For this problem, after downloading the dataset from Kaggle, I loaded the dataset and converted the categorical file names into array of 1s and 0s using the labelbinarizer . I explored the data by visualizing the categorical distribution of the dataset by plotting a graph (using matplotlib) to check if the dataset is well balanced or not. After splitting the dataset into train, validation

sets, the images were converted into 4D tensors for further processing. Once I built CNN models, I fed these tensors and evaluated the model's performance using confusion metrics. I watched, over multiple iterations, how does the number of layers in the convolutional network have an significant effect on the performance of the classifier, how does adding dropout layers reduce potential overfitting, This project gave me a good insight on how to deal with future image classification problems and encouraged me to work on further improving my current model.

Improvement

As an improvement and future work, I would like to try data masking on the training set. Noise from the background of the images can be cancelled by masking images. I believe that without the background noise and restricting the visibility to the green leaves, the model can be trained better, and we may notice significant improvement in the performance.

Another implementation that can be tried is data augmentation. As the dataset is highly unbalanced, augmenting data to the under-represented classes might give a good boost to the total number of training images yielding a well-balanced dataset. Training the model on such dataset may give us significant improvement in the performance.

References:

- https://en.wikipedia.org/wiki/HSL_and_HSV
- <https://homepages.inf.ed.ac.uk/rbf/HIPR2/close.htm>
- <https://www.cs.auckland.ac.nz/courses/compsci773s1c/lectures/ImageProcessing-html/topic4.htm>
- <https://machinelearningmastery.com/evaluate-performance-deep-learning-models-keras/>