

Transfer Learning for Oxford Flowers-102 Using VGG19 and YOLOv5-CLS

1. Introduction

In this assignment we apply **transfer learning** using two pretrained convolutional neural network (CNN) models **VGG19** and **YOLOv5-CLS**—to classify images from the **Oxford Flowers-102** dataset into 102 categories. Both models are initialized with pretrained weights and adapted for the Flowers-102 classification task by replacing the final classification layer to output **102 logits**, which are converted to **class probabilities** using a **softmax** operation.

In this experiment we follow the required evaluation protocol using **two independent random dataset splits** and reporting accuracy and cross-entropy loss for **train/validation/test** over training epochs.

2. Dataset

2.1 Oxford Flowers-102 (Local Format)

The dataset is used in the standard Oxford format:

```
root/  
  jpg/  
  imagelabels.mat  
  setid.mat
```

- Images are loaded from `jpg/` using the naming convention `image_00001.jpg ... image_NNNNN.jpg`.
 - Labels are read from `imagelabels.mat` and converted from **1..102** to **0..101** for training.
-

3. Experimental Protocol

3.1 Random split strategy (performed twice)

A random permutation of indices is generated using a fixed seed, and the dataset is split into:

- **Training:** 50%
- **Validation:** 25%
- **Test:** 25%

This protocol was executed twice:

- **Split A:** `split_seed = 1`
- **Split B:** `split_seed = 2`

The generated split indices are saved to disk as JSON to ensure reproducibility:

- `split_indices_seed_1.json`
- `split_indices_seed_2.json`

3.2 Metrics

For each epoch, the following are computed on **train**, **validation**, and **test**:

- **Top-1 Accuracy**
- **Cross-Entropy Loss**

We also report the class probabilities to csv.

4. Preprocessing and Input Pipeline (Detailed)

4.1 Input size

- **VGG19:** images resized to **224×224**
- **YOLOv5-CLS:** images resized to **224×224** in this implementation (`img_size=224`), consistent with the training configuration used in the experiments.

4.2 Normalization

Because both models use pretrained ImageNet weights, images are normalized using **ImageNet mean/std**:

- `mean = [0.485, 0.456, 0.406]`
- `std = [0.229, 0.224, 0.225]`

4.3 Data augmentation (training only)

Training images undergo the following augmentations:

- `Resize to (img_size, img_size)`
- **Random horizontal flip with probability 0.5**
- **Random rotation within $\pm 15^\circ$**
- **Color jitter:**

- brightness = 0.1
- contrast = 0.1
- saturation = 0.1
- hue = 0.02
- Convert to tensor
- Normalize (ImageNet)

Validation and test transforms are deterministic:

- Resize to (img_size, img_size)
- Convert to tensor
- Normalize (ImageNet)

4.4 Probability outputs

The system outputs class probabilities by applying:

$$p(y = k \mid x) = \text{softmax}(\text{logits}(x))_k$$

Probabilities are exported to CSV files (both full-set and test-set exports), e.g.:

- probs_vgg19.csv, test_probs_vgg19_seed1.csv
- probs_yolov5.csv, test_probs_yolov5_seed2.csv

Example:

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	path	true_label	p.000	p.001	p.002	p.003	p.004	p.005	p.006	p.007	p.008	p.009	p.010	p.011	p.012	p.013	p.014	p.015	p.016	p.017	p.018	p.019	p.020	p		
2	C:\Users\hp\Downloads\102flowers.jpg	61	0.01871	1.681e-05	0.01791	0.004902	0.001658	4.90E-06	0.002845	1.19E-06	0.00032	4.85E-07	0.000574	4.89E-06	1.60E-06	3.94E-07	0.000464	0.01E-05	0.01623	0.009928	0.000393	1.51E-05	9.60E-05	0.00093	0.00093	
3	C:\Users\hp\Downloads\102flowers.jpg	91	3.82E-05	0.000005	0.000065	2.12E-05	0.000000	4.90E-06	1.39E-07	4.29E-06	0.000000	0.000000	2.28E-05	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
4	C:\Users\hp\Downloads\102flowers.jpg	23	6.69E-05	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
5	C:\Users\hp\Downloads\102flowers.jpg	23	6.79E-07	1.50E-05	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
6	C:\Users\hp\Downloads\102flowers.jpg	70	1.28E-05	0.000052	3.88E-07	7.57E-08	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
7	C:\Users\hp\Downloads\102flowers.jpg	73	0.000107	6.58E-05	0.002875	0.004715	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
8	C:\Users\hp\Downloads\102flowers.jpg	91	8.96E-08	2.89E-08	1.01E-05	5.42E-07	4.16E-06	1.09E-05	6.83E-09	7.94E-06	7.00E-05	7.76E-07	6.55E-05	0.005739	4.71E-05	1.76E-05	0.000641	0.01134	6.75E-06	7.56E-09	0.000465	0.000000	0.000000	0.000000	0.000000	
9	C:\Users\hp\Downloads\102flowers.jpg	88	0.000365	0.232E-06	4.59E-05	1.96E-06	3.00E-06	4.77E-07	9.60E-07	1.87E-06	2.12E-06	7.00E-10	0.000327	2.31E-06	2.34E-07	1.88E-09	0.000000	0.001886	8.22E-08	6.01E-05	0.01131	6.14E-06	0.000214	0.000000	0.000000	
10	C:\Users\hp\Downloads\102flowers.jpg	14	6.31E-06	6.68E-06	1.37E-06	1.29E-07	3.35E-05	1.69E-06	1.66E-07	0.000718	1.98E-06	6.80E-08	3.25E-07	3.35E-08	1.84E-08	1.38E-09	0.891601	0.000201	0.000992	0.000003	5.66E-06	0.000338	0.000000	0.000000	0.000000	
11	C:\Users\hp\Downloads\102flowers.jpg	85	0.034726	0.000000	0.000009	8.78E-05	0.010335	5.63E-05	0.00081	5.55E-05	0.00012	5.14E-06	0.000738	7.26E-05	1.04E-05	6.68E-07	0.000888	0.001702	0.003885	0.000400	0.000326	0.000000	0.000000	0.000000	0.000000	
12	C:\Users\hp\Downloads\102flowers.jpg	58	0.000000	3.52E-08	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
13	C:\Users\hp\Downloads\102flowers.jpg	32	0.000000	8.81E-06	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
14	C:\Users\hp\Downloads\102flowers.jpg	95	0.000329	0.000288	0.000021	0.001852	6.54E-06	0.0000179	0.000781	1.70E-07	0.000041	4.27E-07	0.000001	6.87E-07	5.76E-06	1.69E-06	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
15	C:\Users\hp\Downloads\102flowers.jpg	6	0.01783	0.001039	0.019597	0.028479	3.65E-05	0.000176	0.000577	4.30E-07	0.011391	3.44E-06	0.004619	2.64E-06	9.57E-06	1.73E-06	8.49E-06	6.06E-06	0.000907	0.012432	0.002238	0.000799	3.96E-07	0.000000	0.000000	
16	C:\Users\hp\Downloads\102flowers.jpg	96	0.004751	1.40E-06	0.000441	8.28E-05	7.57E-09	2.15E-06	2.18E-08	0.003867	5.12E-07	6.08E-06	5.03E-07	1.06E-07	1.79E-06	2.98E-08	0.000009	1.36E-06	7.39E-06	0.01354	0.000203	0.000000	0.000000	0.000000	0.000000	
17	C:\Users\hp\Downloads\102flowers.jpg	72	2.25E-07	5.72E-06	2.84E-07	2.58E-08	3.01E-07	3.14E-07	7.56E-06	7.30E-06	3.67E-09	1.88E-04	5.64E-08	1.16E-07	1.47E-10	1.75E-04	3.44E-07	5.14E-06	3.56E-05	1.23E-04	0.00034	2.22E-08	0.000000	0.000000	0.000000	
18	C:\Users\hp\Downloads\102flowers.jpg	42	1.30E-11	1.34E-05	0.000139	2.69E-05	0.002543	2.52E-06	8.30E-05	0.000000	0.000000	3.99E-06	1.35E-07	0.000297	5.69E-07	1.27E-06	2.28E-09	0.20089	0.050239	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
19	C:\Users\hp\Downloads\102flowers.jpg	22	1.31E-10	9.87E-10	1.12E-10	3.21E-10	1.28E-14	1.42E-07	3.12E-15	4.20E-14	4.01E-12	4.59E-13	2.24E-14	1.39E-14	1.87E-11	4.59E-12	3.58E-14	2.69E-13	1.01E-12	2.69E-13	8.34E-11	3.96E-11	3.96E-11	7.67E-13	0.000000	
20	C:\Users\hp\Downloads\102flowers.jpg	88	0.000796	2.81E-05	0.000724	0.002831	2.40E-05	2.91E-07	5.78E-05	8.47E-06	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
21	C:\Users\hp\Downloads\102flowers.jpg	77	0.020481	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
22	C:\Users\hp\Downloads\102flowers.jpg	14	2.03E-06	2.81E-05	4.74E-06	8.15E-06	1.40E-06	2.18E-06	0.0045	3.41E-06	2.90E-07	1.48E-05	0.00014	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
23	C:\Users\hp\Downloads\102flowers.jpg	97	0.020908	0.000452	0.001928	0.001393	0.000842	0.000001	0.000315	0.000163	0.002863	3.58E-06	0.02864	5.26E-05	6.62E-05	4.23E-05	0.000104	0.000199	0.000007	0.004217	0.058648	0.000000	0.000000	0.000000	0.000000	
24	C:\Users\hp\Downloads\102flowers.jpg	49	6.96E-06	6.68E-07	0.000119	6.42E-08	0.000042	1.80E-06	6.94E-07	4.34E-06	2.52E-07	3.65E-05	3.42E-07	0.005599	2.80E-05	1.07E-05	2.82E-05	2.55E-05	0.000342	5.38E-07	1.27E-06	1.22E-06	1.11E-06	0.000000	0.000000	
25	C:\Users\hp\Downloads\102flowers.jpg	97	7.73E-08	1.53E-05	3.86E-07	4.54E-05	3.56E-07	0.000178	1.43E-06	5.32E-06	5.66E-08	7.82E-10	2.36E-07	2.34E-07	1.18E-04	1.49E-06	9.28E-09	1.72E-06	5.61E-04	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
26	C:\Users\hp\Downloads\102flowers.jpg	69	0.007265	0.004615	0.000405	0.000000	0.000128	5.10E-05	0.002794	2.80E-06	1.63E-05	8.27E-06	6.66E-05	2.78E-05	0.000021	7.42E-07	0.021451	0.000038	0.000919	0.03065	0.001304	0.000007	1.63E-06	0.000000	0.000000	
27	C:\Users\hp\Downloads\102flowers.jpg	101	3.74E-06	0.000000	0.000000	0.000000	2.14E-06	0.000000	2.18E-05	1.32E-05	2.24E-05	1.14E-07	1.67E-05	6.40E-07	9.24E-05	4.10E-07	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
28	C:\Users\hp\Downloads\102flowers.jpg	70	2.18E-06	3.34E-06	1.24E-07	3.06E-09	0.002609	2.03E-06	8.62E-07	3.76E-07	7.81E-09	1.17E-07	2.76E-07	7.41E-05	3.59E-05	3.56E-06	5.06E-08	0.002876	0.000294	8.09E-07	1.03E-06	1.02E-07	0.000000	0.000000	0.000000	
29	C:\Users\hp\Downloads\102flowers.jpg	95	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
30	C:\Users\hp\Downloads\102flowers.jpg	50	0.002613	8.95E-05	0.01883	0.002546	3.63E-05	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
31	C:\Users\hp\Downloads\102flowers.jpg	68	0.000134	2.47E-05	0.000173	7.15E-05	0.000000	2.22E-06	0.000437	3.28E-07	9.46E-06	8.70E-06	3.37E-06	1.36E-05	1.43E-07	2.65E-05	2.45E-07	0.000321	0.000631	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
32	C:\Users\hp\Downloads\102flowers.jpg	76	0.000004	0.024091	0.000000	0.000000	0.000114	0.000000	0.000006	0.000049	7.78E-05	0.000163	8.25E-07	1.34E-05	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	
33	test_proh.jpg seed1																									

5. Models and Transfer Learning (Detailed Architecture)

5.1 Model 1: VGG19 (ImageNet pretrained)

Base model: `torchvision.models.vgg19(weights=IMAGENET1K_V1)`

Transfer learning modification:

- The VGG19 convolutional feature extractor (`model.features`) is **frozen** (no gradient updates).
- The final fully-connected layer in the classifier is replaced:
 - Original: `Linear(in_features, 1000)`
 - New: `Linear(in_features, 102)`

Trainable vs frozen parameters (Split A run):

- Total parameters: **139,988,134**
- Trainable parameters: **417,894**
- Frozen parameters: **139,570,240**

Interpretation:

This is classic “linear probing” on top of a frozen ImageNet backbone: only the classification head learns Flowers-102-specific decision boundaries.

5.2 Model 2: YOLOv5-CLS (Ultralytics pretrained classifier)

Base model: YOLOv5 classification checkpoint loaded via torch hub:

- `torch.hub.load("ultralytics/yolov5", "custom", path="yolov5s-cls.pt")`

Transfer learning modification:

- The final classifier layer is replaced to output 102 classes:
 - `head.linear = Linear(in_features, 102)`

Freezing strategy:

- Backbone frozen (`requires_grad=False`)
- Classification head unfrozen (`requires_grad=True`)

Trainable vs frozen parameters (Split A run):

- Total parameters: **4,303,142**
- Trainable parameters: **788,582**
- Frozen parameters: **3,514,560**

Interpretation:

Compared with VGG19, YOLOv5-CLS has far fewer total parameters and a larger proportion of trainable parameters (because the head is relatively larger in proportion), which can help faster adaptation.

6. Training Configuration

6.1 Shared components

- **Loss:** Cross-Entropy (`nn.CrossEntropyLoss()`)
- **Optimizer:** Adam
- **Scheduler:** ReduceLROnPlateau (monitoring validation loss)
 - factor = 0.5
 - patience = 3
- **Early stopping:** patience = 7 epochs (based on validation accuracy improvement)
- **Device:** CUDA GPU (NVIDIA RTX 4060 Laptop GPU reported during YOLO run)

6.2 Hyperparameters per model

VGG19:

- epochs = **35**
- batch size = **32**
- learning rate = **1e-4**
- weight decay = **0.0**
- freeze backbone = **True**

YOLOv5-CLS:

- epochs = **30**
 - batch size = **32** (default in our `run_experiment` unless overridden)
 - learning rate = **5e-5**
 - weight decay = **0.0**
 - freeze backbone = **True**
-

7. Results

7.1 Summary table

Model	Split	Seed	Best Epoch	Best Val Acc	Final Test Acc	Final Test Loss
VGG19	1	34	0.7626	0.7642	1.0066	
VGG19	2	35	0.7596	0.7734	0.9365	
YOLOv5-CLS	1	30	0.9184	0.9277	0.3863	
YOLOv5-CLS	2	30	0.9135	0.9199	0.3925	

7.2 Requirement check ($\geq 70\%$ test accuracy)

The requirement is satisfied by **both models**, and strongly exceeded by YOLOv5-CLS:

- VGG19 achieves **~76–77%** test accuracy
- YOLOv5-CLS achieves **~92%** test accuracy

7.3 Learning curves (accuracy and loss)

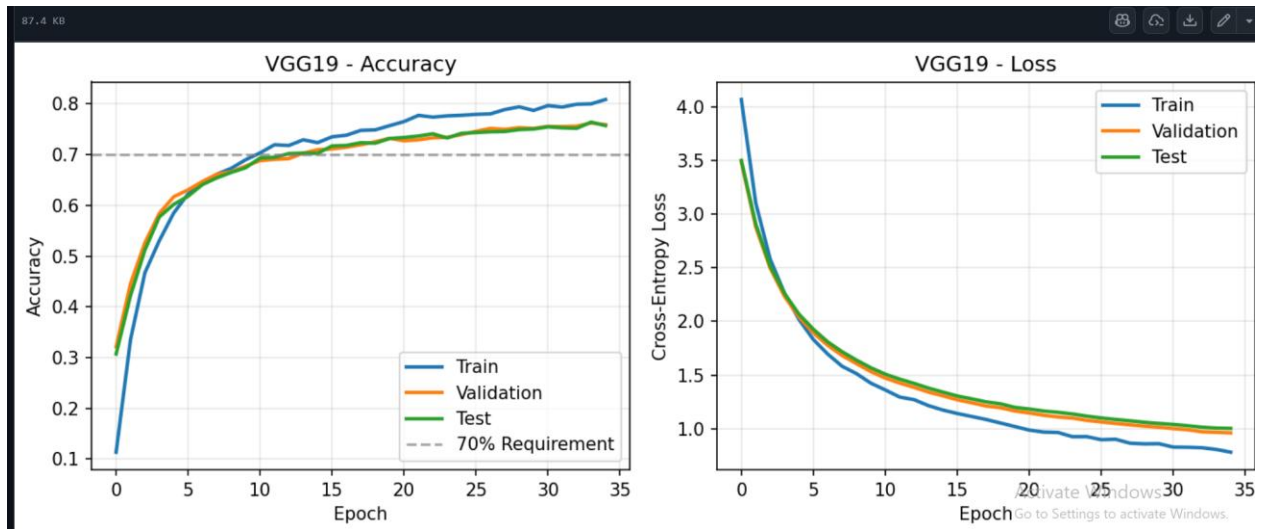
We saved and plotted the training plots per experiment as shown Below.

- Accuracy vs epoch: train/val/test
- Cross-entropy loss vs epoch: train/val/test

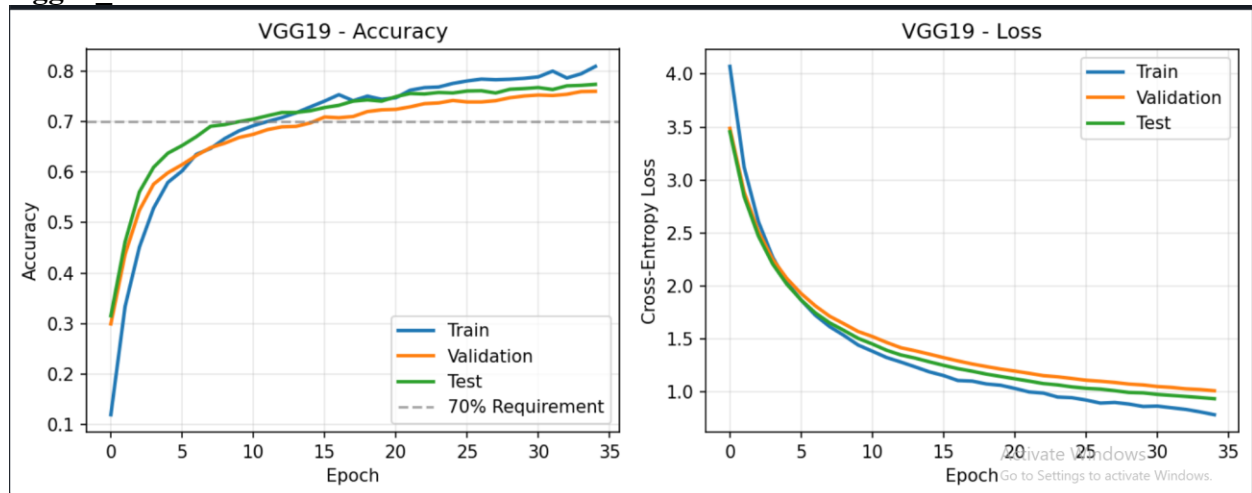
VGG19

- Figure 1: `./results/vgg19_seed1/accuracy_vgg19.png`
- Figure 2: `./results/vgg19_seed1/loss_vgg19.png`
- Figure 3: `./results/vgg19_seed2/accuracy_vgg19.png`
- Figure 4: `./results/vgg19_seed2/loss_vgg19.png`

Vgg19_seed1:



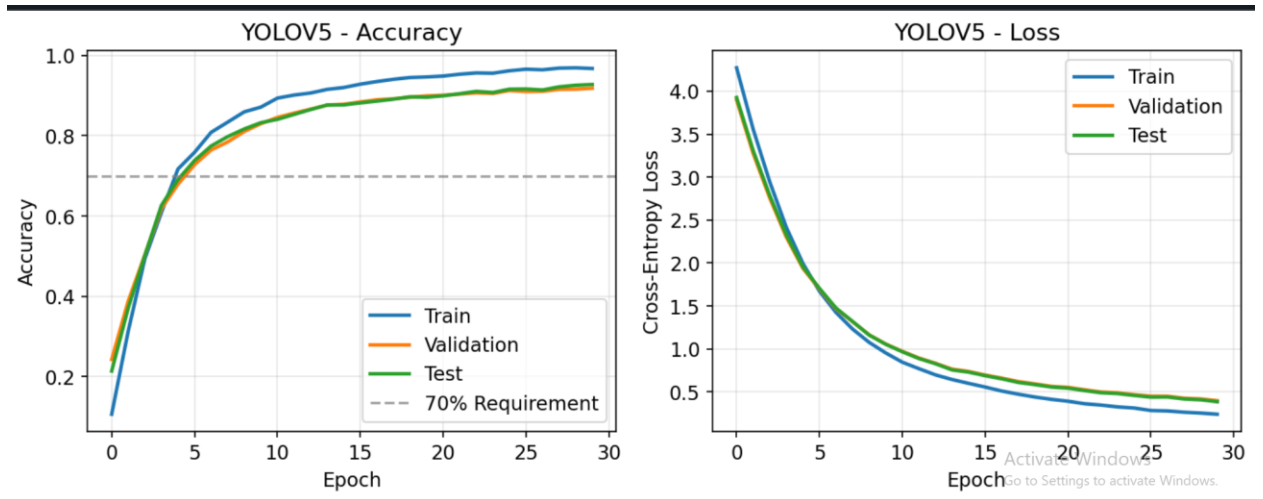
Vgg19 Seed2:



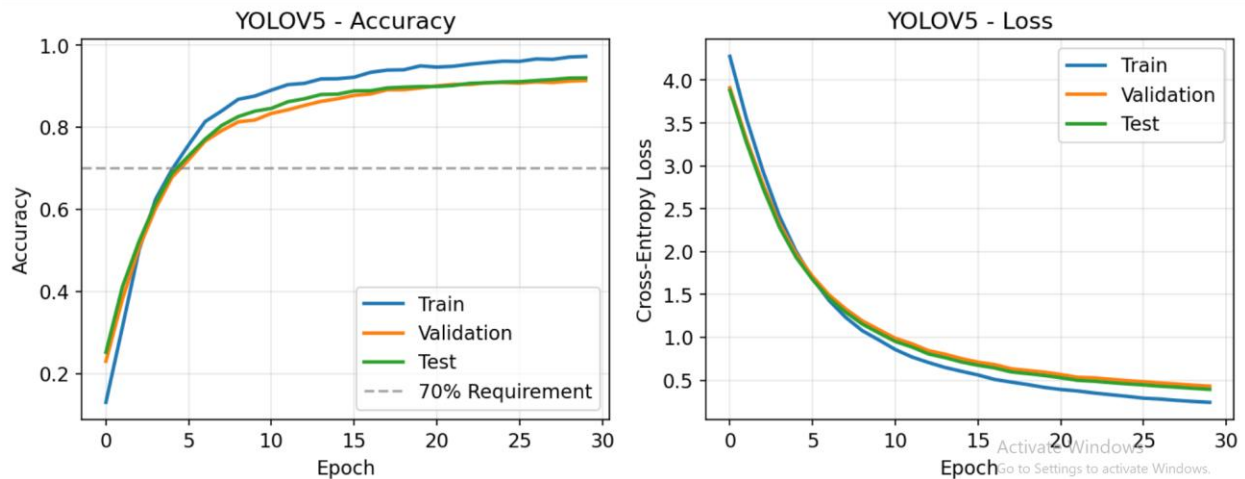
YOLOv5-CLS

- Figure 5: ./results/yolov5_cls_seed1/accuracy_yolov5.png
- Figure 6: ./results/yolov5_cls_seed1/loss_yolov5.png
- Figure 7: ./results/yolov5_cls_seed2/accuracy_yolov5.png
- Figure 8: ./results/yolov5_cls_seed2/loss_yolov5.png

YOLOv5_CLS seed 1:



YOLOV5_seed2:



8. Discussion

8.1 Performance comparison

YOLOv5-CLS significantly outperforms VGG19 on Flowers-102 in both splits:

- +15–16 percentage points higher test accuracy (approx. 92% vs 76–77%)

A likely explanation is that the YOLOv5-CLS pretrained classifier backbone and head design are more effective for fine-grained classification under the chosen augmentation and training regime, while VGG19's frozen feature extractor may limit representational adaptation.

8.2 Generalization and split stability

Both models are consistent across seeds:

- VGG19 varies by $\sim 0.9\%$ absolute test accuracy between seeds ($0.7642 \rightarrow 0.7734$).
- YOLOv5-CLS varies by $\sim 0.8\%$ absolute test accuracy between seeds ($0.9277 \rightarrow 0.9199$).

This indicates the results are not overly sensitive to the random partitioning procedure.

8.3 Training dynamics

Based on the final outcomes:

- VGG19's higher test loss ($\approx 0.94\text{--}1.01$) suggests it remains less confident and/or less well-calibrated than YOLOv5-CLS.
- YOLOv5-CLS achieves substantially lower test loss (≈ 0.39) alongside high accuracy, indicating both strong correctness and stronger probability concentration on correct classes.

9. Conclusion

This study implemented transfer learning for Flowers-102 using **VGG19** and **YOLOv5-CLS**, following a strict 50/25/25 split repeated across two random seeds. Both models achieved the assignment's minimum target of 70% test accuracy, with **YOLOv5-CLS** delivering the best overall performance ($\approx 92\%$ test accuracy). The implementation also exports **class probability outputs** via softmax and produces the required **train/val/test accuracy and cross-entropy curves**.