**Development, fails and teamwork organization**

We decided to follow an incremental approach: start with simple models, increase their complexity to reach overfitting and then apply regularization techniques to improve the validation accuracy. Starting from handcrafted networks, we tried to maximize the training accuracy in order to understand the generalization capabilities of our simple networks. The best result we achieved was around 84-85% validation accuracy over the local split, reaching overfitting of the training set. This seemed to be an upper bound for every network we tried.

After many trials, we decided to move to transfer learning. The first supernets we tried were InceptionV3 and Xception. Surprisingly, we were getting the same result of our best handcrafted model. It was clear there were some problems: after some attempts we realized that we were using the default ADAM learning rate which eventually worked well for the handcrafted model (since its weights were randomly initialized through initializers) but not for the supernets, whose weights only needed to be fine-tuned with a lower learning rate.

Moreover, all the trainings were performed over an offline augmented training set of approximately 12k images. It became obvious that our networks were not able to reach good generalization also because the augmented images were exactly the same at each new epoch. So, once we moved to transfer learning with online augmentation, we finally got, with good consistency, 88-90% validation accuracy. From that moment on, our strategy consisted in separately building models using different supernets and augmentation techniques. The development of each model consisted in the following steps:

1. Fine-tune the entire supernet using a Global Average Pooling layer connected to the softmax dense layer
2. Train a final classifier network that includes the supernet trained at the previous step and append some dense layers. To do so, we loaded the supernet weights trained at step 1 and freezed all its layers.

Using this approach, we understood that the supernets are very good in generalization, reaching 89-91% validation accuracy even without any dense layer. Hence, the extracted features were very good. Training the final classifier model using our pre-trained supernet allowed us in most the cases to get an extra 2-3% over the validation data.

Once we got a satisfying amount of good performing models (tested on the test set during the first phase of the challenge), we decided to go for an ensemble method to improve the generalization capabilities of our models. To get the maximum performance out of the ensemble, we decided to include in it models with an almost balanced mix of supernets of the same type (to avoid giving too much “voting” power to a specific architecture). The final ensemble includes 2 Xception, 2 EfficientNetB2 and 1 InceptionResNetV2 models and the prediction is performed by maximizing the sum of the class probabilities.

We are strongly convinced that this approach helped us in improving the test accuracy for the following reasons:

* different supernets learn different patterns
* training models with different augmentation strategies helps in capturing the most of the variance
* we independently trained models using different train-validation splits, similarly to what happens in bootstrapping in the Bagging technique

**Model selection**

For our models we decided not to use cross-validation for model selection. This choice as been made because training would have taken too much time. To overcome this, we used our test accuracy of the “development phase” of the challenge to select our best performing models.

**Kaggle**

We mainly used Kaggle for the most computationally intensive tests. We improved the execution speed by using mixed precision (floats with 16 bits) and Nvidia SLI parallel execution on two GPUs (2x Tesla T4 provided by the cloud server). The parallel execution showed faster execution because the batch size is split between the two GPUs, which eventually unify the calculations and apply gradient descent to compute the new weights. For our models, 32-64 x 2 turned out to be a good choice for the batch size. Higher values for batch size seemed to cause higher overfitting in our tests. Mixed precision calculations are theoretically useful for limiting the overfitting and work as a regularization mechanism for the floating-point computations.

**Image pre-processing**

The images are pre-processed according to the function needed by the specific supernet. We also tried applying standardization to the images with respect to the mean and standard deviation of the *offline* and *non augmented* training set, learnt by fitting the image data generators (both training and validation) to the training split only. It didn’t show any improvements with respect to the non-standardized inputs, and this was part of the reason we didn’t eventually stick to the images standardization. We suspect this being caused by the fact that the online augmentation changes the mean and standard deviation of the online generated training samples, thus offline computed parameters are no longer representative of the new distribution. Other types of pre-processing we tried are adjusting saturation and contrast. This has been performed by defining a custom pre-process input function (to be passed to the image data generators) that slightly altered those two properties, in addition to the specific supernet pre-processing function. The initial models we uploaded exploited this technique with good results, by applying the same pre-process at test time. Later, we dropped this approach since we discovered that caused several CPU bottlenecks during the training. One solution, which we decided not to implement, could have been inserting some pre-processing layer inside the network architecture.

Another technique that turned out be very useful has been the resizing of the images implemented using a resizing layer. Most of our models showed improved performances whenever a resizing in the rage 192-299 (preserving the original aspect ratio) with bicubic interpolation was applied.

**Augmentation and minority classes handling**

To visualize the effects of augmentation we created an additional notebook which allowed us to plot some examples of the augmented images. In this way we were able to understand which were plausible intervals for the parameters of the augmentation. To enhance our independent training framework, we tried to diversify these parameters for the models included in the ensemble to reach a greater generalization capability.

Chart, bar chart

Description automatically generatedChart, bar chart

Description automatically generatedFor what concerns the imbalanced dataset we tried different approaches: for all models we used scikit-learn class-weights during the training phase to increase the importance of samples from the underrepresented classes; additionally, for some models, we also chose to oversample the minority classes in such a way that, in the end, all the classes had the same number of samples. Note that the 80-20% train split has been performed prior to this step, as we wanted the validation to be a real representation of the original dataset distribution. For the same reason, we decided to build the validation split in a stratified way. The oversampling strategy has been implemented by duplicating, without augmentation, the images from each class (trying to replicate each sample from a specific class the same number of times). The augmentation is finally computed online from the training generator, which loads the images from the rebalanced training split folder.

Figure 2: balanced training split

Figure 2: original imbalanced training split

**Regularization methods**

We used many regularization methods, including dropout layers (and its variation gaussian dropout), L2 regularization in the loss function, global average and max pooling layers. The most convenient and practical methods that we employed in all our tests are the dropout layer and the global average pooling one, which showed significant improvements in the validation accuracy, while preventing too much overfitting. The gaussian alternative of the dropout layer is known to provide more regularization than a standard dropout layer, so its rate parameter was tuned in a few attempts in order not to reduce the training accuracy too much. L2 regularization did not improved the learning using the default lambda parameter. However, it seemed to reduce the overfitting using a lambda in the range (0.001;0.01). This was also true for the dropout, which appeared to be beneficial with a uniform rate among the layers in the range of (0.45;0.55). For all our models we decided to use a GAP instead of flattening layers which helped in reducing drastically the number of parameters, allowing faster trainings and better generalization capabilities.

**Supernets**

We tried multiple convolutional neural networks pre-trained on the Imagenet dataset. We experimented with Xception, InceptionResNetV2, InceptionV3, EfficientNetB5 and EfficientNetB2.

**Learning rate**

We initially failed to apply transfer learning to our model because the learning rate was the default one (at 0.001) and was way too high for fine-tuning the pretrained supernets. Indeed, it caused a very fast overfitting of the training, but ending up with a very low validation accuracy. We managed to tweak the learning rate correctly by playing with a learning rate scheduler. We created an exponential decay, with a low initial value (about 10^-4). This way it starts learning fast, and it gradually decreases the learning rate so that by the end of the training it is very low, to achieve as many improvements as possible. The exponential decay technique proved to be successful in the training of the supernets and especially for the fine-tuning, where more precise control of the learning rate is needed to maximize the validation accuracy. Another technique used for adjusting the learning rate manually consists in the following steps: train with a fixed initial learning rate, take note of the epoch in which the validation accuracy improvement stalls, define a scheduler that step decreases the learning rate at that epoch and restart from the second step.

We did not try other optimizers since ADAM already combines both Momentum and RMSProp heuristics.

**Experimental approaches**

**Quasi SVM**

We tried implementing a quasi-SVM approach, by using a modified dense layer. This behaves like a random Fourier feature extractor with a gaussian kernel initializer. This approach proved to increase regularization capability without showing any significant improvement concerning the usual dense layer.

**CutMix augmentation**

CutMix is a new augmentation method that promises to improve the accuracy of the model, by generating images that are a mix of 2 different images of different classes. This library aims to create a random bounding box where to place a different image. The goal is to train a model which can learn to classify multiple classes at the same time with a single image. The labels are modified accordingly, by putting a higher weight on the label corresponding to the class of the image that occupies most of the area. The loss function of the model is still the categorical cross-entropy, but now the encoding of the label is not one-hot but it’s a continuous function. Using this technique, the model should improve its localization ability as it is forced to classify using a partial view.

We managed to successfully use this library, present in the Keras-CV module. We understood that this method requires a training set composed of images processed with cutmix and normal images as well. It eventually didn’t turn useful for our dataset since we didn’t see any improvement in the new models with respect to the standard augmentation technique. Therefore, we decided to stay with the augmentation we were previously using.

**Keras tuner**

We also gave a try to the Keras Hyperband tuner to find a good configuration for the dense layers. In particular, it has been applied to the *lambda* parameter of the L2 regularizers, *dropout rate* and dense *units* parameters. However, due to time constraints, we limited to implement it without fully testing it. The partial results we got seemed to be reasonable and were used as inspiration for our final models.

Draft report anndl

Outline of the topics to be covered (highlighted = already done)

1. Baseline model composition and accuracy
2. Regularization with dropout, gaussian dropout and l2 regularization in output dense layer
3. Online vs offline augmentation
4. Transfer learning with xception and the other supernets
5. Technique for fine tuning
6. Oversampling technique for under-represented classes and class\_weights approach
7. Exponential decay and adaptive learning rate schedulers
8. Flow and flow from directory
9. Standardization of images
10. Kaggle execution improvement with mixed precision and 2x gpu execution
11. Final models and some parameters used in the best performing model, image resizing
12. Cutmix augmentation not learning
13. Quasi svm dense layer (fourier transform with gaussian kernel)
14. Ensemble method of the best models and different supernets
15. Failure of the learning rate too high

TODO: the other points; I will do document formatting and proof reading