Tooploox Data Scientist Exercise – Solution

The solution was implemented in Python. It uses several libraries. The most important ones are: numpy, sklearn, keras, skimage and OpenCV. The implemented solution consists of 4 files:

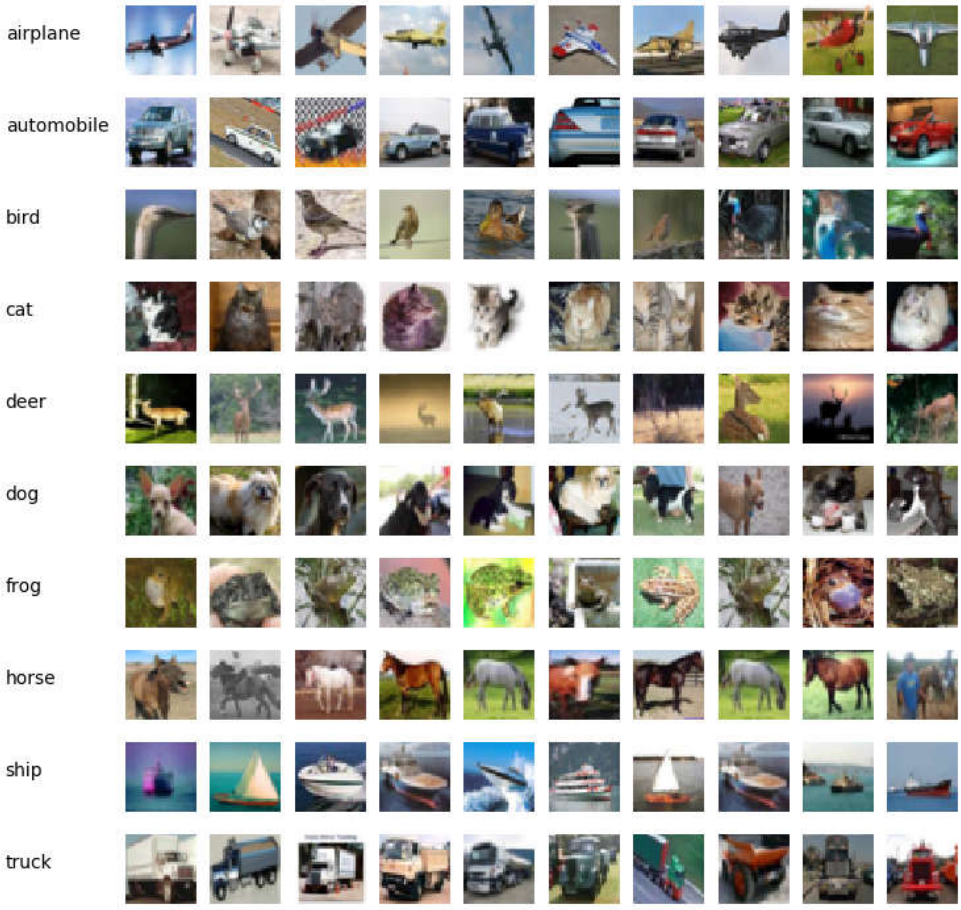
- utils.py – set of util methods operating on CIFAR-10 or helping in peforming classification
- process_cifar.py – visualizes 10 images per each class
- shallow_learning.py – performs SVM classification on HOG features (with hyperparameter optimization)
- transfer_learning.py – extracts features using transfer learning approach with the use Inception v3 model, visualizes them using two dimension reduction techniques – PCA and t-SNE, performs SVM classification based on these features (with hyperparameter optimization). Moreover, to increase the accuracy additional approaches were performed: using different pretrained model (in this case InceptionResNet v2), combining features from two models (used features obtained by Inception v3 and InceptionResNet v2) as well as data augmentation.

The order of executing files is arbitrary, but suggested one is as follows: process_cifar.py, then shallow_learning.py and, finally, transfer_learning.py (each module from the mentioned ones, firstly check if dataset is downloaded and extracted, and if not, it performs such operation). Due to the fact that some of the operation are long-running, their results are saved on disk during the first execution of such operation (and during next executions the results are read from disk). I don't have access to CUDA-enabled GPU, so I decided to perform all computation on 1/10 of the dataset, as it was suggested in the task. All generated images are saved to disk (files 'random_images_per_class.png', 'PCA.png' and 't-SNE.png') in order not to block the whole script.

Steps of solution (referring to steps from the task description):

1. CIFAR-10 is being downloaded from the following url https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz. It has 5 training batches and a test batch. Due to lack of access to CUDA-enabled GPU, I decided to use 1/10 of the data from each batch. Each batch contains images in random order (as it was stated on CIFAR-10 website), so, to simplify, first 1/10 of the data was read from each batch. Whole dataset is perfectly balanced among different classes, so good evaluation metric can be accuracy and is treated during this task as the primary one, but also additional metrics such as precision, recall, f1 are calculated.

2. Visualization of 10 random images for each class:



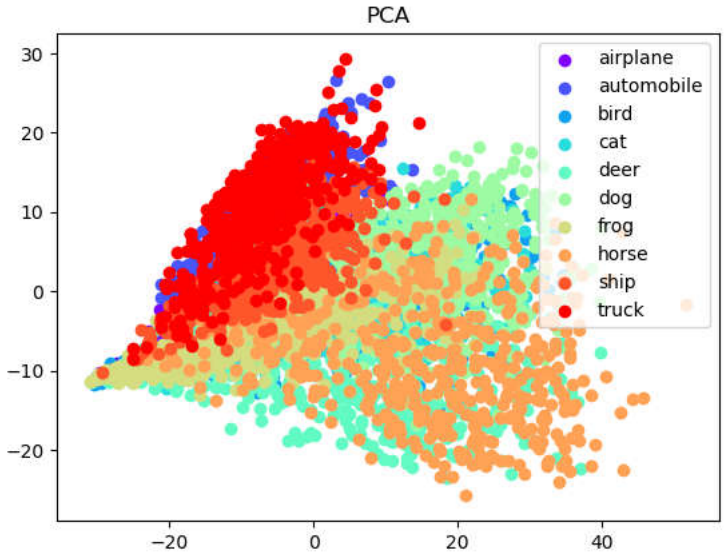
3. As a shallow classifier, I extracted HOG features and then, SVM was utilized for classification (with hyperparameter optimization)
   Accuracy on test set: **0.477** (for 'C'=0.1 parameter)
   Evaluation metrics per each class (precision, recall, f1 and support):

	precision	recall	f1-score	support
0	0.41	0.47	0.43	103
1	0.50	0.60	0.54	89
2	0.48	0.33	0.39	100
3	0.40	0.27	0.32	103
4	0.42	0.34	0.38	90
5	0.35	0.26	0.30	86
6	0.48	0.60	0.53	112
7	0.49	0.70	0.57	102
8	0.53	0.59	0.56	106
9	0.62	0.56	0.59	109
avg / total	0.47	0.48	0.47	1000

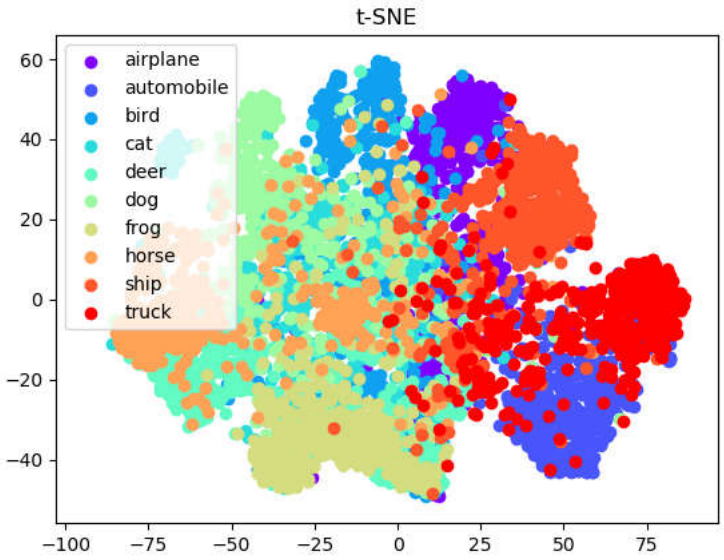
4. For transfer learning, Inception v3 pretrained model was used. The penultimate layer from such network was used to extract features (as it is a standard way).

5. Visualization of visual features extracted from pretrained model was carried out by 2 dimensionality reduction techniques:

- PCA



- t-SNE – this method is much more computationally intensive than PCA, so it is recommended to initially use another dimensionality reduction technique, and then apply t-SNE. In this case, firstly PCA with 50 components was executed, and then t-SNE on the reduced dataset.



Comparing these two results obtained by 2 different methods, we can notice that t-SNE better visualize separation between classes (but some overlappings are also visible).

6. On the top of features extracted from Inception v3 model, a SVM classifier was trained with hyperparameter optimization. The best results were provided using 'C'=0.0001.

7. Obtained accuracy on the test set: **0.812**. Evaluation metrics per each class:

	precision	recall	f1-score	support
0	0.75	0.76	0.75	103
1	0.88	0.83	0.86	89
2	0.89	0.76	0.82	100
3	0.72	0.74	0.73	103
4	0.75	0.78	0.77	90
5	0.75	0.74	0.75	86
6	0.82	0.86	0.84	112
7	0.83	0.83	0.83	102
8	0.86	0.95	0.90	106
9	0.87	0.84	0.86	109
avg / total	0.81	0.81	0.81	1000

Bonus tasks:

3 additional approaches will be presented (each makes an improvement over the results from 7th step)

8. Trying a different pretrained network which achieves better results on ImageNet dataset. Inception v3 has 159 layers and scores accuracy 0.788 on ImageNet. I decided to use InceptionResNet v3 network which has 572 layers and achieves accuracy 0.804 on ImageNet. The process of extracting features was similar as in the previous steps. Also in this case, features were fed to a SVM classifier with hyperparameter optimization. The best results were provided using 'C'=0.001. Obtained accuracy on the test set: **0.851**.
   Detailed results for other evaluation metrics per each class:

	precision	recall	f1-score	support
0	0.83	0.83	0.83	103
1	0.89	0.82	0.85	89
2	0.87	0.78	0.82	100
3	0.79	0.77	0.78	103
4	0.84	0.83	0.84	90
5	0.84	0.83	0.83	86
6	0.83	0.90	0.86	112
7	0.86	0.91	0.89	102
8	0.88	0.92	0.90	106
9	0.89	0.90	0.89	109
avg / total	0.85	0.85	0.85	1000

9. Combining features extracted from two pretrained models: Inception v3 and InceptionResNet v3. Also in this case, a SVM classifier with hyperparameter optimization was applied. The best results were achieved using 'C'= 0.0001. Obtained accuracy on the test set: **0.87**. Details for other evaluation metrics:

	precision	recall	f1-score	support
0	0.78	0.83	0.81	103
1	0.92	0.89	0.90	89
2	0.89	0.79	0.84	100
3	0.81	0.81	0.81	103
4	0.88	0.84	0.86	90
5	0.86	0.85	0.85	86
6	0.85	0.92	0.88	112
7	0.90	0.92	0.91	102
8	0.89	0.96	0.92	106
9	0.95	0.87	0.91	109
avg / total	0.87	0.87	0.87	1000

The results are better than using only features from one of the pretrained models.

10. Data augmentation. This approach was used to the initial solution with Inception v3 model. For each training batch, additional 250 images were generated resulting 1250 images per batch. The following transformations were selected to apply: horizontal flip, zooming and shifting. Horizontal flipping seemed natural for object classes in the dataset, contrary to vertical flipping. Moreover, images contain objects at different scale and, sometimes, slightly moved from the center of the image. Again, a SVM classifier with hyperparameter optimization was utilized. The best results were obtained using 'C'=0.0001. The achieved accuracy was **0.824** on the test set (increase from value 0.812 without data augmentation). Other evaluation metrics have the following values:

	precision	recall	f1-score	support
0	0.74	0.76	0.75	103
1	0.89	0.83	0.86	89
2	0.91	0.77	0.83	100
3	0.77	0.75	0.76	103
4	0.77	0.81	0.79	90
5	0.80	0.78	0.79	86
6	0.81	0.88	0.85	112
7	0.84	0.84	0.84	102
8	0.83	0.95	0.89	106
9	0.89	0.84	0.87	109
avg / total	0.83	0.82	0.82	1000