

Improving Transfer Learning Performance: an Application in the Classification of Remote Sensing Data

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Abstract: The present paper aims to train and analyze Convolutional Neural Networks (CNN or ConvNets) capable of classifying plant species of a certain region for applications in an environmental monitoring system. In order to achieve this for a limited training dataset, the samples were expanded with the use of a data generator algorithm. Next, transfer learning and fine tuning methods were applied with pre-trained networks. With the purpose of choosing the best layers to be transferred, a statistical dispersion method was proposed. Through a distributed training method, the training speed and performance for the CNN in CPUs was improved. After tuning the parameters of interest in the resulting network by the cross-validation method, the learning capacity of the network was verified. The obtained results indicate an accuracy of about 97%, which was acquired transferring the pre-trained first seven convolutional layers of the VGG-16 network to a new sixteen-layer convolutional network in which the final training was performed. This represents an improvement over the state of the art, which had an accuracy of 91% on the same dataset.

1 INTRODUCTION

Vegetation monitoring can be done by farmers to distinguish plants, check planting failures and verify vegetation health and growth. The visual distinction of plants is useful to identify unwanted plants (weed) that deteriorate the health of several species of vegetation (Aitkenhead et al., 2003). Such monitoring can be difficult when the plantation area is large or when it is fenced by plants. A possible solution is the use of a remote sensing monitoring system using images from satellites.

Some satellites use multispectral sensors which provide images of the visible and invisible spectrum. The reflectance of a plant at a certain wavelength depends on the flux of radiation that reaches it and on the flux that is reflected. This second variable is conventionally observed in the intensity levels of a plant image in the invisible spectrum of light, as the near infrared spectrum is reflected by the cell structure of plants with high magnitude, varying between different plants (Horler et al., 1983).

The dataset analyzed in this work was obtained through photo captures taken by the *RapidEye* German satellite system, which provides multispectral

data. The dataset contains images from different areas containing four classes of plants: agriculture, arboreal vegetation, herbaceous vegetation and shrubby vegetation, present in the *Serra do Cipo* region in the central area of southern Brazil (Nogueira et al., 2016). For this task, the green, red and near-infrared bands are appropriate for distinguishing the classes of interest (Nogueira et al., 2016). Each image taken by the satellite contains various plant species, making it necessary to consult specialists for separating and classifying them. Thus, a class distribution of the dataset with 1311 multispectral scenes is obtained.

The recognition of the species patterns was one of the main difficulties discussed by the original authors regarding the interpretation of the images contained in the dataset, given their complex *intra*class variance and *inter*class similarity (Nogueira et al., 2016). These issues make the sample preparation and separation into groups costly and limited. As a consequence, there are complex and unbalanced samples so that classification algorithms such as usual *ANN* (Artificial Neural Networks), *SVM* (Support Vector Machine) and *decision-tree* provide unsatisfactory results for this task. However, literature shows that deep learning approaches (i.e. Convolutional Neural Net-

work - *CNN*) and other methods (i.e. data augmentation, transfer learning and fine tuning), have a much better performance in these cases, because they allow to model and train a classifier, (e.g. distinguishing vegetation) using images as inputs, even with scarcity and complexity of data (Gu et al., 2018). In this paper, we begin by describing CNN deep learning models and the motivation to use transfer learning and fine-tuning methods. Then, the solution strategy for the classification task is presented along with approaches called data augmentation and cross-validation, to deal with few and unbalanced data. We also show in theory and experimentally how hyperparameters for the model, the methods and the approaches described affect the training performance. In order to train the model with different layer topologies, a statistical dispersion method is proposed to evaluate each convolutive layer of the model and help to choose which layers are the best to be transferred to the fine tune model.

To increase considerably the training speed for the CNN in a *CPU*, parallelism operators and a distributed learning method were used, which simulates larger minibatches by dividing the data through *workers*. Our experiments are then compared to baselines and state of the art approaches, indicating superior results.

2 THEORETICAL FRAMEWORK

The convolutional neural network is a type of deep learning architecture that has recently stood out in the image recognition field achieving a very high accuracy (Gu et al., 2018). The inputs of a CNN classifier are given by digital images, in the form of tensors, that are brought to feature extractors. Each extractor performs operations, through filters, in parallel to extract features from the images starting from more generic, low-level features and culminating in higher level features that are more specific to the dataset. A second *Neural Network* is conventionally placed after the last convolutional layer to operate as a classifier.

As the complexity of the images increases, there is a need to change CNN hyperparameters. However, as the number of convolutional layers, the filter size and number of CNN filters are increased, the computational cost increases significantly (He and Sun, 2015). This effect adds difficulties in experimental research involving real applications, such as those re-

Table 1: Original Species Samples.

Species	#Samples	Proportion (%)
AGR	47	3.58
FOR	962	73.37
HRB	191	14.57
SHR	111	8.46
Total	1311	100

quiring rapid scenario changes ^{1,2} being necessary to explore the architecture’s parallelism capacity.

An approach called Transfer Learning (*TL*) may decrease the number of required operations allowing the transfer of learning, acquired in one problem, to another problem with similar characteristics. What makes TL more effective is the possibility of using pre-trained networks such as *VGGNet* (Simonyan et al., 2013), *GoogLeNet* (Szegedy et al., 2015), *ResNet* (He et al., 2016) and *AlexNet* (Krizhevsky et al., 2012), which stood out in the challenges of the *Large Scale Visual Recognition Challenge (ILSVRC - ImageNet)* for object detection and image recognition (Russakovsky et al., 2015).

In models that require more specific classification, as in the scope of this paper, there is a need for Fine-Tuning (*FT*) the model, freezing some layers of the pre-trained networks and constructing convolutional layers on top of them.

3 Solution Strategy

3.1 Preparation of Data and Data Augmentation

The dataset used for the network training ³ was found in the paper by (K. Nogueira et al. 2016) which also uses the artifice of convolutional networks for the classification of four distinct vegetative species, as shown in Fig. 1. The resolution of each image is 64 x 64 pixels.

The dataset has unbalanced and scarce samples making it difficult to develop the classification model. Table 1 shows the distribution of samples between classes.

¹Drive.ai, "Building the Brain of Self-Driving Vehicles", 2018. Available: <https://www.drive.ai/> [January 29, 2018].

²Descartes Labs, "A data refinery, built to understand our planet", 2017. Available: <https://www.descarteslabs.com/> [August 15, 2017]

³The dataset is available for download at <http://www.patreeo.dcc.ufmg.br/2017/11/12/brazilian-cerrado-savanna-scenes-dataset/> [December 6, 2018].

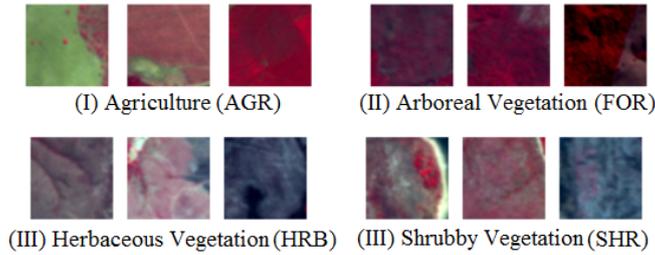


Figure 1: Group of four classes: AGR, FOR, HRB and SHR

Table 2: Balanced classes samples generated using Keras ImageDataGenerator in each new training.

Species	# Training Samples	# Test Samples
AGR	1770	540
FOR	1770	540
HRB	1770	540
SHR	1770	540
Total	7080	2160

Some approaches can be used to train neural networks with unbalanced data avoiding the problem of limited generalization, such as penalizing with higher weights the errors of classification of classes with less samples. Another approach makes it possible to increase the amount of data of each class proportionally, thus balancing the data. In this article, the second approach was chosen to solve the problem of data scarcity. Another advantage of the data increase in a neural network is that it acts as a regularizer, making the model more robust, preventing overfitting (Cireřan et al., 2010) and improving the performance of unbalanced models (Chawla et al., 2002).

Through the *ImageDataGenerator* from the python deep learning library *keras*, it becomes possible to generate new images from the dataset with random transformations applied to an image. We used the following transformations: width and height displacement, shear range, zoom, horizontal rotation, and brightness adjustment. Figure 2 illustrates four examples of random transformations in a single image. Before increasing the data, the original dataset is divided into training and test sets, respectively, 75% and 25% of the samples. The same sets are used in all experiments. Then, in each new training, the original training set is balanced, proportionally to each class, through data augmentation. After each training, the test set is also expanded proportionally. Table 2 illustrates the increase of data using the image generator for the training and test sets.

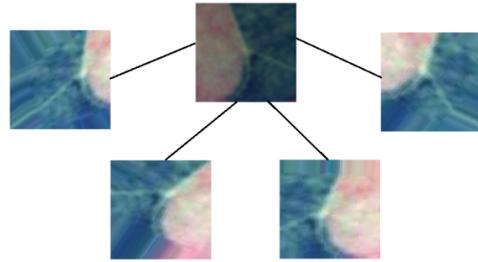


Figure 2: Examples of transformations performed by the Keras ImageDataGenerator in a single image.

3.2 Pre-trained Network and Transfer Learning

The training of many-layered convolutional networks, based on the random initialization of weights, requires a high computational cost due to the amount of parallel operations that feature extractor filters perform. Using pre-trained networks it is possible to minimize this cost initializing pre-trained weights and bias thereby reaching the convergence of the model much earlier. There are several models of pretrained networks such as VGGNet, GoogleNet, ResNet and AlexNet. In this paper, the VGG-16 network was chosen, because it stands out for its uniform and effective architecture for applications involving image classification. The sixteen layers of the VGG-16 network use only 3×3 convolution order and 2×2 order pooling. Convolution is an image filtering process that aims to detect patterns creating feature maps. The pooling process reduces the spatial size of the features discovered by the convolution layers. Fig. 3 shows the architecture of the VGG-16 networks (Gu et al., 2018).

The VGG-16 network is pre-trained using the ImageNet database. This database has about fourteen million high quality natural images with more than a thousand labeled categories, that is, classes with their proper titles.

Transfer learning is a technique that uses pre-

VGG - 16

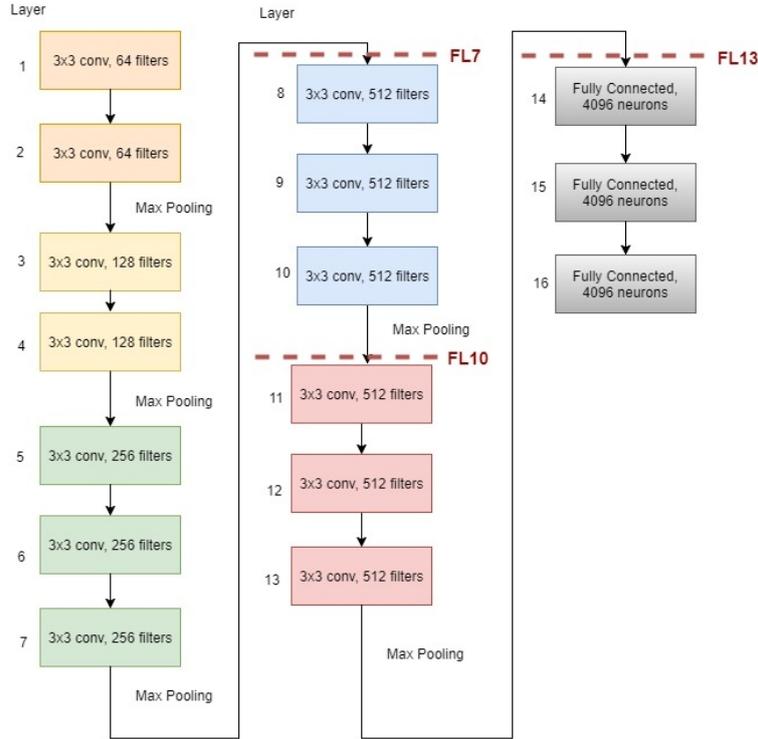


Figure 3: VGG-16 networks architecture. The codes next to the dotted lines indicate the frozen layers in the experiments.

trained networks which take the generic features of images, such as color blobs, edges and corners in the first layers. At each subsequent layer, the characteristics taken from the images become more and more specific with the training datasets which can be obtained, for example, from the imagenet database. After the training step, the classification layers of the pre-trained network (layers 14 to 16) are removed, keeping the previous ones frozen (fixed). The images of the target dataset are executed in this truncated network in order to produce bottleneck features. These features are used to train a new classifier and obtain the prediction of the target dataset classes.

Our target dataset has few samples, besides being very different from the pre-trained network’s dataset, so truncating the last layer of that network may not be enough to obtain a satisfactory accuracy. This is because features taken from the layers closest to the output are not useful for the classification of the model. One solution to this problem is fine tuning which allows the lower Y layers of the transfer-learning network to be frozen extracting characteristics from these layers and after the last layer, new convolution and classification layers can be added. A new training of the resulting network can be performed,

taking into account that the weights and bias of the Y layers are fixed. Freezing more layers results in a network with lower accuracy in exchange for a training that requires less computational complexity, as the training of a network with less convolutional layers demands less complexity to be calculated. In addition to the freezing of layers, the fine tuning method is also related to the tuning of the hyperparameters of the resulting network.

3.3 Cross-Validation

In order to evaluate the learning algorithm and how it responds to the data augmentation, a cross-validation metric is used. The cross validation divides the samples of the increased training set into different training and validation samples by making combinations between them. A specific case of cross-validation is the k -Fold cross-validation method, which divides the samples into k_f subsets at random and without repetition, using all the data in that division. The convolutional neural network model is trained k_f times, where in each training a single subset is selected for the test and $k_f - 1$ subsets for the training. The method is commonly used in Machine Learning applications

with 10 folds ($k_f = 10$) aiming at adjusting the generalization of the algorithm (Refaeilzadeh et al., 2009). In order to obtain a resulting accuracy, the average of the k_f trainings is calculated.

3.4 CNN Layer Statistical Analysis

The output of each CNN layer is a feature map. Interpreting the feature maps in-between the layers may show how well and in which layers the model is learning the specific features of each class. However, they are not trivially interpretable and consequently it is difficult to choose the best layers to be frozen.

Some algorithms for dimensionally reduction (i.e. PCA or t-SNE) can lead us to check whether, in a certain convolutional layer, the features of each class was separated by reducing the dimensionally to two features and drawing a scatter plot (Jolliffe, 2011; Maaten and Hinton, 2008). However, in some cases, it is difficult to verify whether the CNN has been able to separate the features or whether the algorithm has been able to reduce the dimension correctly. Another algorithm that can be used to interpret the features maps in CNNs is called DeepResolve (Liu and Gifford, 2017). It is based on a gradient-ascent method and does not require inputs by calculating a class-specific optimal 'image' H for each class in each layer (Simonyan et al., 2013). This method's output provides helpful information to analyze and decide which layers are important to be frozen.

We propose a simpler statistical analysis of each convolutional layer by calculating the mean of the between-class standard deviation vector, for each layer, which is calculated between the mean feature maps of all classes.

Each three-dimensional feature map matrix is reshaped into a single dimension of vector (feature vector). The standard deviation vector previously mentioned is given by (1):

$$\vec{s}_m = \sqrt{\frac{\sum_{n=1}^N (\vec{C}_{nm} - \vec{C}_m)^2}{N-1}} \quad (1)$$

Where \vec{C}_{nm} is the mean feature vector between all the images from class n in convolutional layer m and \vec{C}_m is the mean vector between the classes in a given layer. Those terms can be calculated by (2):

$$\vec{C}_{nm} = \frac{\sum_{j=1}^{J_n} \vec{F}_{jnm}}{J_n} \quad \vec{C}_m = \frac{\sum_{n=1}^N \vec{C}_{nm}}{N} \quad (2)$$

Where \vec{F}_{jnm} denotes the feature vector from class n in a layer m of image j and J_n is the number of images in a given class n . Replacing the equations (2) in

equation (1), we calculate the vector \vec{s}_m and the scalar mean M_{S_m} (3).

$$M_{S_m} = \bar{\vec{s}}_m \quad (3)$$

The number of classes is four ($N = 4$) and the maximum number of convolutional layers is thirteen ($m = [1, 2, \dots, 13]$). It is expected that the mean of the inter-class standard deviation in each layer (M_{S_m}) increases because higher layers extract more specific features, which should therefore exhibit larger inter-class variance. This variable could tell which is the appropriate convolutional layer that should be frozen and then perform a new training. For example, if the variable decreases considerably in a given layer, this means that the features are getting worse on the new domain (they are too specific to the original domain), and therefore it is not useful to freeze that layer.

3.5 Distributed Training Using Large Minibatches

In order to take advantage of the computational power of a multi-core CPU and increase the training speed effectively, a distributed training method was used. The method proposed by (Goyal et al., 2018) simulates large *minibatches* of size kn by dividing the batches of the dataset through k *workers* not compromising, until a certain point, the model's accuracy. In order to maintain the same behavior as a regular minibatch of size n , the method uses a linear scaling rule which consists in multiplying the *learning rate* (η) by the number of workers (k). An assumption is made for this rule to take effect as shown in equation 4.

$$\nabla l(x, w_{t+j}) \approx \nabla l(x, w_t), \quad \text{where } j < k \quad (4)$$

The first term $\nabla l(x, w_{t+j})$ represents the gradient of the loss function for a sample x and weights w_{t+j} at the training iteration $t + j$. The gradient is used in the minibatch *Stochastic Gradient Descent* (SGD) with a learning rate η and small minibatch of size n (Goyal et al., 2018). For the large minibatch, the loss is only calculated using the second term $\nabla l(x, w_t)$. With the previous assumption and setting a new learning rate ($\hat{\eta}$) proportional to the number workers ($\hat{\eta} = k\eta$), the SGD updates from small and large minibatch is similar (Goyal et al., 2018). As an effect, increasing the batch size should not substantially affect the loss function optimization. As described by the authors, the assumption is not true at the beginning of the training when the weights are changing quickly. To solve this problem a *gradual warmup* is used, starting the training from a base learning rate η and increasing this value constantly until it reaches the learning rate $\hat{\eta}$ proportional to k after 5 *epochs* (Goyal et al., 2018).

Additionally, the learning rate is divided by 10 at the 30th, 60th and 80th epochs, similar to (He et al., 2016).

3.6 Experiments

The experiments performed in this work were carried out on two Intel[®] Xeon[®] Platinum 8160 CPUs with 24 cores each (96 threads in total) and 192GB of RAM that made possible the application of the distributed training and considerably increase the training speed.

The implemented model was simulated in the Keras framework with Intel[®] Tensorflow backend that allows the use of dataflow programming. Also, Intel[®] MKL-DNN that accelerates the Deep Learning framework on Intel[®] processors (allowing the use of Load Balance System Optimization⁴ (LBSO) parameters) and the open source framework Horovod (as a base of the distributed training) were used.

The experiments used transfer learning freezing Y layers, denoted "FL- Y ", and fine tuning. Freezing of the layers below 13 (FL-13), 10 (FL-10) and 7 (FL-7) were performed as depicted in Fig. 3. It is relevant to notice that all the convolutional layers in the FL-13 experiment are frozen which means that fine tuning method has no effect. For all experiments, the softmax function was used in the output layer composed of four neurons, which provides the degree of certainty of an input image in relation to each of the four specified classes. The class that contains the highest value is chosen to represent the input image.

The impacts of variations of the hyperparameters of interest, within predefined ranges of values, on the training time and resulting accuracy of the model were analyzed in all experiments. These analyses considered variations in parameters such as dropout, number of epochs and base learning rate. Also, the number of workers (k) and LBSO parameters such as intra-operation parallelism (maximum number of threads to run an operator) and inter-operation parallelism (maximum number of operators that can be executed in parallel) were evaluated for the model's accuracy. Other parameters such as pooling size and convolution filter size were kept fixed in order to avoid incompatibility with the architecture of the pre-trained networks. For k-fold cross-validation the value of $k_f = 10$ was used, which results in better performance in comparison to lower values of k_f . The SGD optimization algorithm was used for the all the training experiments.

⁴Boosting Deep Learning Training & Inference Performance on Intel[®] Xeon[®] and Intel[®] Xeon Phi[™] Processors, 2018. Available: <https://software.intel.com/en-us/articles/boosting-deep-learning-training-inference-performance-on-xeon-and-xeon-phi> [November 5, 2018]

Table 3: Variation of hyperparameters of Interest (keeping the batch size fixed $n = 32$).

Parameter	Range of Values		
	Min	Max	Optimal*
Dropout	0%	70%	50%
# Epochs	35	650	100
Base LR (η)	10^{-5}	10^{-3}	10^{-5}
# Workers (k)	1	12	5
Intra-op	2	48	19
Inter-op	0	4	2
Simul. Batch Size (kn)	32	384	160
Frozen Layers	7	13	7

*The optimal value is the best estimate found for the parameter of interest

Table 4: Topologies of the FL – 13, FL – 10 and FL – 17 experiments.

		FL-13	FL-10	FL-7
Convolutional	Layers	-	3	6
	Filters	-	128x3	512x6
Classification	Layers	2	1	2
	Neurons	512-256	512	512-256
	Dropout (%)	0-0	0.3	0.5-0

Table 3 presents the range of values in which the hyperparameters of interest were evaluated and the optimal values obtained experimentally.

The three experiments that provided the best results from the hyperparameters adjustments and freezing of the layers below 13 (FL – 13), 10 (FL – 10) and 7 (FL – 7) were selected. As discussed previously, each convolutional layer of the pre-trained network that is not frozen (learning not transferred) must be added in the fine-tuning network. The three best experiments and their topologies are shown in Table 4.

4 Results and Discussions

In order to evaluate the performance of the model with the different analyzed topologies, the three best experiment configurations of each topology were compared. Additionally, the full training experiment was done. Each experiment was performed ten times, calculating the uncertainty of the results and obtaining more precise accuracy values. Table 5 indicates the total simulation time of the training performed, through 10-fold cross-validation, and the resulting accuracy of each experiment. It is important to note that in the original dataset, the proportion of the class with more samples is 73.37%. Considering this observation, it is considered that values of weighted accuracy around 73% are unsatisfactory, because the classifier should be better than chance. To obtain results that are comparable to the original paper, the overall test accuracy of the experiments was also weighted by each class proportion. At each fold of the k-Fold cross-validation method, the model was saved to ob-

Table 5: Results $FL-13$, $FL-10$, $FL-7$ and $FL-0$.

Experiment	Training Time*	Overall Test Accuracy	Overall Test Accuracy (Weighted)
$FL-13$	15 min \rightarrow 4 min	45.1 \pm 1.9 %	79.43 \pm 1.3 %
$FL-10$	50 min \rightarrow 12 min	81.8 \pm 1.4 %	76.7 \pm 1.2 %
$FL-7$	183 min \rightarrow 37 min	97.3 \pm 0.9 %	97.1 \pm 1.0 %
$FL-0$	567 min	55.7 \pm 2.1 %	77.6 \pm 1.6 %

*The values indicates the decrease (\rightarrow) of the training time when using the Intel *MKL-DNN* as opposed to default TensorFlow

tain the class prediction and the normalized confusion matrix on the augmented test set. The diagonal elements of this matrix show the normalized true positive predictions of each class which are then weighted by each class proportion and added. This procedure is repeated k_f times and after that the overall test accuracy was calculated. Table 6 shows the confusion matrices of experiments $FL-13$, $FL-10$ and $FL-7$.

In order to evaluate the training time of the experiment that demands most computational power ($FL-7$) varying some hyperparameters for the distributed learning (*intra-op* and k) and keeping the other optimal values fixed (as show in Table 3), the Table 7 was generated. For all the variations expressed, the model’s loss function presents similar behavior and final values.

It is noted from the results presented in Tables 5 and 6 that the experiment $FL-13$ has high uncertainty, regarding the achieved accuracy values and it is also unreliable because the most predictions were just in a single class. As noted earlier, the pre-trained network learned from different datasets that are distinct when compared to the dataset employed in this paper. Consequently, only the lower-level features are useful for classifying the specific vegetative species of interest accurately.

Increasing the number of *workers* and *intra-op*, as shown in Table 7, decreases the training time considerably, but at certain point ($k > 8$) the model’s performance decreases. Also, a proportionally low value for *intra-op* in relation to k increases the training time and, as a limitation, the multiplication of ($k \cdot Intra-op$) should be less than or equal to the number of total threads ($k \cdot Intra-op \leq 96$). The best trade-off between performance and training time was obtained when balancing *intra-op* and k values as shown in the highlighted column in Table 7.

As discussed and described previously, it is also possible to use a statistical method to find the most suitable layer to be frozen and train the deep learning model. Figure 4 shows a chart that contains the mean of the inter-class standard deviation in each layer (M_{S_m}) for each experiment.

Looking at the lightest bars, it can be seen that

after the 9th convolutional layer the M_{S_m} value remains low, which confirms that the model can’t find useful features that distinguish the classes. So, we may choose to freeze all layers that are part of the 9th layers max-pooling block and below, leading to the $FL-10$ model.

Alternatively, observing that M_{S_m} has a maximum at the 6th layer, it is logical to freeze until there. Again, fixing the boundary to the max pooling block leads to the $FL-7$ model.

The $FL-10$ and $FL-7$ experiments provided superior results compared to the $FL-13$ experiment that does not use fine tuning. The expressive gain of accuracy of the $FL-7$ and reliability (the true class prediction is more distributed through the classes) of the experiment $FL-10$ are due to the ability of the convolutional networks, added in these experiments, to learn the more specific features of the dataset used, which was expected for these configurations. In relation to the training time, it can be seen that it tripled with the addition of three convolution layers ($FL-13$ experiment to $FL-10$) and tripled again by doubling the convolution layers ($FL-10$ to $FL-7$). This proves the expectation of computational complexity attributed to training a network with more convolutional layers.

The superior results can also be observed when looking at the mean interclass standard deviations in Figure 4. Both $FL-10$ (dark grey bars) and $FL-7$ (black bars) show higher deviations for the deeper layers, but only $FL-7$ maintains the upward trend of separability.

It is important to note that, for the target dataset, freezing less and less layers results in better results, but in addition to the computational cost, the chances of obtaining poor results are even greater with data augmentation. This is due to, with this decrease, the architecture is increasingly approaching the full training model (i.e., starting from scratch) having a much larger number of parameters to be trained and possibly overfitting the model during the training (Gu et al., 2018). In order to confirm this statement, the experiment $FL-0$ (training from scratch) was made and the results are shown in table 5. For this experiment, in the training phase, the model’s training and validation accuracies presented very high values, but in the testing phase the overall test accuracy value was very low, which indicates an overfitting of the data.

The baseline accuracies for this dataset prediction proposed by the original authors were less than 82.5%, using different techniques as BIC (Stehling et al., 2002), CCV (Pass et al., 1997), GCH (Swain and Ballard, 1991) and UNSER (Unser, 1986) as seen in Table 8.

Table 6: Normalized confusion matrix *FL-13*, *FL-10* and *FL-7* experiments. The columns indicate the predict class for the test set.

	AGR	FOR	HRB	SHR	AGR	FOR	HRB	SHR	AGR	FOR	HRB	SHR
AGR	0.3	0.26	0.26	0.19	0.85	0.04	0.09	0.02	0.99	0.01	0.00	0.00
FOR	0.01	0.99	0.00	0.00	0.03	0.73	0.05	0.18	0.00	0.97	0.01	0.02
HRB	0.26	0.21	0.23	0.30	0.01	0.00	0.94	0.05	0.00	0.01	0.99	0.01
SHR	0.20	0.29	0.23	0.28	0.01	0.00	0.24	0.75	0.00	0.01	0.03	0.96

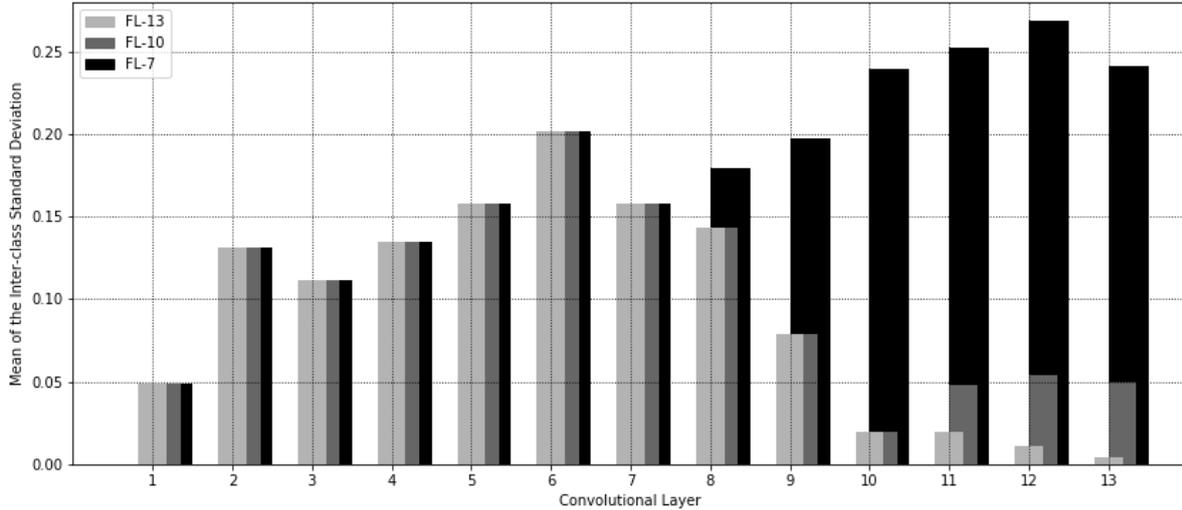


Figure 4: Mean of the inter-class standard deviation (M_{S_m}) in each convolutional layer for the *FL-(13,10 and 7)* experiments.

Table 7: Training time comparison when varying some hyperparameters using Intel MKL-DNN.

Hyperparameter	Values			
# <i>Intra-op</i>	20	48	19	12
# <i>workers</i> (<i>k</i>)	1	2	5	8
Simul. Batch Size (<i>kn</i>)	32	64	160	384
Training Time (min)	1598	903	37	69

Table 8: Comparison to baselines and deep learning models for the test set.

Technique	Weighted Accuracy	Technique	Weighted Accuracy
CCV	80.6 ± 2.3%	BIC	85.5 ± 1.4%
GCH	80.1 ± 2.4%	Fine Tuning (original paper)	90.54 ± 1.8%
UNSER	80.3 ± 0.2%	Fine Tuning (<i>FL-7</i>)	97.1 ± 1.1%

The best accuracy obtained by the authors of the article used as inspiration was $90.5 \pm 1.8\%$. In the mentioned paper, the AlexNet pre-trained network architecture with fine tuning and layer freezing was used, but without data augmentation (Nogueira et al., 2016). The architecture of the AlexNet network is different from the one used in the present article having a smaller number of parameters and greater complexity of operations. The results obtained with VGG-16 and the auxiliary methods specified above have shown to be promising (accuracy about 97%) in relation to those with differentiated architecture. The possible differences in results are related to the use of data aug-

mentation and the VGG-16 network in having fixed parameters such as pooling size and convolution filter size. In this way, with the change of the other hyperparameters, the impacts of these variations are more effectively realized, resulting in a satisfactory fine-tuning.

5 Conclusions and Future Work

This paper used methods that have helped convolutional networks to learn more effectively the specific characteristics of vegetative species groups. The data augmentation method was essential in achieving effective accuracy by balancing the data to prevent overfitting, while transfer learning accelerated the training process of the network, smartly, by skipping training steps. The fine-tuning approach enabled to truncate any layers of the transfer-learning network and the insertion of convolutional layers, to distinguish the classes with higher accuracy. The statistical analysis proposed helps to choose which layers should be frozen avoiding unnecessary extra experimental tests for the correct choice.

The distributed learning (training the model by dividing the dataset between workers) and the tuning of

the parallel operators (LSBO parameters) have shown the possibilities to train a convolutional network in a CPU with high training speed. It is relevant to notice that the maximum number of workers that resulted in good performance is limited, perhaps due to the small dataset.

The final result which indicates an accuracy of about 97% is relevant for applications involving remote sensing for the classification of vegetation species whose images are derived from satellites.

The classification model implemented may not work well if the camera is not multispectral, being an essential equipment for the plant classification task. Also, for satisfactory training and inference results, the dataset must be divided into small tiles to reduce the number of classes present in each image.

The theoretical and experimental study of solutions for implementing a classifier using unbalanced data have great importance for future work, since most environmental monitoring applications rely on disproportionate class data. It is intended to apply the concepts and experiences learned in new datasets with more classes and more data. Also, for future work, pixel-wise semantic segmentation deep learning models (Badrinarayanan et al., 2015; Chen et al., 2018; Ronneberger et al., 2015) may be used to classify the plants species which makes it possible to classify whole images containing multiple classes at the same time and without being necessary to crop them into small tiles.

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