PROVOST Iantsa & SOUCASSE Bastien — DLCV Lab 4

- Development
    - **Apple MacBook Air (2017)**
        - Intel Core i5 Chip: 1.8GHz dual-core Intel Core i5, Turbo Boost up to 2.9GHz, with 3MB shared L3 cache.
    - **Apple MacBook Air (2020)**
        - Apple M1 Chip: 8-core CPU with 4 performance cores and 4 efficiency cores, 7-core GPU, and 16-core Neural Engine.
- Testing
    - **CREMI (201)**
        - Intel Xeon W-1290 12-core CPU, and RTX 3060 12Go GPU.

Keras

1. Convolutional Neural Network on MNIST Dataset

1.2. First CNN

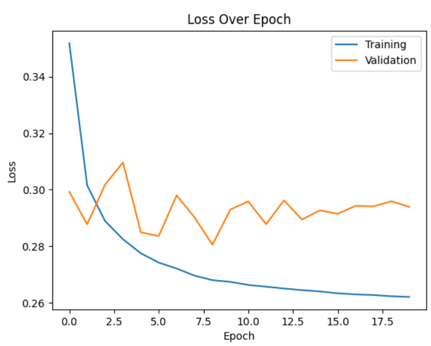
N.B.: After running the program with 40 epochs and realizing it takes a lot of time, we decided to lower the number of epochs to 20. Indeed, the results seem to stabilize around that number.

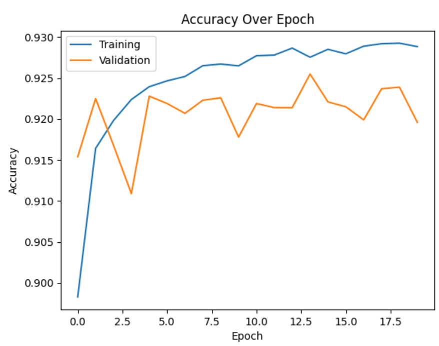
Model Summary

ID	Loss	Accuracy	Training Time
model1	0.2940	91.96%	46.96s

- Conv2D: 32, 3, 1, 'valid'.
- Flatten.
- Dense: 10, 'softmax'.

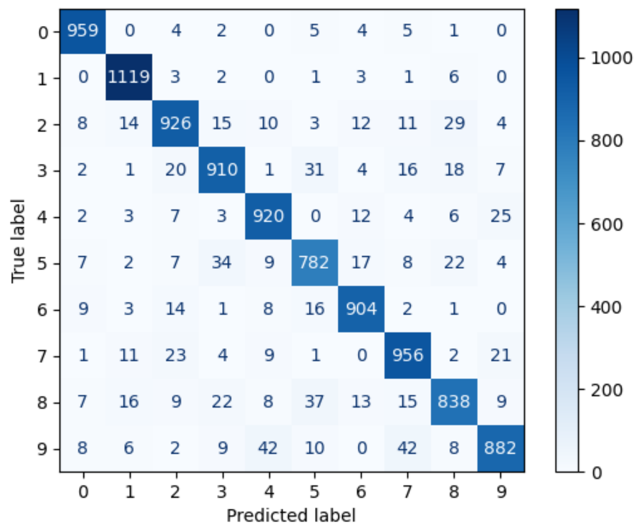
Loss and Accuracy Plots





The plots for training data seem normal, but the validation data give don't follow: the model is overfitting.

Confusion Matrix



The diagonal is where there are the higher numbers, which is a good thing since it represents the true positives. When it comes to misclassified images, we can observe that the most misclassified digits are:

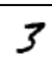
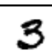
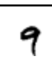
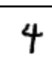
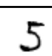
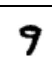
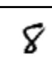
- 5 as 3 (34)
- 8 as 5 (37)
- 9 as 4 (42)
- 9 as 7 (42)

10 Worst Classified Images

First of all, let's define what we mean by "badly classified" images. Here, we consider an image badly classified if:

- it is misclassified
- the probability predicted by the model that it's their actual category is low

As a consequence, we decided to gather all the misclassified images and selected the ones that had the ten lowest predicted probability for their actual class.

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	1727	7	3	
9	6511	5	3	
8	4910	4	9	
7	565	9	4	
6	5874	3	5	
5	7786	7	9	
4	8297	5	8	

3	7689	5	8	
2	3862	3	2	
1	2371	9	4	

Note that this ranking is for an arbitrary run.

In this ranking, we can notice that there are the most confusions between:

- 5 and 3 (2)
- 5 and 8 (2)
- 4 and 9 (3)

Looking back at the confusion matrix, we can see that those 3 confusions all appear in the most misclassified digits list, at least in one way (the two ways being x misclassified as y, and y miscalssified as x).

1.3. Comparison

Model	Accuracy	Time
best lab3.3	97.59%	42.64s
model1	91.96%	46.96s

The CNN model takes a little bit more time (5s) than the lab3.3 best model and provides an about 5% lower accuracy. For now, the CNN model is not better but it must be improvable.

1.4. Model Improvement

1.4.1. A New Architecture

Let's use an architecture more complex given in class.

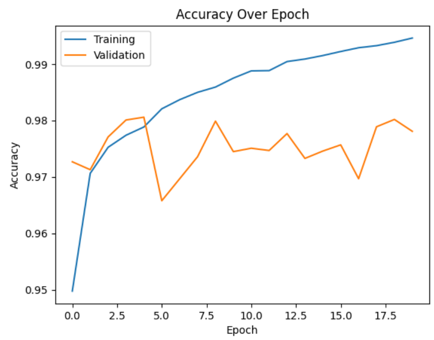
Model Summary

ID	Loss	Accuracy	Training Time
model2	0.5195	97.81%	144.61s

- Conv2D: 32, 3, 1, 'valid'.
- Conv2D: 64, 3, 1, 'valid'.
- MaxPooling: 2, 1, 'valid'
- Conv2D: 128, 3, 1, 'valid'.
- Flatten.
- Dense: 10, 'softmax'.

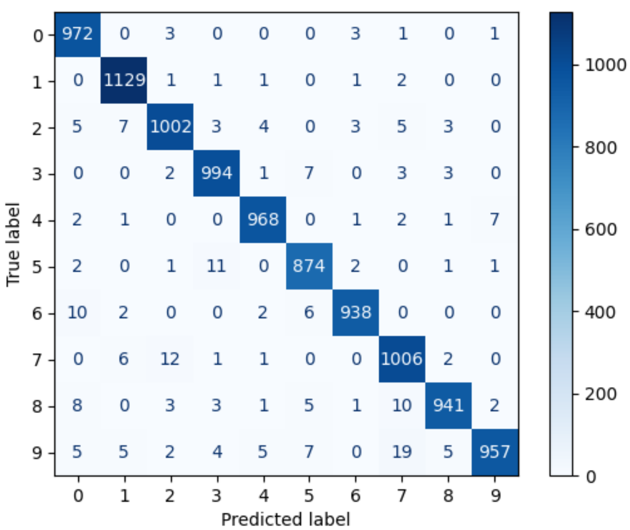
This model's accuracy is much better, it even reaches the lab3.3 best model accuracy. However, the training time is way longer (about 3 times), but it remains reasonable.

Loss and Accuracy Plots



Our model is definitely **overfitting** but later than model1. Indeed, even though we got a very good accuracy and the training loss is decreasing as expected, the validation loss is increasing.

Confusion Matrix



Just like the first model, the diagonal is where there are the higher numbers. Moreover there are very few misclassified images (which is logical since the accuracy is higher). When it comes to misclassified images, we can observe that the most misclassified digits are:

- 6 as 0 (10)
- 8 as 7 (10)
- 5 as 3 (11) (also noticed in first model)
- 7 as 2 (12)
- 9 as 7 (19)

There are less misclassified images but more categories.

10 Worst Classified Images

N.B.: To know what is meant by "10 worst classified images", see same section in **1.2**.

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	7813	8	9	
9	2135	1	6	
8	2298	0	8	
7	290	5	8	
6	5936	9	4	
5	4838	5	6	
4	9982	6	5	
3	2770	7	3	
2	7886	4	2	
1	3794	3	8	

First of all, none of the images in this ranking appear in the first model ranking. Then, we can only observe 1 confusion in both ways between 5 and 6, which was not in the first model ranking. Also this confusion doesn't appear in the most misclassified images. But, they look "harder to recognize" (such as the 7th, 8th and 9th) than the ones in the first model.

1.4.2. Fighting Against Overfitting

This time, let's build a model with data normalization, to prevent overfitting. And then, try and improve its accuracy.

Model Summaries

Legend:

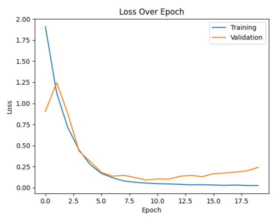
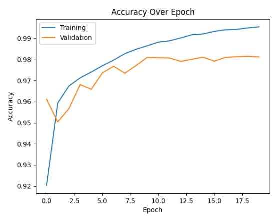
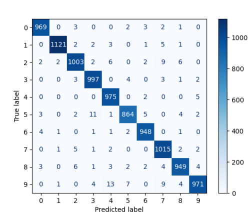
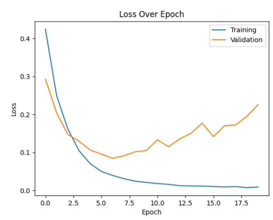
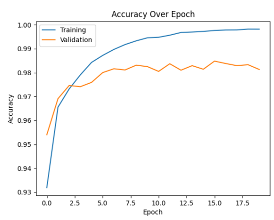
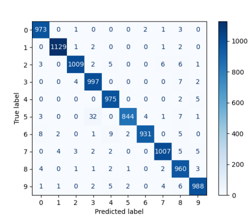
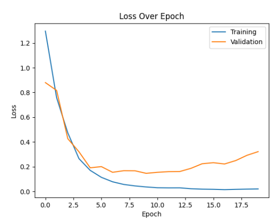
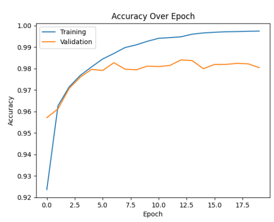
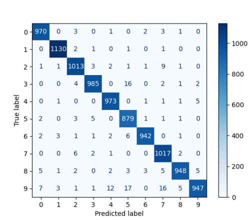
- Conv2D: num_filters, kernel_size, stride, padding.
- MaxPooling: pool_size, stride, padding.

ID	Architecture	Loss	Accuracy	Training time
model3	- Conv2D: 32, 5, 1, 'valid' - Conv2D: 64, 5, 1, 'valid' - `BatchNorm` - MaxPooling: 2, 1, 'valid' - Conv2D: 128, 5, 1, 'valid' - Flatten - Dense: 10, 'softmax'	0.2406	98.12%	143.87s
model4	- Conv2D: 32, 5, 1, 'valid' - Conv2D: 64, 5, 1, 'valid' - `BatchNorm` - MaxPooling: 2, 2, 'valid' - Conv2D: 128, 5, 1, 'valid' - Flatten	0.2260	98.13%	113.17s

	- Dense: 10, 'softmax'			
model5	- Conv2D: 64, 5, 1, 'valid' - Conv2D: 128, 5, 1, 'valid' - BatchNorm - MaxPooling: 2, 2, 'valid' - Conv2D: 256, 5, 1, 'valid' - Flatten - Dense: 10, 'softmax'	0.3216	98.04%	211.00s

Those 3 new models provide rather identical accuracies, that are slightly better than the model2 one. The training time allows to decide between them. Indeed, even if these information are not sufficient to choose a model, model4 seems to be the best model so far.

Loss, Accuracy Plots and Confusion Matrices

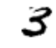
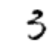
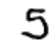
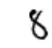
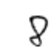
ID	Loss Plot	Accuracy Plot	Confusion Matrix
model3			
model4			
model5			

Whether it is about loss or accuracy, for all 3 models, we can observe some overfitting since the training values are improving and not the validation ones. Nevertheless, the scale is small so even if it may look huge, they actually all have:

- about 0.2-0.25 delta for the loss
- +/- 0.2 delta for the accuracy

They all look quite equivalent. More importantly, they show better results than model2.

10 Worst Classified Images

	model3				model4				model5			
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	4196	9	5		3559	5	8		9614	5	3	
9	924	7	2		9904	8	2		4534	7	9	
8	6157	5	9		9698	5	6		6624	5	3	
7	6166	3	9		1101	3	8		5922	3	5	
6	9645	7	1		9331	3	5		1686	6	8	
5	5176	4	8		5265	4	6		4783	9	4	
4	1138	1	2		6651	8	0		2406	4	9	
3	543	7	8		6391	4	2		3941	6	4	
2	4256	2	3		5745	1	7		2189	8	9	
1	2369	3	5		9638	7	9		3951	7	8	

2. Convolutional Neural Network on CIFAR10 Dataset

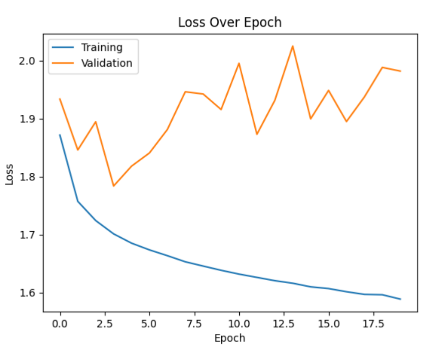
2.2. First CNN

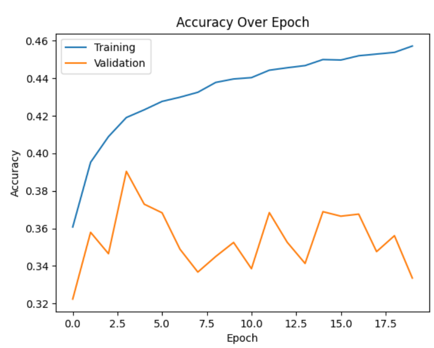
Model Summary

ID	Loss	Accuracy	Training Time
model1	1.9821	33.35%	53.39s

- Conv2D: 32, 3, 1, 'valid'.
- Flatten.
- Dense: 10, 'softmax'.

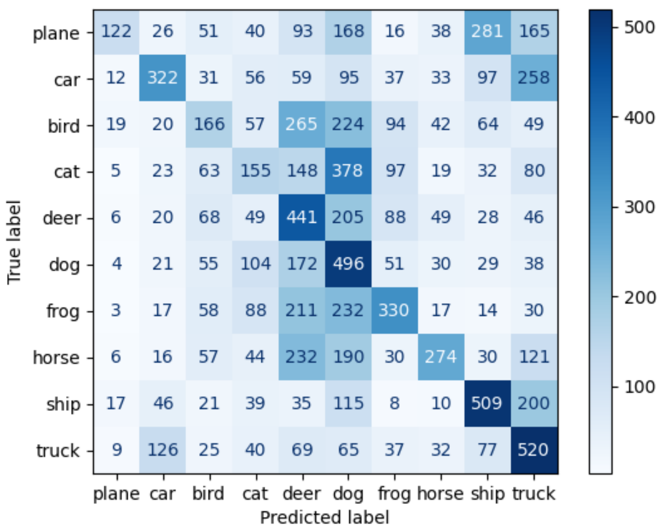
Loss and Accuracy Plots





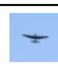
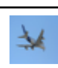
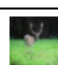
Not only the accuracy is low, but both loss and accuracy plots show overfitting. This model is not satisfactory at all.

Confusion Matrix



The confusion matrix looks bad: there is no high value diagonal. It adds a proof that the model is bad.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	7451	Car	Truck	
9	7196	Ship	Plane	
8	8309	Frog	Deer	
7	5918	Truck	Car	
6	7811	Ship	Plane	
5	1889	Ship	Truck	
4	7455	Truck	Car	
3	4971	Car	Truck	
2	3024	Ship	Plane	
1	5008	Horse	Deer	

1.3. Comparison

Model	Accuracy	Time
best lab3.3	44.50%	46.06s
model1	33.35%	53.39s

Our best lab3.3. model gives a more than 10% better accuracy than our first CNN model. Let's try to improve it.

1.4. Model Improvement

Model Summaries

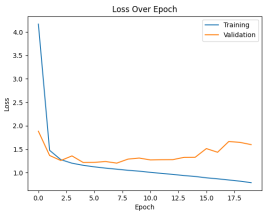
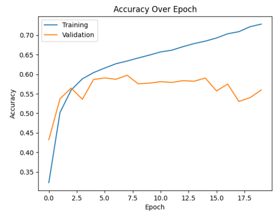
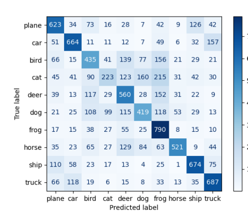
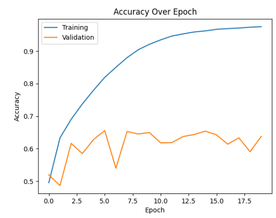
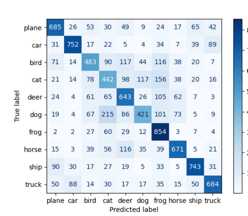
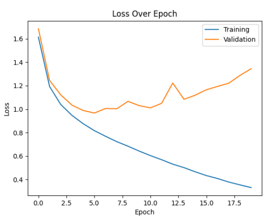
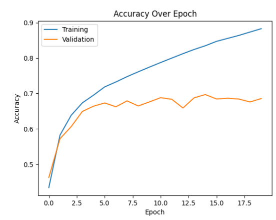
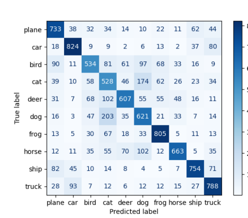
Legend:

- Conv2D: num_filters, kernel_size, stride, padding.
- MaxPooling: pool_size, stride, padding.
- Dense: units, activation_function.

ID	Architecture	Loss	Accuracy	Training time
model5	- Conv2D: 64, 5, 1, 'valid' - Conv2D: 128, 5, 1, 'valid' - BatchNorm - MaxPooling: 2, 2, 'valid' - Conv2D: 256, 5, 1, 'valid' - Flatten - Dense: 10, 'softmax'	1.5979	55.96%	200.59s
model6	- Conv2D: 64, 5, 1, 'valid' - MaxPooling: 2, 2, 'valid' - BatchNorm - Conv2D: 128, 5, 1, 'valid' - MaxPooling: 2, 2, 'valid' - BatchNorm - Flatten - Dense: 128, 'relu' - Dense: 10, 'softmax'	3.3476	63.78%	95.43s
model7	- Conv2D: 64, 5, 1, 'valid' - Conv2D: 64, 5, 1, 'valid' - MaxPooling: 2, 2, 'valid' - BatchNorm - Conv2D: 128, 5, 1, 'valid' - Conv2D: 128, 5, 1, 'valid' - MaxPooling: 2, 2, 'valid' - BatchNorm - Flatten - Dense: 128, 'relu' - Dense: 10, 'softmax'	1.3447	68.57%	158.78s

The accuracy increases through the different models. What's more, the one giving the best accuracy (model7) is not even the slower one. 68% might not seem a great accuracy, but it doubled since model1 which is good news.

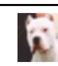
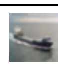
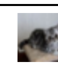
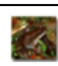
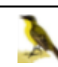
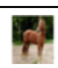
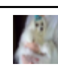
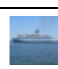
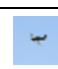
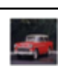
Loss, Accuracy Plots and Confusion Matrices

ID	Loss Plot	Accuracy Plot	Confusion Matrix
model5			
model6			
model7			

Compared to model1, the confusion matrices are much better: they all present the famous diagonal.

Even though we managed to improve the accuracy, it's becoming harder to fight overfitting. Indeed, all 3 models show a lot of overfitting. (Notice that the last one looks like it's slightly less overfitting???)

10 Worst Classified Images

	model5				model6				model7			
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	9935	Truck	Car		5122	Cat	Frog		5251	Cat	Dog	
9	2284	Plane	Ship		9206	Plane	Ship		1090	Ship	Plane	
8	5040	Frog	Cat		7236	Truck	Car		8201	Frog	Cat	
7	9407	Car	Frog		7329	Truck	Car		6760	Cat	Dog	
6	5546	Deer	Horse		3253	Ship	Truck		6002	Plane	Bird	
5	1433	Deer	Horse		2060	Cat	Dog		783	Ship	Frog	
4	8915	Car	Truck		5729	Car	Ship		1631	Truck	Car	
3	757	Plane	Ship		447	Ship	Plane		4721	Plane	Car	
2	1272	Frog	Deer		1650	Bird	Dog		1653	Car	Truck	
1	3549	Truck	Car		3402	Frog	Deer		9148	Dog	Cat	

3. Data Augmentation on CIFAR10 dataset

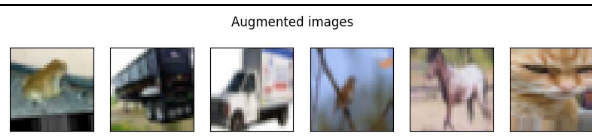
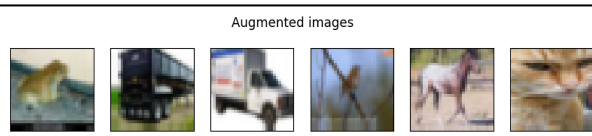
Our last model (model7) is the best one we could get with a CNN so far, but it shows overfitting. One way to reduce overfitting is to increase the size of the training dataset. Let's try to improve our model by doing data augmentation on our dataset.

3.1. Results

Model Summaries

All the models described below are heritated from model7, so we will only specify the parameters of the `ImageDataGenerator` in the Architecture column.

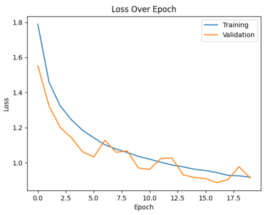
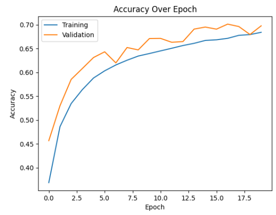
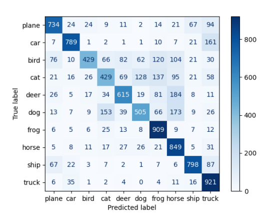
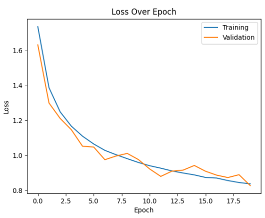
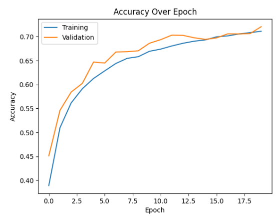
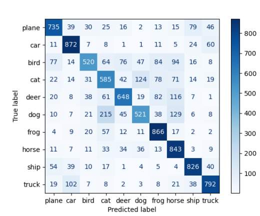
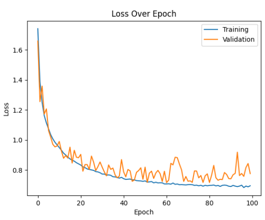
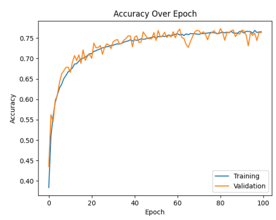
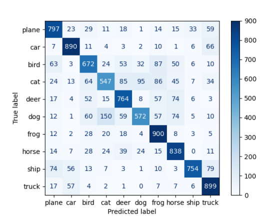
ID	Architecture	Epochs	Loss	Accuracy	Training time
model8	- horizontal_flip=True - height_shift_range=0.1 - width_shift_range=0.1 - rotation_range=10 - zoom_range=0.2	20	0.9139	69.78%	340.25s
model9	- horizontal_flip=True - height_shift_range=0.1 - width_shift_range=0.1	20	0.8267	72.08%	323.14s
model10 (model9bis)	- horizontal_flip=True - height_shift_range=0.1 - width_shift_range=0.1	100	0.7761	76.33%	1557.88s (311.58s for 20 epochs)

ID	Images
original	
model8	
model9 & model10	

For model8, the parameters were chosen according to what is plausible for the subjects of our images. That's why we, for example, did not add a vertical flip (an upside down ship or truck makes no sense). As for model9(bis), some parameters were removed as a test. Finally, model10 is actually model9, but trained on 100 epochs.

When it comes to perfomance, the accuracy gets better as the training time goes down, which suggests that each model might be better than the previous one. To confirm it, let's take a look at the plots.

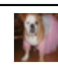
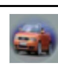
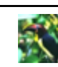
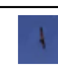
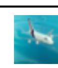
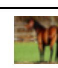
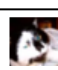
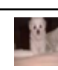
Loss, Accuracy Plots and Confusion Matrices

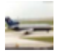
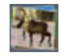
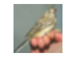
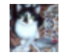
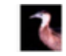
ID	Loss Plot	Accuracy Plot	Confusion Matrix
model8			
model9			
model10			

It was observed in the previous section (Model summaries) that our new models were providing better accuracies, but our main problem that we are trying to solve with data augmentation is overfitting. Looking at the model8 accuracy plot, we can see that the validation curve is above the test one. It could mean that the model is underfitting but the gap is not that big.

With model9, we managed to slightly reduce the gap a bit. Since the curves look like they keep going up, we trained it again on more epochs (model10). Even though the test accuracy oscillates around the train accuracy, the test accuracy follows closely the train accuracy which means less/no overfitting.

10 Worst Classified Images

	model8					model9					model10				
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Prob. Act.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Prob. Act.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Prob. Act.	Image
10	1396	Truck	Car	0.4971		7279	Cat	Dog	0.4975		6832	Truck	Car	0.4924	
9	2063	Truck	Car	0.4951		6267	Car	Truck	0.4974		1051	Frog	Bird	0.4839	
8	3404	Cat	Dog	0.4934		4005	Cat	Dog	0.4965		3094	Plane	Bird	0.4833	
7	9141	Frog	Cat	0.4921		2964	Ship	Plane	0.4941		8884	Horse	Plane	0.4832	
6	8595	Truck	Car	0.4904		8437	Deer	Horse	0.4930		2153	Plane	Ship	0.4783	
5	9102	Deer	Horse	0.4885		9295	Dog	Cat	0.4929		5805	Truck	Car	0.4771	
4	7384	Dog	Cat	0.4873		9649	Cat	Dog	0.4925		5240	Truck	Car	0.4769	

3	6055	Ship	Plane	0.4821		6228	Horse	Deer	0.4904		7942	Car	Truck	0.4742	
2	6399	Truck	Car	0.4803		1733	Dog	Cat	0.4874		5085	Frog	Bird	0.4732	
1	4125	Plane	Ship	0.4783		3130	Dog	Cat	0.4869		4421	Dog	Bird	0.4692	

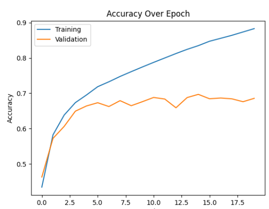
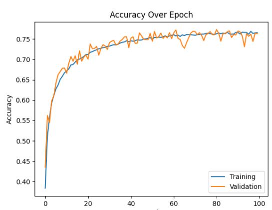
By analysing each ranking, we can observe that

- model8 tends to mistake Car as Truck (4 times)
- model9/10 also (Car as Truck 3 times, Truck as Car 1 time), and Cat as Dog, Dog as Cat (3 times each)

These classes are respectively of the same type of subject, and kind of look alike. Therefore, they are not aberrant mistakes.

3.2. Comparison

To conclude this part, let's compare our new best model (model10) with the ones of our original model (model7) that was the base.

ID	Accuracy Plot	Accuracy	Training time
model7		68.57%	158.78s
model10		76.33%	1557.88s (311.58s for 20 epochs)

In spite of an almost twice longer training time, model10 overperforms model7. Indeed, model10 provides an accuracy that is almost 8% higher and the problem of overfitting seems solved (even if the plots are not on the same number of epochs, we do not need more epochs to see that the test accuracy will not get higher in model7).

4. Transfer learning / Fine-tuning on CIFAR10 dataset

4.1. Results

For this part, we are going to use ResNet50 pre-trained on ImageNet. We want to specify our input shape and remove the classifier to add our own so the model can classify 10 classes.

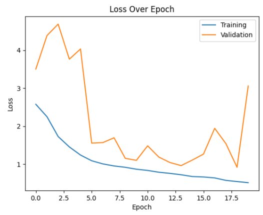
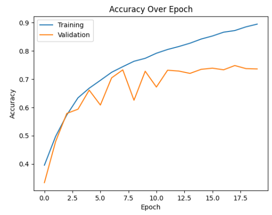
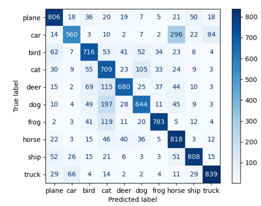
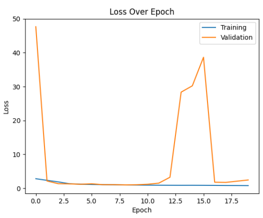
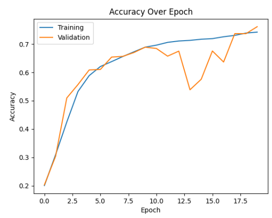
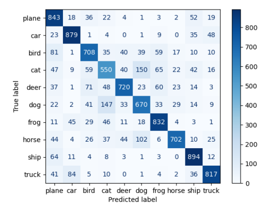
Model Summaries

Now that we know data augmentation helps improve results, we want to try fine-tuning with and without data augmentation.

ID	Data Augmentation	Loss	Accuracy	Training time
MyResNet	No	3.0612	73.63%	1153.49s
MyResNetDA	Yes, same than model9	2.4440	76.15%	1172.44s

We expected MyResNetDA to provide a higher accuracy and it did, but very slightly (+3%). As ResNet50 has 50 layers and none of them were frozen, it is trained entirely and so the training time is quite long (about 20 minutes).

Loss, Accuracy Plots and Confusion Matrices

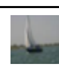
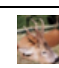
ID	Loss Plot	Accuracy Plot	Confusion Matrix
MyResNet			
MyResNetDA			

MyResNet's accuracy plot shows overfitting, whereas data augmentation seems to do its job in MyResNetDA. Indeed, the test accuracy seems very close to train accuracy until around the 9th epoch (we couldn't figure out the drop). Then it gets back on track towards the end.

Although both confusion matrices look OK, with the diagonal representing the true positives, we cannot say the same about loss plots. They look abnormal, and we unfortunately could not figure out why.

After many tries, with different types of normalization and/or layer freezing, we did not manage to get interesting/better results.

10 Worst Classified Images

	MyResNet					MyResNetDA				
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Prob. Act.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Prob. Act.	Image
10	3029	Truck	Car	0.4975		1771	Deer	Bird	0.4934	
9	7970	Dog	Cat	0.4925		7639	Car	Truck	0.4913	
8	9778	Dog	Cat	0.4895		6581	Truck	Car	0.4890	
7	5432	Ship	Truck	0.4883		7093	Deer	Bird	0.4852	
6	778	Ship	Plane	0.4871		8761	Ship	Plane	0.4848	
5	169	Ship	Plane	0.4856		1549	Truck	Car	0.4822	
4	2744	Car	Truck	0.4838		4223	Plane	Ship	0.4812	
3	55	Plane	Ship	0.4825		2809	Frog	Deer	0.4778	
2	7605	Deer	Bird	0.4733		3182	Plane	Ship	0.4763	
1	7714	Dog	Cat	0.4722		2879	Ship	Plane	0.4752	

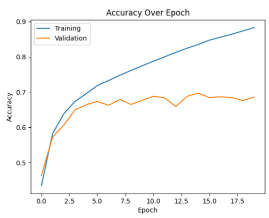
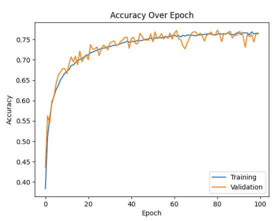
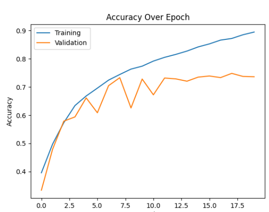
By analysing each ranking, we can observe that

- MyResNet tends to mistake Cat as Dog (3 times)
- MyResNetDA tends to mistake Ship as Truck and Truck as Ship (3 times in total)

In the same way than in the previous part about data augmentation, the mistakes done by our models are "understanble" since it confuses subjects that are of the "same type".

4.1. Comparison

To conclude this part, let's compare the model improvements (model10 and MyResNetDA), and our model from part 2 (model7).

ID	Accuracy Plot	Accuracy	Training time
model7		68.57%	158.78s
model10		76.33%	1557.88s (311.58s for 20 epochs)
MyResNet		76.15%	1172.44s

Our improved models (model10 and MyResNetDA) provides about the same accuracy but MyResNetDA overfits, unlike model10. What is more, MyResNetDA is almost 4 times slower.

As a conclusion, MyResNetDA was able to improve model7 but could not compete with model10.

PyTorch

1. Conv2D Neural Network on MNIST Dataset

1.1. First CNN

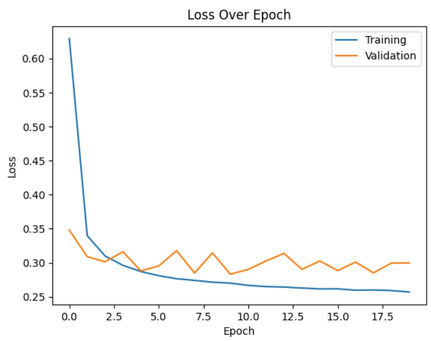
Model Summary

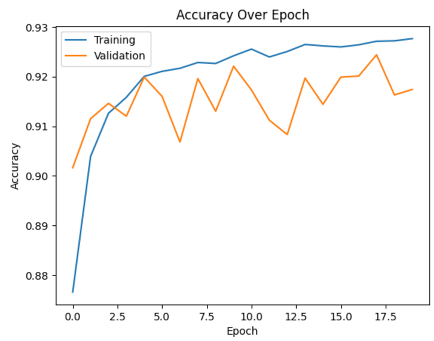
ID	Loss	Accuracy	Training Time
model1	0.2996	91.74%	92.76s

- Conv2D: 32, 3, 1, 'valid'.
- Flatten.
- Dense: 10 ('softmax').

N.B.: This is the same model1 as with Keras to have the same base, but it won't be improved the same way as Keras, since we chose to improve it the most relevant way possible. This will allow us to have other CNN architectures giving good accuracies.

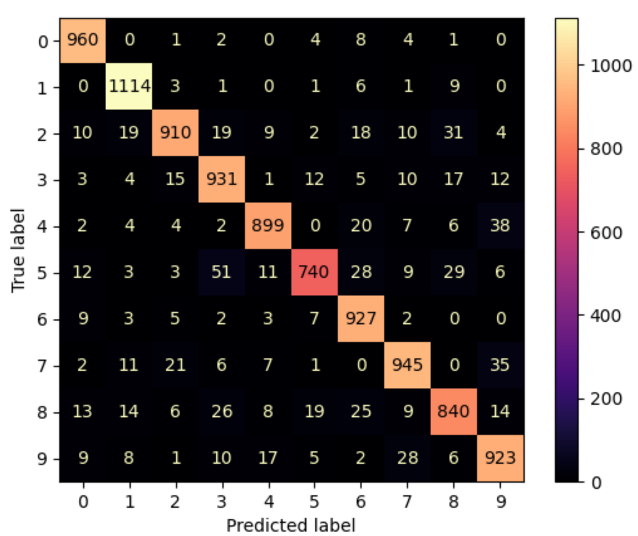
Loss and Accuracy Plots





These plots may show some overfitting, but not much.

Confusion Matrix



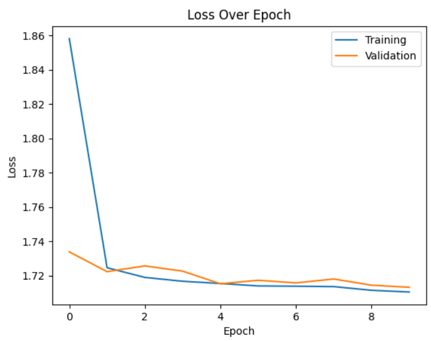
As in Keras, the confusion matrix shows that most the images are well classified (the diagonal). The most misclassified digits are:

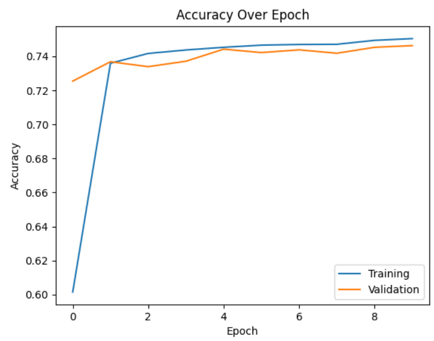
- 7 as 9 (35)
- 4 as 9 (38)
- 5 as 3 (51)

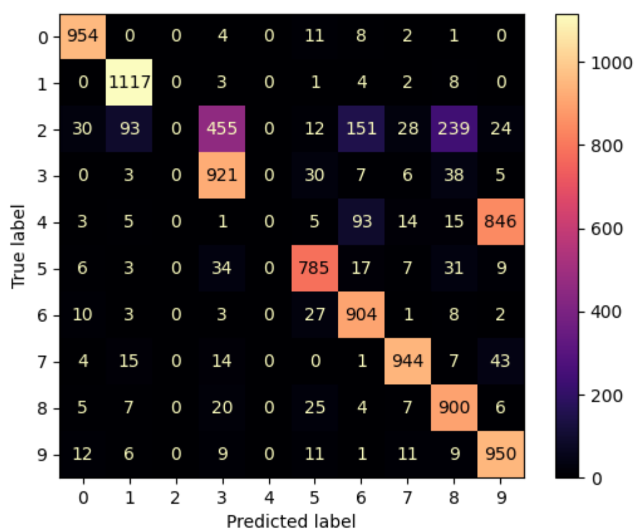
Nota Bene

In PyTorch, the Softmax activation is already done by the CrossEntropyLoss criterion, as mentionned in the official documentation: "Note that this is equivalent to the combination of LogSoftmax and NLLLoss." (That's why we put softmax between parenthesis.)

As we didn't know this at first, we did a first version of this model with a softmax activation on the linear layer. The results were drastically different.



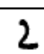
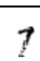
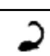
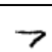




The confusion matrix shows that not only the elements are not well classified, but also some classes are nerver predicted.

10 Worst Classified Images

The same way as before, we're going to determine the 10 worst classified images by the model.

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	6885	6	2	
9	6599	1	7	
8	9487	6	2	
7	3189	4	7	
6	5688	9	7	

				
5	1940	0	5	
4	1017	2	6	
3	1310	7	3	
2	3682	6	2	
1	9916	9	7	

1.2. Model Improvement

1.2.1. A New Architecture

Once again, we are going to complexify our architecture.

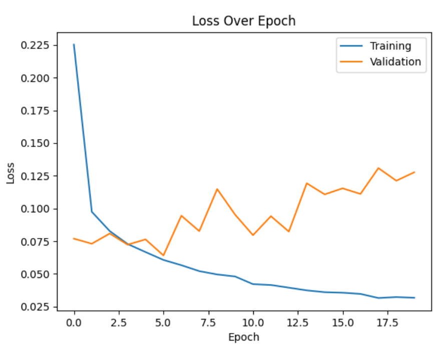
Model Summary

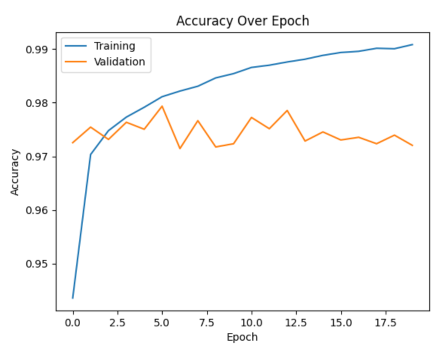
ID	Loss	Accuracy	Training Time
model2	0.1276	97.20%	97.12s

- `Conv2D: 64, 3, 1, 'valid'.`
- Conv2D: 32, 3, 1, 'valid'.
- `MaxPooling: 2, 1, 'valid'.`
- `Conv2D: 16, 3, 1, 'valid'.`
- Flatten.
- Dense: 10 ('softmax').

This model is definitely better than the first one. For only a few seconds longer, it gives a 6 to 7 percent better accuracy.

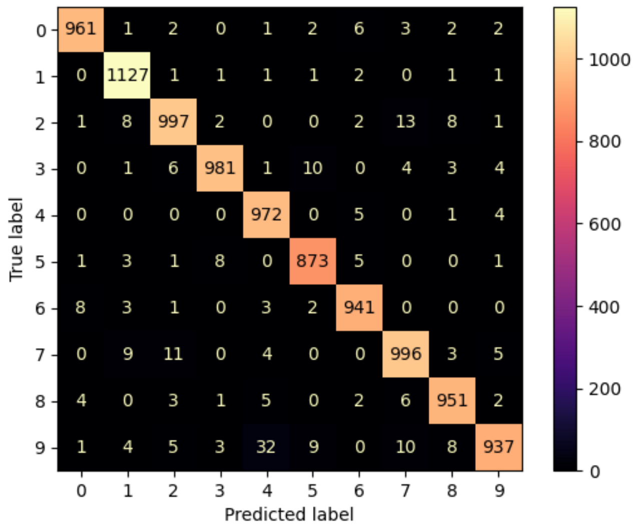
Loss and Accuracy Plots





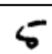
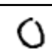
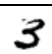
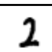
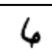
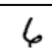
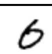
However this time, there is an obvious overfitting detected as the training loss keeps descending but the validation one is ascending.

Confusion Matrix



However, the confusion matrix—and also the accuracy obviously—still shows that most of the images are classified correctly.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	5593	6	0	
9	5176	4	8	
8	8	6	5	
7	2370	6	0	
6	6532	5	0	
5	9614	5	3	
4	8069	1	2	
3	6847	4	6	
2	5228	4	6	
1	965	0	6	

With this model, we're starting to understand why the neural network is wrong sometimes, as one might be wrong the same way on some images.

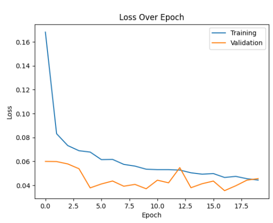
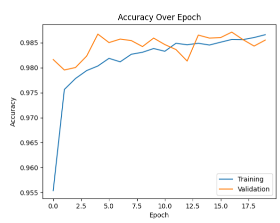
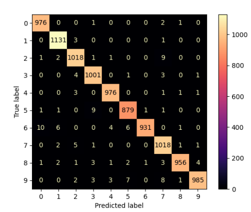
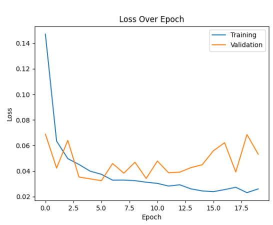
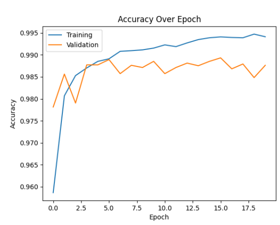
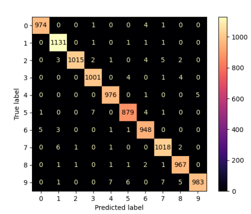
1.2.2. Fighting Against Overfitting

This time, let's build a model with data normalization, to prevent overfitting. And then, try and improve its accuracy.

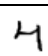
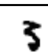
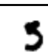
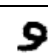
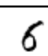
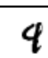
Models Summaries

ID	Architecture	Loss	Accuracy	Training time
model3	- Conv2D: 64, 3, 1, 'valid'. - Conv2D: 32, 3, 1, 'valid'. - `Dropout.` - `Activation: 'relu'.` - MaxPooling: 2, 1, 'valid'. - Conv2D: 16, 3, 1, 'valid'. - Flatten. - Dense: 10 ('softmax').	0.0456	98.55%	98.83s
model4	- Conv2D: 64, 3, 1, 'valid'. - Conv2D: 32, 3, 1, 'valid'. - Dropout. - Activation: 'relu'. - MaxPooling: 2, 1, 'valid'. - Conv2D: 16, 3, 1, 'valid'. - Flatten. - `Dense: 128, 'relu'.` - Dense: 10 ('softmax').	0.0432	98.76%	103.71s

The 2 new models provide rather identical results, slightly better than the model2 ones.

ID	Loss Plot	Accuracy Plot	Confusion Matrix
model3			
model4			

Here, model3 seems to have less overfitting, but it depends also on the run as the difference is very subtle.

	model3				model4			
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	1147	7	4		2953	5	3	
9	8059	1	2		5937	3	5	
8	9664	7	2		6091	5	9	
7	4063	5	6		359	4	9	

6	4838	5	6		2130	9	4	
5	3073	2	1		3030	0	6	
4	2035	3	5		4860	9	4	
3	217	5	6		8277	8	3	
2	9755	5	8		8521	1	2	
1	9015	2	7		6081	5	9	

2. Conv2D Neural Network on CIFAR10 Dataset

2.1. First CNN

Model Summary

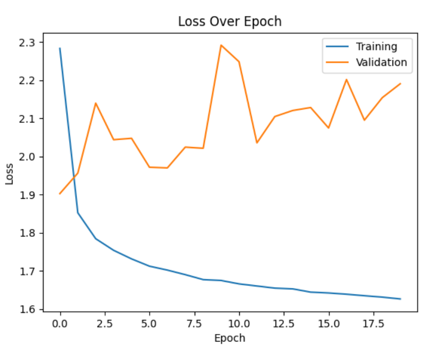
For the first run, we chose once again to try the model1 on the new dataset

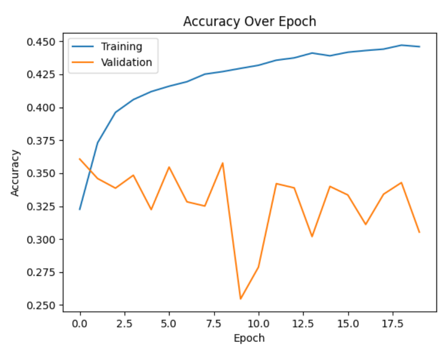
ID	Loss	Accuracy	Training Time
model1	2.1902	30.53%	100.20s

- Conv2D: 32, 3, 1, 'valid'.
- Flatten.
- Dense: 10 ('softmax').

For the first time, we obtain bad results from a model. The color images were much more complicated to analyse.

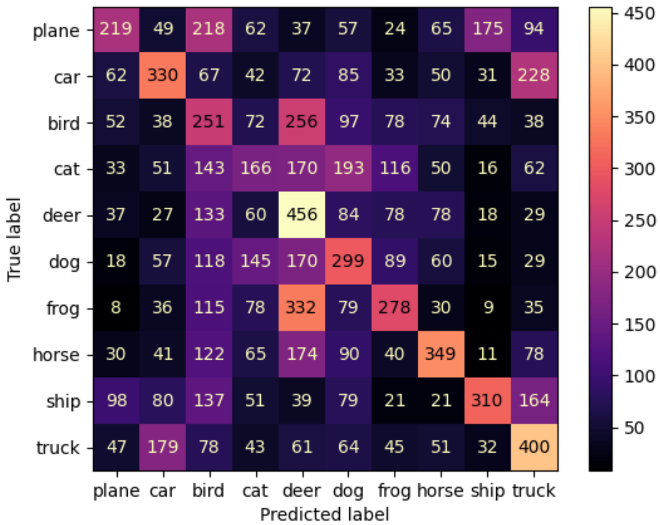
Loss and Accuracy Plots





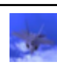
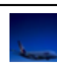
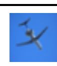
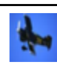
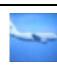
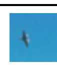
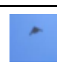
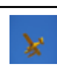
Also, the overfitting is already tremendous.

Confusion Matrix



To confirm everything we've seen so far, the confusion matrix shows that the predictions are very far from the actual values. We can barely distinguish the diagonal.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	3650	Ship	Plane	
9	9590	Ship	Plane	
8	2968	Ship	Plane	
7	9766	Ship	Plane	
6	7454	Ship	Plane	
5	3278	Ship	Plane	
4	4981	Plane	Car	
3	1651	Ship	Plane	
2	7431	Car	Truck	
1	2200	Car	Plane	

2.2. Model Improvement

2.2.1. A New Architecture

Model Summary

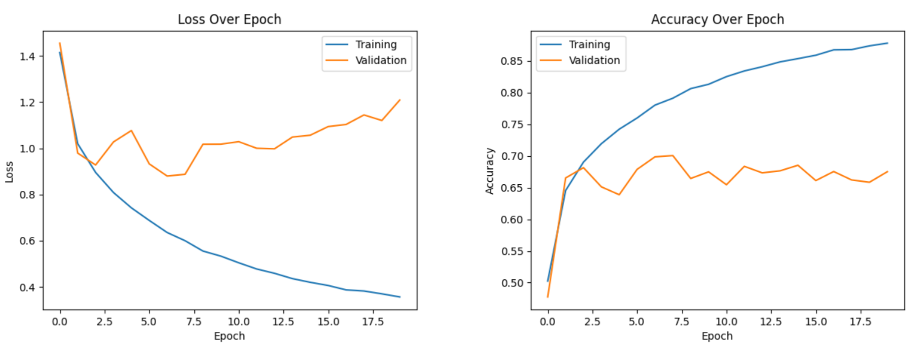
This time, the model4, one of the best models we've tested, is used.

ID	Loss	Accuracy	Training Time
model4	1.2091	67.51%	107.47s

- Conv2D: 64, 3, 1, 'valid'.
- Conv2D: 32, 3, 1, 'valid'.
- Dropout.
- Activation: 'relu'.
- MaxPooling: 2, 1, 'valid'.
- Conv2D: 16, 3, 1, 'valid'.
- Flatten.
- Dense: 128, 'relu'.
- Dense: 10 ('softmax').

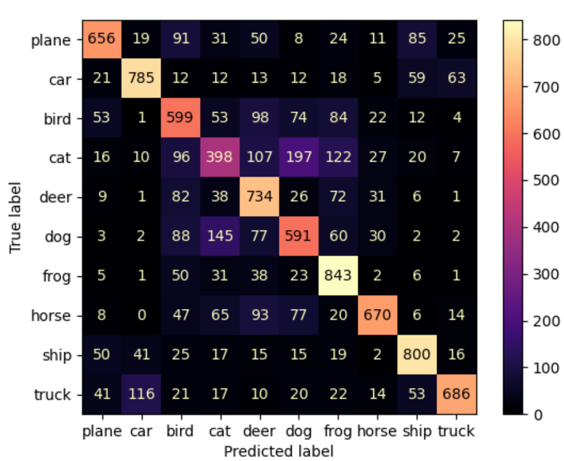
We might be lucky, but this model actualy improves drastically the results we've had with model1. The accuracy is already almost as good as the fourth model tested with Keras.

Loss and Accuracy Plots



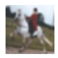
On the other hand, the overfitting is still very present, though we might have limited it.

Confusion Matrix



The confusion matrix also shows an important improvement as the diagonal is much more visible now.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	1692	Car	Truck	
9	1732	Car	Truck	
8	9854	Car	Truck	
7	4866	Car	Truck	
6	1829	Truck	Car	
5	3150	Truck	Car	
4	5041	Car	Truck	
3	6615	Dog	Horse	
2	6968	Plane	Ship	
1	3812	Car	Truck	

2.2.2. Going Further

Model Summary

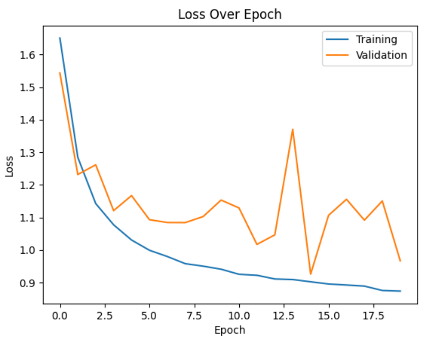
Let's imagine a new model, inspired by model4, but trying to improve the final accuracy.

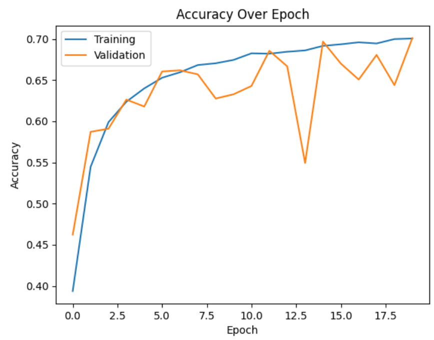
ID	Loss	Accuracy	Training Time
model5	0.9670	70.11%	134.46s

- Conv2D: 64, 3, 1, 'valid'.
- Conv2D: 32, 3, 1, 'valid'.
- Dropout.
- Activation: 'relu'.
- MaxPooling: 2, 1, 'valid'.
- `Conv2D: 64, 3, 1, 'valid'.`
- `Conv2D: 32, 3, 1, 'valid'.`
- `Dropout.`
- `Activation: 'relu'.`
- `MaxPooling: 2, 1, 'valid'.`
- Conv2D: 16, 3, 1, 'valid'.
- Flatten.
- Dense: 128, 'relu'.
- `Dense: 256, 'relu'.`
- Dense: 10 ('softmax').

This model gives the best results for this dataset. On the other hand, the training time is starting to grow bigger.

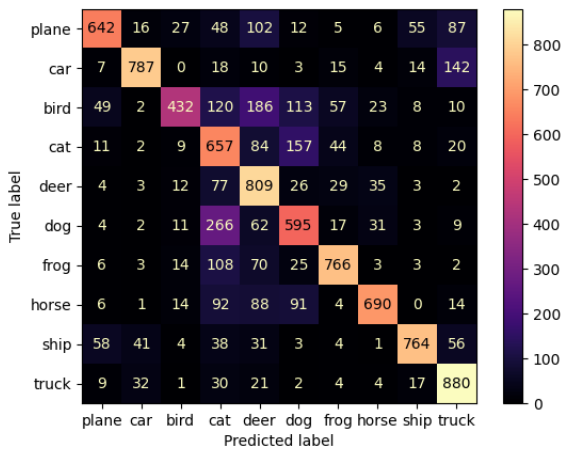
Loss and Accuracy Plots





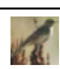
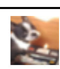
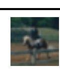
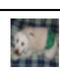
There is persistent overfitting but at this point, there is not much solution but to use data augmentation. We will try to focus on that next.

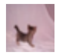
Confusion Matrix



The confusion matrix is not perfect but it's the best we've had on this dataset, confirming that the model is better.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	5918	Truck	Car	
9	2322	Bird	Plane	
8	4766	Truck	Car	
7	3151	Car	Ship	
6	81	Truck	Car	
5	6342	Plane	Ship	
4	5416	Car	Truck	
3	4056	Ship	Plane	

2	5392	Car	Plane	
1	9981	Horse	Deer	

3. Data Augmentation

Model Without Data Augmentation

We are now going to use a stable model based on `model5` that we previously saw, and matching the one we used on the Keras version. We will declare it as `PraisyNet` for no reason.

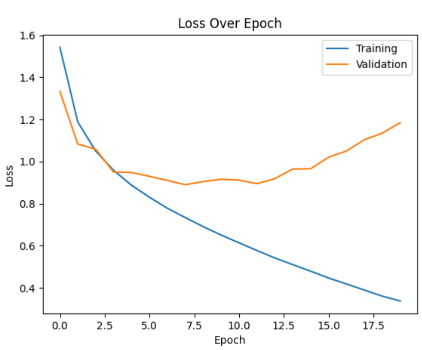
Model Summary

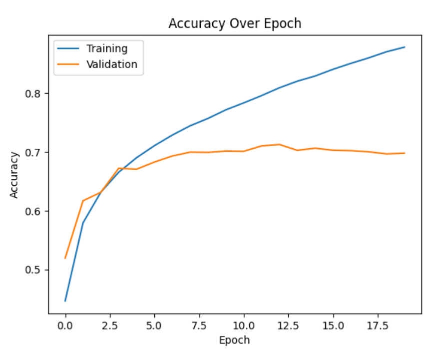
ID	Data Augmentation	Loss	Accuracy	Training Time
PraisyNet	No	1.1851	69.80%	160.63s

The model architechture is the following:

- Layer1
  - Conv2d(NUM_CHANNELS, 64, 5, stride=1, padding=0)
  - Conv2d(64, 64, 5, stride=1, padding=0)
  - MaxPool2d(2, stride=2, padding=0)
  - LazyBatchNorm2d()
- Layer2
  - Conv2d(64, 128, 5, stride=1, padding=0)
  - Conv2d(128, 128, 5, stride=1, padding=0)
  - MaxPool2d(2, stride=2, padding=0)
  - LazyBatchNorm2d()
- Flatten
- Classifier
  - LazyLinear(128)
  - ReLU()
  - LazyLinear(NUM_CLASSES)

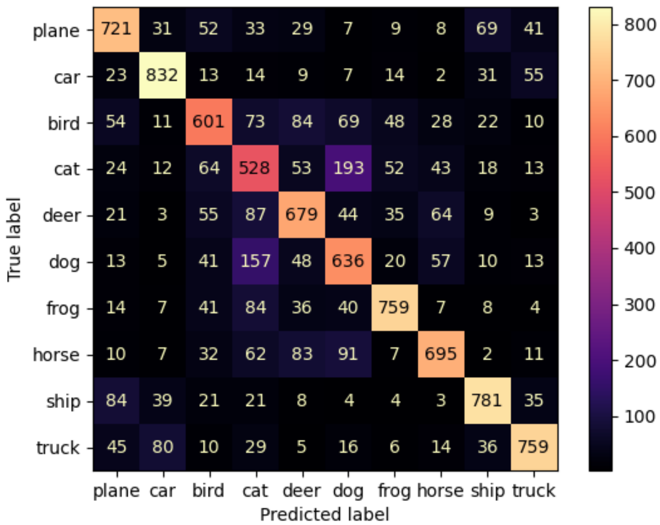
Loss and Accuracy Plots





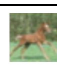
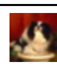
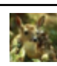
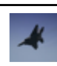
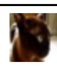
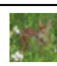
As we have seen before with `model5`, there is a lot of overfitting here.

Confusion Matrix



The confusion matrix is good, confirming this is a good base model.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	8981	Deer	Horse	
9	9084	Cat	Dog	
8	6814	Car	Truck	
7	9461	Frog	Deer	
6	7929	Bird	Plane	
5	4032	Dog	Cat	
4	2641	Frog	Deer	
3	8187	Horse	Dog	
2	1631	Truck	Car	
1	8808	Cat	Frog	

Model With Data Augmentation

We are now going to use a stable model based on `model5` that we previously saw, and matching the one we used on the Keras version.

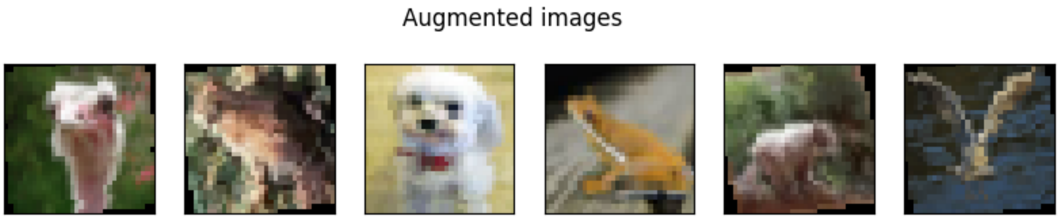
Model Summary

ID	Data Augmentation	Loss	Accuracy	Training Time
PraisyNet	Yes	0.7004	77.18%	899.34s (179.87s for 20 epochs)

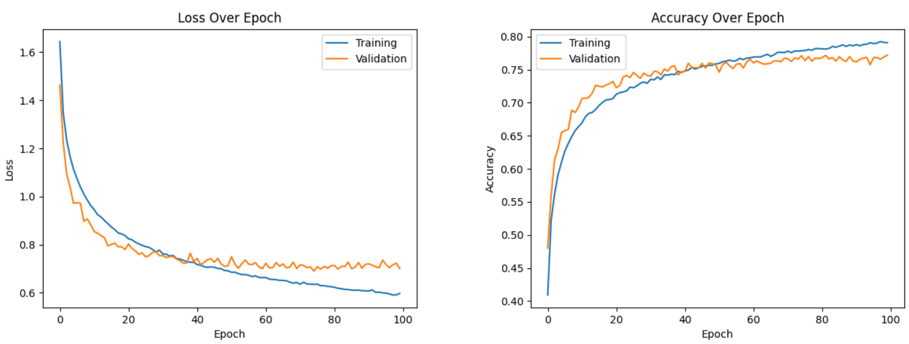
The same model as before is used, and the Data Augmentation set up as the following:

- RandomAffine(0, scale=(.2, 1.2), shear=10)
- RandomHorizontalFlip()
- RandomRotation(10)

A sample of the augmented dataset images:

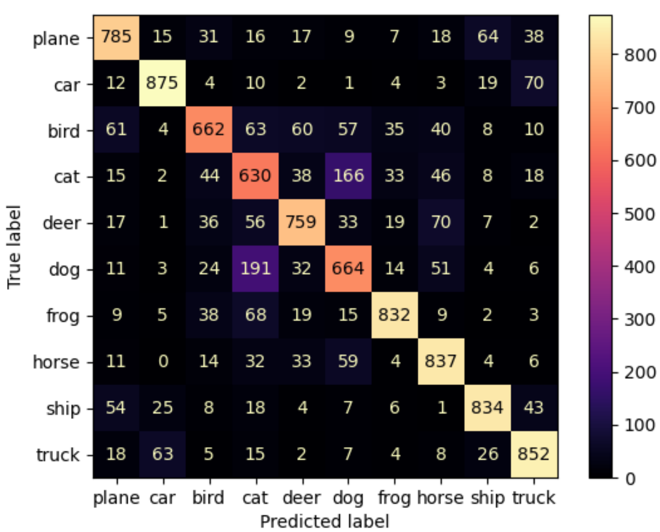


Loss and Accuracy Plots



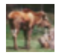
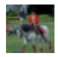
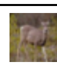
There is clearly no overfitting anymore. The validation accuracy follows the training accuracy even up to 100 epochs.

Confusion Matrix



The confusion matrix is still good. So the results are not changed, the model only learns better.

10 Worst Classified Images

Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	365	Plane	Deer	
9	6901	Plane	Bird	
8	8698	Deer	Frog	
7	1118	Horse	Deer	
6	8344	Deer	Horse	
5	9132	Deer	Bird	
4	453	Dog	Cat	
3	115	Horse	Cat	
2	6786	Dog	Cat	
1	4571	Horse	Deer	

4. Transfer learning / Fine-tuning on CIFAR10 dataset

For this part, we are going to use ResNet50 pre-trained on ImageNet. We want to specify our input shape and remove the classifier to add our own so the model can classify 10 classes.

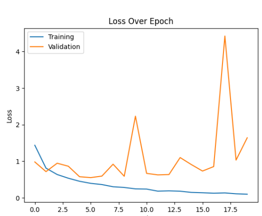
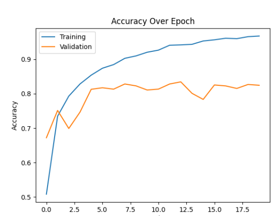
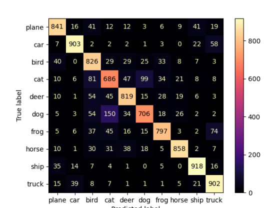
Model Summaries

Now that we know data augmentation helps improve results, we want to try fine-tuning with and without data augmentation.

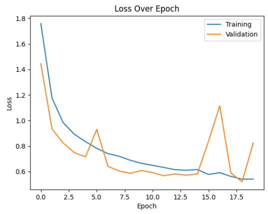
ID	Data Augmentation	Loss	Accuracy	Training time
MyResNet	No	1.6432	82.43%	1076.82s
MyResNetDA	Yes	0.8252	80.67%	1079.93s

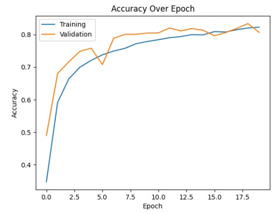
For both MyResnet and MyResNetDA, the accuracy has increased of more than 10% compared to PraisyNet (69.80%), which is a quite good improvement (even though the training time also increased).

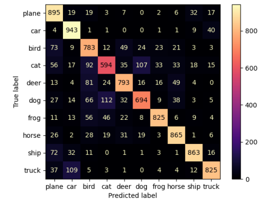
Loss, Accuracy Plots and Confusion Matrices

ID	Loss Plot	Accuracy Plot	Confusion Matrix
MyResNet			

MyResNetDA

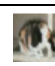
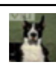
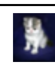
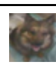
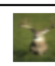
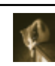
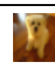
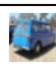
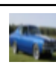
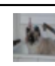
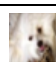
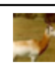
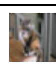






Despite better accuracies in both models, their respective plots are questionable. Indeed, for MyResNet, the accuracy and loss plots show overfitting around the third epoch. Fortunately (or not), we can add data augmentation in order to solve our problem. The thing is, we now observe on the accuracy plot a train accuracy that is above the test accuracy. This is a sign of underfitting, due to data augmentation. We might be adding and changing input data so much that the model become very efficient on the “simple” data in the test dataset (because it's not transformed), but still has trouble giving a good result on a lot of different data.

10 Worst Classified Images

	MyResNet				**MyResNetDA**			
Rank	Image Idx.	Pred. Cat.	Act. Cat.	Image	Image Idx.	Pred. Cat.	Act. Cat.	Image
10	8033	Dog	Cat		9336	Dog	Cat	
9	9542	Truck	Car		3390	Dog	Cat	
8	345	Cat	Dog		4248	Dog	Cat	
7	1731	Cat	Dog		8069	Bird	Deer	
6	4930	Truck	Car		6383	Dog	Cat	
5	5598	Truck	Car		9406	Cat	Dog	
4	8549	Truck	Car		5724	Cat	Dog	
3	4206	Truck	Car		6174	Dog	Cat	
2	601	Cat	Dog		5237	Bird	Deer	
1	3067	Dog	Cat		6237	Dog	Cat	

By analysing each ranking, we can observe that

- MyResNet tends to mistake Car as Truck (5 times), Cat as Dog (2 times) and Dog as Cat (3 times)
- MyResNetDA tends to mistake Cat as Dog (6 times) and Dog as Cat (2 times)

As mentionned earlier, since those classes are of "same type", the error is understandable.