

Classification of Fungi Species: A Deep Learning Based Image Feature Extraction and Gradient Boosting Ensemble Approach

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Abstract

Deep learning has been successful in a variety of challenging image classification tasks, characterized by complex and large datasets. Ensemble learning further improves model performance by inferring compound decision boundaries in the feature space, and assorting importance to the most representative features to effectively discriminate between image classes. This paper details a deep learning based feature extraction and subsequent boosting ensemble approach for fungi species classification. The proposed workflow leverages state-of-the-art deep learning architectures such as ResNeXt and EfficientNet among others, trains them by transfer learning onto a fungi image dataset for feature extraction, and finally integrates the output representation vectors with geographic metadata to train a gradient boosting ensemble classifier that predicts the fungi species. The authors trained multiple deep learning architectures, assessed their individual performance and selected effective feature extraction models. Multiple experiments were performed in choosing these models, and to subsequently perform hyperparameter tuning to train the boosting classifier.

Keywords

Ensemble Learning, Convolutional Neural Networks, Gradient Boosting Ensemble, Metadata-aided Classification, Image Classification, Transfer Learning

1. Introduction

This paper presents the participation of SSN College of Engineering for the (CLEF) FungiCLEEF 2022 challenge for fungi species identification held jointly by LifeCLEF 2022 lab of the CLEF 2022 conference and the FGVC9 workshop organized in conjunction with CVPR 2022 conference.

The infection rate of Fungi based diseases such as Mucormycosis in India was recorded to be at 45,374 and a mortality rate of over 4300. Fungi are also essential to the survival of many organisms and sustaining the food cycle as they attract attention as predators of invertebrate animals, act as catalysts and so on. Manual identification of such species is no easy task as it involves running-through almost 5.1 million species.

The aim of the FungiCLEF challenge is to assist citizens, scientists and nature enthusiasts by automatic recognition of fungi species based on non-standardized photographs, habitat,

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substrate and location information which are available as a part of the meta-data.

2. Related work

The usage of Convolutional Neural Networks in the classification and identification of fungi species is a concept that has been floating around for quite a while. The integration of computer vision and machine learning with the development of more efficient algorithms will undoubtedly be a hotspot for future studies in the context of the mushroom industry [1].

A study in 2021 in the Turkish Journal of Computer and Mathematics Education [2] used a CNN to classify various species of fungi, specifically on fungi affected apple leaf diseases. They obtained an accuracy of 88.9% in the classification of fungi.

In another study, pre-trained deep learning models were employed in classifying 9 kinds of *Aspergillus*. The methodology comprised of preprocessing, deep-learning and performance evaluation. This study achieved a 93.3333% testing accuracy proving that the transferred knowledge is accurate, compatible and reliable [3].

A submission to the Danish Fungi 2020 showed that experiments using Convolutional Neural Networks and the recent Vision Transformers showed that ViT achieves results superior to CNN baselines with 80.45% accuracy and 0.743 macro F1 score, reducing the CNN error by 9% and 12% respectively. By incorporating metadata into the decision tree process, the error rate came down significantly by 15% [4].

In a study to evaluate rapeseed samples obtained in the process of storage experiments with different humidity and temperature conditions, the classification was carried out based on the different levels of contamination with filamentous fungi. The classifiers that were compared were devised on the basis of the environments Tensorflow (deep learning) and Statistica (machine learning). The lowest classification error of 14% for the test set, 18% classification error for Multi-Layer Perceptron Networks (MLPN), and 21% classification error for Radial Basis Function Networks (RBFN), in the process of recognizing mold in rapeseed with the use of CNN [5]

Another paper focused on developing a method for classification of mushroom using its texture feature, which is based on the machine learning approach. The performance published was 76.6% by using SVM classifier, which was found better with respect to the other classifiers like KNN, Logistic Regression, Linear Discriminant, Decision Tree, and Ensemble classifiers. [6]

3. Methods

Convolutional Neural Networks are a deep learning algorithm that use 3 major types of layers namely Convolutional layer, Pooling layer, and a Fully connected layer. In our approach to this problem we have used different convolutional neural network based approaches like ResNet101, ResNet50 and EfficientNetb0. The workflow was implemented using Python v3.9.0 and primarily uses Tensorflow V2.4.0

3.1. Dataset

The training dataset of the FungiCLEF 2022 challenge consists of 295938 training images spread over 99% fungi and 1% protozoa belonging to 1604 species observed mostly around Denmark. This challenge being a new entrant into the foray of LifeCLEF challenges unfortunately cannot be compared to previous year datasets. The dataset includes 30 different country codes 5 localities with just over 1% distribution among Store Hareskov and Hegedal and the remaining 98% over the other localities. All the methods used involve Convolutional Neural Networks. The models used are Resnet101 and Effecientnetb0.

3.2. Image Preprocessing

The photos were first placed into an Input sequencer, where the outlier images were found. The images were analysed and it was discovered that they were of varying sizes and scales. As a result, image augmentation was used to convert all of the photographs to RGB and scale them to a standard size of 800 by 600 pixels (224,224,3) dimensions [7].

The images were linearly normalised to values between 0 and 1 to reduce the effect of irrelevant characteristics in the context of the needed task, such as variance in lighting conditions among the shots. To make the model more general, immune to the impact of positional and orientation-based bias, and prevent memory by improving image diversity, transformations such as scale and rotation, as well as contrast and saturation variations, were induced on the model inputs. The aforementioned modifications were utilized to augment the input photos with RandAugment[8]. RandAugment has two parameters: the number of augmentation transformations to apply in order (N) and the magnitude of all modifications (M). N=3 and M=4 were chosen as the values[8] for the ResNet model by experimentation.

3.3. Feature Extraction

Feature extraction is a method prescribed to transform raw data into numerical features. It is preferred as applying machine learning algorithms directly on the raw data yields poorer results. High data rate and information redundancy can be cut down using feature extraction. Since the task this time involved a large data set of over 110GB of training images along with geographic metadata the data rate is very high. Thus redundant features are an obvious by-product. Feature extraction thus helped extract only the unique features that describe the images such as shapes and edges.

3.4. Deep Learning Models Considered

The feature extraction moedels for fungi image was selected after experimenting with multiple deep-learning architectures.

ResNet101 [9] is a well-known convolutional neural network model that was introduced in 2015. This model addresses the degradation problem, which asserts that as network depth grows, accuracy becomes saturated and subsequently rapidly declines. ResNet solves the degradation problem by using shortcut connections that bypass one or more layers, which was inspired by

the Highway network [10], which employed gated shortcut connections to manage the flow of information in the shortcut. Figure 1 presents the ResNet101 network architecture.

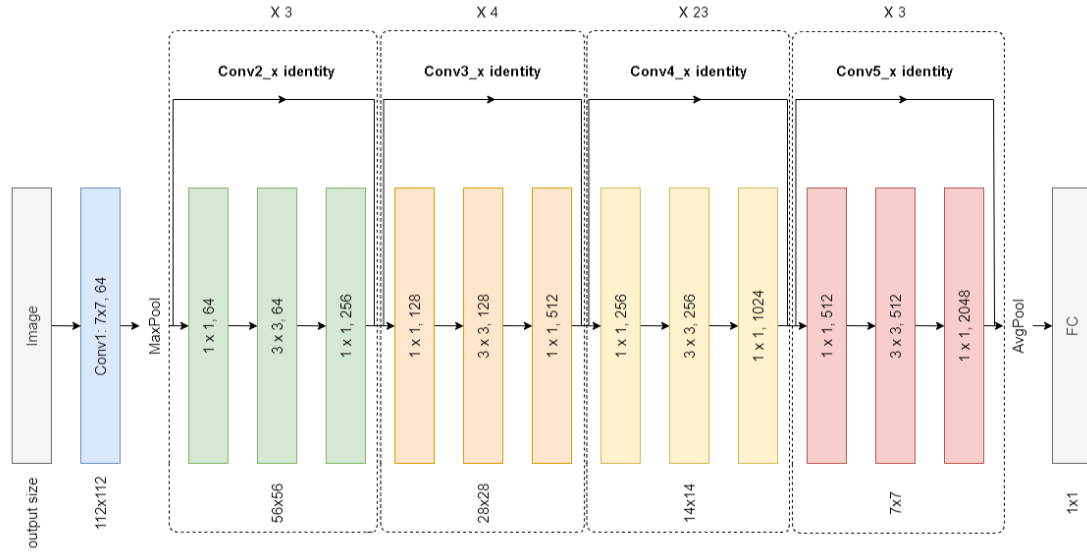


Figure 1: Network architecture of the ResNet101 convolutional neural network used for feature extraction

EfficientNetB0 [11] is a convolutional neural network model with 237 layers that was built in 2019. It's a small-scale architecture with about 11 million trainable parameters. It was created with the help of a multi-objective neural network that prioritized precision and floating point operations. It supports compound scaling while maintaining network balance across all dimensions. It employs an inverted bottleneck, as well as a depth-wise convolutional network that includes squeeze and excitation operations. It employs MBConv blocks [12] that serve as Inverted Linear BottleNeck layers. These layers use Depth-Wise Separable Convolution operations. The network architecture of EfficientNetB0 is depicted in Figure 2.

Another popular convolutional neural network model, ResNeXt101 [13], is very similar to the ResNet101 model. ResNet101 features a lot of sequential layers, while ResNeXt101 contains a lot of parallel stacking layers. Like the Inception module [14, 15], it uses a split-transform-merge technique. ResNeXt shares hyper-parameters for all the blocks, unlike the Inception module which has different filters and sizes for each block.

3.5. Gradient Boosting Ensemble Classifier

Ensemble methods are techniques used to counter the high variance produced from a single neural network by adding an inherent bias which is obtained from multiple models. They tend to give higher accuracy's than their resident models. Boosting is an ensemble technique which sequentially adds the new models to the existing features to correct the errors.

In our method, an ensemble of the models trained off the aforementioned architectures were conjoined with metadata features — country, three-level-precise location information, substrate

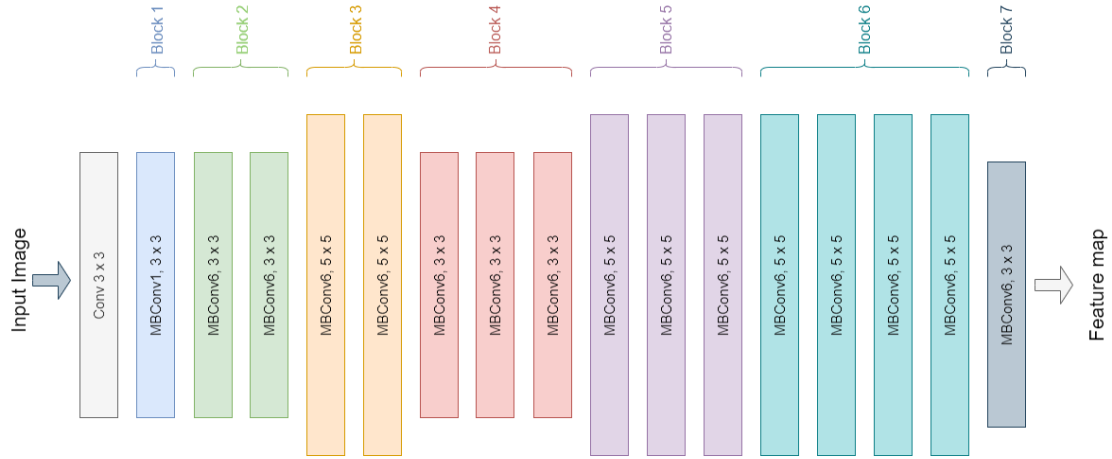


Figure 2: Network architecture of the EfficientNetB0 convolutional neural network used for feature extraction. The MBConv block represents Inverted BottleNeck layers made up of Depth-Wise Separable Convolution operations as described in [12]

and habitat. These metadata features along with the 4096 features extracted from each of the two models, was concatenated and fed to a gradient boosting classifier.

The team used the XGBoost library package [16] for implementing the boosting classifier. XGBoost is a high-speed and high-performance implementation of gradient boosted decision trees. XGBoost’s superior execution speed was factored-in while choosing from all the available implementation libraries.

4. Experiments

Transfer learning from the weights obtained during training with the ImageNet data set [17], and fine-tuning on the FungiCLEF-2022 training data were used to train the model. The prediction accuracy of the models was tracked throughout training in order to select the collection of feature extractors to employ for ensembling later. ResNeXt101 and EfficientNetB0 were chosen as feature extractors for ensembling based on observed network performance. The ensembling was performed using the XGBoost gradient boosting library package.

The forward propagation is described during training and prediction. Each observation is made up of numerous fungus photos, as well as contextual geographic information like nation and exact area where the photograph was taken on four layers, as well as specific attributes like substrate and habitat. Each image in an observation is preprocessed before being fed through the two feature extraction networks to generate two 4096-element-long representation vectors. These vectors are combined with numeric encoded nation, location at three-level precision, substrate, and habitat metadata for the image to produce a final vector with a size of 8198. The boosting ensemble classifier is fed these 8198 features to generate a probability distribution over all potential fungi species classes. This workflow is depicted in Figure 3.

To obtain a single aggregate distribution of probabilities over all classes, the corresponding

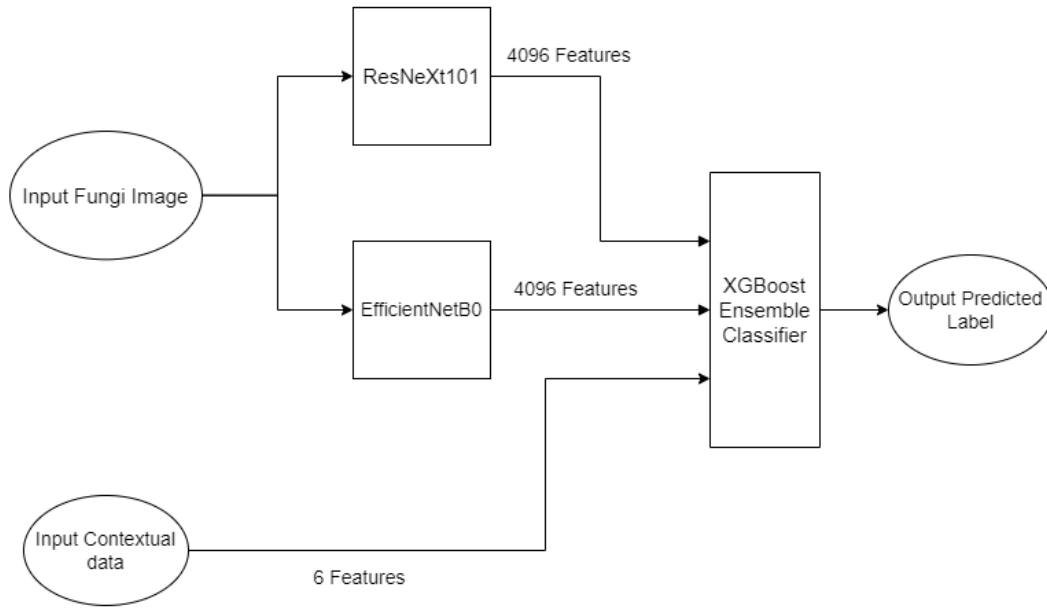


Figure 3: Prediction workflow used in the proposed work for the classification of fungi species from their images and matadata

class probability values collected for each image in an observation are averaged. As a result, each observation has only one unique probability distribution. The classification label is assigned to the class that has the highest aggregate probability value.

The subsequent sections describe the model training experiments and parameters.

4.1. Model Training

The details of the model training process, performed through transfer-learning is presented in this section. A summary of the parameters used for model training is tabulated in Table 1.

Table 1

Model training parameters used to train each of the convolutional neural networks used for this classification task

Parameter	ResNet101	EfficientNetB0	ResNeXt101
Optimizer	Adam	Adam	Adam
Learning rate	0.00003	0.003	0.003
Batch Size	32	32	32
Epochs	45	50	25

4.1.1. ResNet101

The feature extraction layers of ResNet101 were trained with a two-step classification block, comprising two dense blocks with 4096 and 1604 neurons respectively. The extracted features were percolated through a flatten layer to obtain, before feeding to the classification block. In addition, a dropout layer was added after the dense layer to avoid overfitting. Dropout rates between 0.3 and 0.7 were experimented and set to 0.55 in the final version of the model. The model was trained with the Adam optimizer at an initial learning rate of 0.00003. It was backpropagated using the Categorical Cross-Entropy (CCE) loss. For feature extraction, the output of the first dense layer was used to produce a feature vector of 4096 elements. During training, the model's prediction accuracy was tracked to later choose the feature extractor to use for ensembling.

4.1.2. EfficientNetB0

EfficientNetB0 was also trained with a two-step classification block, comprising two dense blocks with 4096 and 1604 neurons respectively. The extracted features were percolated through a flatten layer to obtain, before feeding to the classification block. The dropout layer added after the dense layer for this network was experimented between 0.3 and 0.7 and fixed at 0.3. The model was trained with the Adam optimizer at an initial learning rate of 0.03. It was backpropagated using the Categorical Cross-Entropy (CCE) loss. For feature extraction, the output of the first dense layer was used to produce a feature vector of 4096 elements.

4.1.3. ResNeXt101

The ResNeXt101 architecture was augmented, following the same strategy as the aforementioned two i.e. by adding a two-step classification block of 4096 and 1604 neurons respectively. Here, the dropout after experimenting, was set at 0.6 — a significantly high rate due to excessive early-onset overfitting. Adam optimizer along with CCE loss was used for training, with an initial learning rate of 0.003.

4.2. Loss, Metrics, Activation and Optimizer Used

The loss functions, activation functions, optimizer, and evaluation metrics used in the model training experiments are listed under this section, along with their parameterizations and equations.

4.2.1. Adam Optimizer

Adam is a stochastic optimization method which is used on gradient descent and maintains a single learning rate (α) throughout training. Adam combines the advantages of the Adaptive Gradient Algorithm and Root Mean Square Propagation. Unlike the Root Mean Square Propagation in which the first moment about the mean is used Adam uses the average of the second moments about the mean too.

4.2.2. Categorical Cross Entropy Loss

The categorical cross entropy is a measure of the difference between two discrete probability distributions. It is calculated using the formula

$$Loss = - \sum_{i=1}^n y_i \log t_i,$$

where, y_i represents the corresponding target value for t_i the scalar model output.

4.2.3. Softmax Activation

The softmax activation function is used along with this as the output of the model needs to be positive for ensuring every output value exists. In this situation softmax re-scales the model output to inherit the right properties. The Softmax activation function returns the probability of each class based on the equation below.

$$softmax(z_i) = \frac{exp(z_i)}{\sum_j exp(z_j)}$$

where, z represents the values from the neurons of the output layer. The exponential acts as the non-linear function. These values are divided by the sum of exponential values to normalize and convert them into probabilities.

4.2.4. F1-Score Metric

The F1-Score is usually calculated as the harmonic mean of precision and recall. Concretely,

$$F_1 = \frac{2p_s r_s}{p_s + r_s},$$

$$p_s = \frac{T_p}{T_p + F_p}$$

$$r_s = \frac{T_p}{T_p + F_n}$$

where, F_1 represents the F1-score, p_s represents precision, r_s represents recall, T_p represents true-positive, F_p represents false-positive and F_n represents false-negative.

4.2.5. Accuracy Metric

The accuracy score (Acc) is computed as the ratio of correct predictions to the total number samples. Concretely,

$$Acc = \frac{T_p + T_n}{T_p + T_n + F_p + F_n}$$

where, Acc represents the accuracy score, T_p represents true-positive, T_n represents true-negative, F_p represents false-positive and F_n represents false-negative.

4.3. XGBoost Ensemble Classifier

Ensembling was done with the XGBoost classifier. A grid-search strategy⁶ was adopted and hyperparameters were fine-tuned [18] for optimal performance when training the XGBoost classifier. The tree's maximum depth was set to 32. The model would become more sophisticated and prone to overfitting if this parameter was increased. Because increasing this value will consume too much memory during training the deep tree, a low value of 16 was chosen.

Learning rates greater than 0.03 were found to cause rapid divergence, therefore values in the $10e - 3$ to $10e - 5$ range were utilized. Grid-search was carried out by altering the learning rates in this range and using decision trees ranging from 100 to 1000. To fine-tune the tree-level parameters, the combinations with the best accuracy scores were chosen.

The maximum depth of the tree is left to be selected according on the classifier's training progress and is not fixed in stone. This causes the depth to increase until the leaves are pure (i.e., all samples belong to the same class) or the minimum number of samples required to divide further has been reached. Some classes may require deeper branches to gather more information from the features due to the data set's long-tailed distribution. To prevent overfitting, a grid search over values in the range of 32 to 256 was used to set an upper limit on the number of leaves.

The learning task and accompanying learning target are then specified using objective parameters. The Softmax objective function was chosen to set up the classifier for multiclass classification, and the number of classes was set at 1604, explicitly.

5. Results and Conclusion

The metadata provided with the metadata — namely country, location at three-levels of precision, substrate, and habitat metadata — were employed as a categorical features for the gradient boosting classifier. The inclusion of contextual information showed a strong impact on the classification results — the testing F1-score of the best submission improved from 15.71% to 16.28%. Likewise, the cross-validation accuracy and F1-score for the same model improved from 61.72% and 41.95% to 63.88% and 42.74%, upon inclusion of the geographic data.

Figure 4 represents the relative importance of the 16 most effective image features extracted using the trained neural networks, along with the six metadata features used to train the ensemble classifier. The feature importance values were normalized and scaled between 0 and 100 to realize the relative impacts. Features named as f1, f2, etc. denote features extracted from the neural networks. It is worth mentioning that f0 through f4095 denote features extracted using EfficientNetB0, while f4096 through f8191 represent the ResNeXt101-extracted features. It is evident that the country, level-0 location, and habitat information have a significant influence on classification. Further, the more specific location information — level-1 and level-2 — have not contributed as much to the classification. The substrate metadata also serves a significant impact.

The ensemble classifier's performance was improved over several runs, by tuning the hyperparameters of the gradient boosting classifier. The contest prescribed F1-scores macro-averaged across all classes as the evaluation metric. Model runs were evaluated on the given stratum of validation set using this metric, and the models of top-5 runs were used to submit results to the

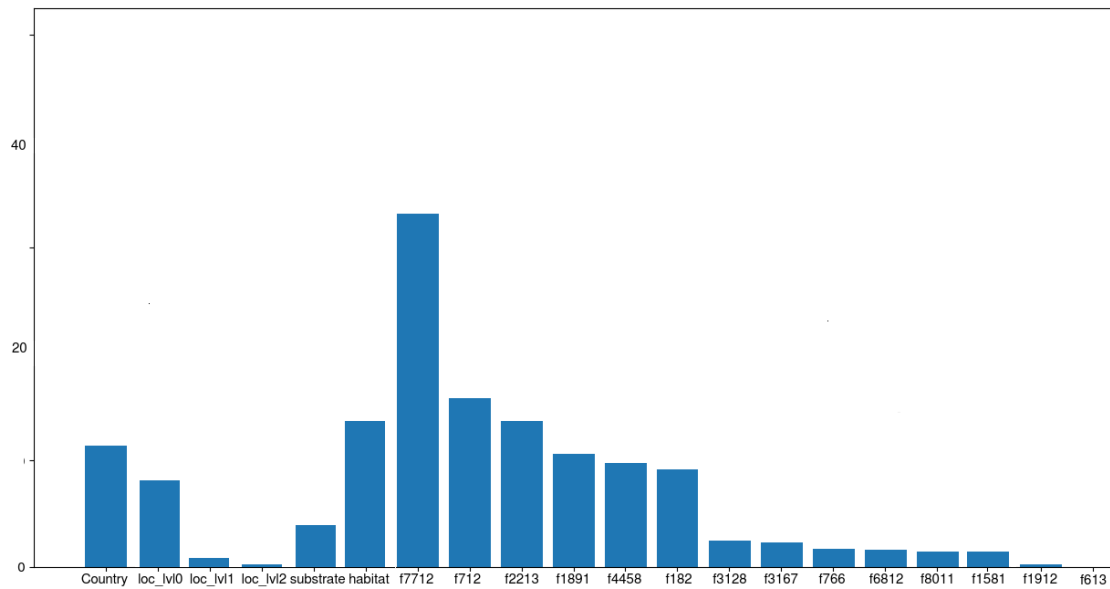


Figure 4: Relative importance on a scale of 0-100 of the 14 most impactful features extracted from the deep-learning models, along with the six metadata features used to train the classifier

competition. The metrics were evaluated as an average over the five iterations (for 5-fold cross validation) performed in each run during training. Our team achieved a training accuracy of 67.12%, validation accuracy of 63.88%. The corresponding model secured an F1-score of 16.28% on the competition’s test data. Our team placed 31st among 40 participating teams. A complete summary of the model performance is listed in Table 2 below:

Table 2

Performance metrics of the 5 best submissions, ordered best to worst

Submission	Training Accuracy	Validation Accuracy	Validation F1-Score	Test F1-Score
1	67.12	63.88	42.74	16.28
2	63.76	60.79	38.88	16.23
3	60.11	58.21	38.42	15.64
4	60.14	57.13	37.21	14.17
5	53.42	49.22	30.97	12.35

Based on the results, it is apparent that the inclusion of contextual geographic data for fungi species classification has has a contributing effect. Furthermore, the ensembling of features extracted using multiple neural architectures, and adopting transfer learning to adapt the pretrained models to the specific data domain, looks promising. Several existing approaches have introduced metadata such as population counts of various species, more location-specific geographic data such as city, state, etc, as well as climatic features like temperature and humidity.

An interesting approach is to employ class-wise probability priors to the neural networks based on such metadata [19].

On account of insufficient computing resources to complete all model training experiments in time for the large dataset of fungi images, the run submissions had to be generated before complete model convergence. Significant improvements were observed in classification accuracy after the submission deadline in the validation, as well as testing performance (through the late submission option). Submission number 3 (refer to Table 2), in particular, showed good improvements when the boosting classifier was trained further with the same hyperparameter settings. Hence, the team believes and suggests that the ensembling approach is an effective option for applying to data-intensive and high-complexity image classification tasks that are commonly released as a LifeCLEF task. Further, approaches involving input image resolution variations, usage of alternative pre-trained weights [20], as well as the inclusion of custom training layers to the frozen base model when transfer learning [21] can greatly improve the quality of feature extraction. Finally, the application of image preprocessing techniques can be of significance in improving the overall model performance, particularly that of the neural networks used for feature extraction [22].

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