

# 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.

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## 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.
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## 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.

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## 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 **±15°**
- 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	p	
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	1.68E-05	0.011791	0.004902	0.001658	4.00E-06	0.002645	1.19E-06	0.00032	4.85E-07	0.008574	4.89E-06	1.60E-06	3.94E-07	0.000464	4.01E-05	0.001623	0.006928	0.01383	1.51E-05	9.60E-05		
3	C:\Users\hp\Downloads\102flowers\jpg\	91	3.82E-05	3.10E-06	0.000605	2.12E-05	0.000261	4.93E-05	1.36E-07	0.000476	4.28E-05	0.00488	2.28E-05	0.001379	0.002981	0.003293	2.68E-05	1.42E-06	0.026375	0.009973	0.002095	9.98E-07	0.000593		
4	C:\Users\hp\Downloads\102flowers\jpg\	22	0.00973	8.69E-05	0.000139	4.05E-06	7.99E-07	2.63E-05	2.43E-06	0.003488	1.72E-06	0.001409	0.002758	1.09E-06	0.001409	0.002758	1.58E-06	0.016892	0.000147	2.65E-05	0.000433	0.009476	0.021471	0.00041	
5	C:\Users\hp\Downloads\102flowers\jpg\	23	6.79E-07	1.50E-05	0.00027	2.04E-05	1.34E-05	0.000148	4.14E-07	0.015419	2.69E-05	0.005773	1.89E-05	0.00454	0.000994	0.000291	0.000297	4.10E-05	0.01295	0.000449	0.000322	4.37E-06	0.008512		
6	C:\Users\hp\Downloads\102flowers\jpg\	70	1.28E-05	0.000552	3.88E-07	7.57E-08	0.002102	3.75E-05	6.81E-06	9.36E-06	8.61E-07	3.11E-07	7.59E-05	8.09E-05	3.01E-07	4.58E-05	4.02E-06	0.006343	0.003845	3.23E-05	3.23E-05	6.48E-08			
7	C:\Users\hp\Downloads\102flowers\jpg\	73	0.000107	6.58E-05	0.002875	0.004715	0.000271	0.000898	0.000102	1.10E-06	0.000217	3.17E-07	0.200849	1.84E-05	1.22E-05	3.52E-07	2.43E-05	0.008929	3.19E-06	0.001134	3.75E-05	2.40E-05	0.016516		
8	C:\Users\hp\Downloads\102flowers\jpg\	91	8.96E-08	2.89E-08	1.01E-06	5.42E-07	4.16E-06	1.09E-06	6.83E-06	7.94E-07	7.00E-06	8.76E-07	1.21E-06	0.005327	2.31E-07	2.34E-07	1.88E-06	0.01886	8.22E-08	6.01E-05	0.01131	6.14E-06	0.000214		
9	C:\Users\hp\Downloads\102flowers\jpg\	88	0.000636	2.32E-06	4.59E-05	1.96E-06	3.00E-06	4.77E-07	1.87E-06	2.12E-06	0.000327	2.31E-07	1.21E-06	0.00088	0.001131	0.000214	0.000338	0.000338	0.000338	0.000338	0.000338	0.000338			
10	C:\Users\hp\Downloads\102flowers\jpg\	14	6.31E-06	6.08E-06	1.37E-06	1.29E-07	1.09E-07	1.69E-06	1.66E-06	0.007818	1.39E-06	6.80E-08	3.25E-07	3.33E-07	1.88E-06	1.38E-07	0.091861	0.000209	5.66E-05	3.68E-05	0.000338	0.000338			
11	C:\Users\hp\Downloads\102flowers\jpg\	88	0.034728	6.72E-05	0.000306	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	0.00088	0.01702	0.000385	0.003481	0.03236	0.000194	4.58E-05		
12	C:\Users\hp\Downloads\102flowers\jpg\	58	0.002933	5.92E-06	5.96E-06	4.01E-07	0.000644	7.69E-06	7.31E-06	9.23E-05	1.47E-06	2.05E-07	1.53E-05	5.49E-06	0.000178	3.19E-05	0.000203	0.000462	0.000974	3.42E-05	4.54E-05				
13	C:\Users\hp\Downloads\102flowers\jpg\	32	0.004367	6.81E-06	0.000214	2.76E-05	1.86E-06	2.27E-06	0.000301	2.15E-06	0.000111	1.96E-06	3.13E-07	1.98E-07	3.93E-06	2.79E-07	9.37E-07	6.41E-07	2.47E-05	0.000114	0.017503	0.000164	4.35E-07		
14	C:\Users\hp\Downloads\102flowers\jpg\	95	0.003329	0.002828	0.000231	0.001852	6.54E-06	0.000179	0.031761	1.70E-07	0.000417	4.27E-07	0.005571	6.87E-07	8.57E-06	5.86E-06	1.69E-06	1.30E-05	8.22E-05	0.000517	0.000421	0.002113	4.98E-07		
15	C:\Users\hp\Downloads\102flowers\jpg\	6	0.01783	0.001039	0.019597	0.028479	3.65E-05	0.000176	0.09577	4.30E-07	0.01139	1.34E-05	0.004619	2.64E-06	9.95E-06	1.73E-06	8.49E-06	6.06E-06	0.000807	0.012430	0.002238	0.00799	3.39E-06		
16	C:\Users\hp\Downloads\102flowers\jpg\	9	0.000475	1.40E-06	0.000144	2.28E-05	7.57E-09	3.51E-06	2.18E-08	0.003867	5.12E-07	1.06E-06	1.79E-06	2.98E-06	0.000909	1.36E-05	8.92E-06	7.39E-06	0.01354	0.000323	0.000323	0.001013			
17	C:\Users\hp\Downloads\102flowers\jpg\	72	2.25E-07	5.72E-07	2.84E-07	8.52E-08	3.01E-07	2.14E-07	7.56E-06	7.30E-07	3.60E-09	9.99E-10	1.88E-07	5.64E-08	1.16E-07	1.47E-10	1.75E-05	3.44E-07	5.14E-06	3.56E-05	3.94E-05	2.22E-08			
18	C:\Users\hp\Downloads\102flowers\jpg\	42	0.003117	1.34E-05	0.000139	2.69E-05	0.000253	4.52E-06	8.30E-06	0.000165	3.99E-06	1.39E-07	0.002397	5.69E-06	1.72E-07	2.28E-09	0.000909	0.000195	0.001010	7.32E-05	0.00023	0.001119			
19	C:\Users\hp\Downloads\102flowers\jpg\	22	1.30E-06	9.87E-10	1.12E-12	3.01E-13	1.28E-16	1.42E-07	3.01E-13	4.20E-14	4.01E-12	4.45E-13	2.42E-14	1.39E-14	1.87E-11	4.59E-12	3.58E-16	2.39E-16	1.01E-12	2.66E-13	8.64E-11	3.96E-11	7.67E-13		
20	C:\Users\hp\Downloads\102flowers\jpg\	80	0.000706	2.81E-05	0.006724	0.002831	2.40E-05	2.91E-06	7.24E-05	8.47E-06	0.000168	1.38E-08	0.02305	9.99E-06	2.69E-05	2.99E-07	0.001757	9.00E-05	7.18E-06	0.016817	0.000305	8.67E-06	0.004844		
21	C:\Users\hp\Downloads\102flowers\jpg\	37	0.000484	0.000219	0.000809	8.60E-05	8.24E-06	0.000159	0.01244	9.24E-06	0.00087	0.000513	1.69E-06	0.000249	0.002697	4.08E-05	1.92E-06	1.54E-07	0.000851	0.0004642	0.01664	0.000259	3.98E-05		
22	C:\Users\hp\Downloads\102flowers\jpg\	14	2.03E-06	2.81E-05	4.74E-06	8.15E-06	1.04E-05	1.18E-06	2.16E-05	0.008485	3.41E-05	2.90E-07	1.48E-05	0.000115	2.53E-09	0.166754	0.000328	1.11E-05	0.000109	1.15E-05	0.000298	0.011826			
23	C:\Users\hp\Downloads\102flowers\jpg\	97	0.022098	0.000452	0.021926	0.01893	0.000182	0.005041	0.000155	0.000163	0.008265	5.08E-06	0.028654	2.56E-05	6.62E-05	4.23E-05	0.000144	0.000199	0.000571	0.004217	0.058648	0.000406	0.000939		
24	C:\Users\hp\Downloads\102flowers\jpg\	49	6.95E-06	6.68E-07	0.00015	6.42E-08	0.005442	1.80E-06	6.94E-07	4.34E-06	2.56E-07	3.65E-05	3.42E-07	0.005295	2.80E-05	5.10E-07	2.82E-05	2.55E-05	0.003542	5.38E-05	9.77E-06	1.22E-06	4.11E-08		
25	C:\Users\hp\Downloads\102flowers\jpg\	79	7.35E-06	1.53E-05	3.86E-07	4.54E-05	3.56E-07	0.000178	1.43E-06	5.32E-06	5.66E-06	7.82E-10	2.36E-07	2.34E-07	1.18E-07	1.49E-06	9.28E-06	1.72E-06	5.61E-08	4.11E-06	1.45E-07	3.39E-05	1.69E-06		
26	C:\Users\hp\Downloads\102flowers\jpg\	69	0.007265	0.004615	4.00E-05	3.74E-06	0.000128	5.10E-05	0.002794	2.80E-05	1.63E-05	9.27E-08	6.06E-05	2.76E-05	0.000201	7.42E-07	0.021451	0.003418	0.000939	0.003065	0.003104	1.63E-06			
27	C:\Users\hp\Downloads\102flowers\jpg\	101	3.17E-06	0.002	5.95E-05	0.000105	2.14E-06	0.00014	2.18E-05	1.32E-05	2.24E-05	1.41E-07	1.67E-05	6.40E-07	9.24E-05	4.10E-07	0.000138	4.14E-07	0.000968	0.007424	0.000894	1.01E-05	8.94E-06		
28	C:\Users\hp\Downloads\102flowers\jpg\	70	2.84E-06	3.34E-06	1.24E-07	3.06E-09	0.00269	2.03E-05	5.82E-07	3.76E-06	7.81E-09	1.18E-07	2.76E-07	7.41E-05	3.87E-05	5.98E-06	3.56E-05	5.00E-08	0.002376	0.000293	9.06E-07	1.03E-06	1.02E-07		
29	C:\Users\hp\Downloads\102flowers\jpg\	73	0.004853	0.002038	0.045729	0.025406	0.000158	0.00268	0.000427	0.000108	0.005011	2.09E-05	0.020452	1.01E-05	0.000384	0.000183	0.002297	0.001304	0.000378	0.006984	0.0055	0.000707	0.019604		
30	C:\Users\hp\Downloads\102flowers\jpg\	50	0.020613	8.95E-05	0.01883	0.002546	3.63E-05	3.07E-06	0.0087	1.38E-05	0.001698	8.11E-07	0.017688	3.80E-06	1.69E-06	1.89E-07	0.000117	0.000178	8.83E-05	0.00031	0.029256	0.00214	3.70E-05		
31	C:\Users\hp\Downloads\102flowers\jpg\	68	0.000314	2.47E-05	0.000173	7.16E-05	0.000139	2.23E-06	0.000437	3.23E-07	9.46E-06	5.70E-06	3.37E-06	1.36E-06	1.24E-06	2.65E-05	0.000231	0.000631	0.003137	4.70E-05	2.50E-08				
32	C:\Users\hp\Downloads\102flowers\jpg\	76	0.00049	0.024091	0.000386	0.000114	0.000165	0.00046	0.000949	7.76E-05	0.000163	8.25E-07	1.54E-05	0.000531	6.17E-05	0.000253	0.002135	2.06E-05	0.000966	0.131861	0.002135	0.002647			

Go to Settings to activate Virtual Machine

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## 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.

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### 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.

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## **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  $\sim 76\text{--}77\%$  test accuracy
- YOLOv5-CLS achieves  $\sim 92\%$  test accuracy

### 7.3 Learning curves (accuracy and loss)

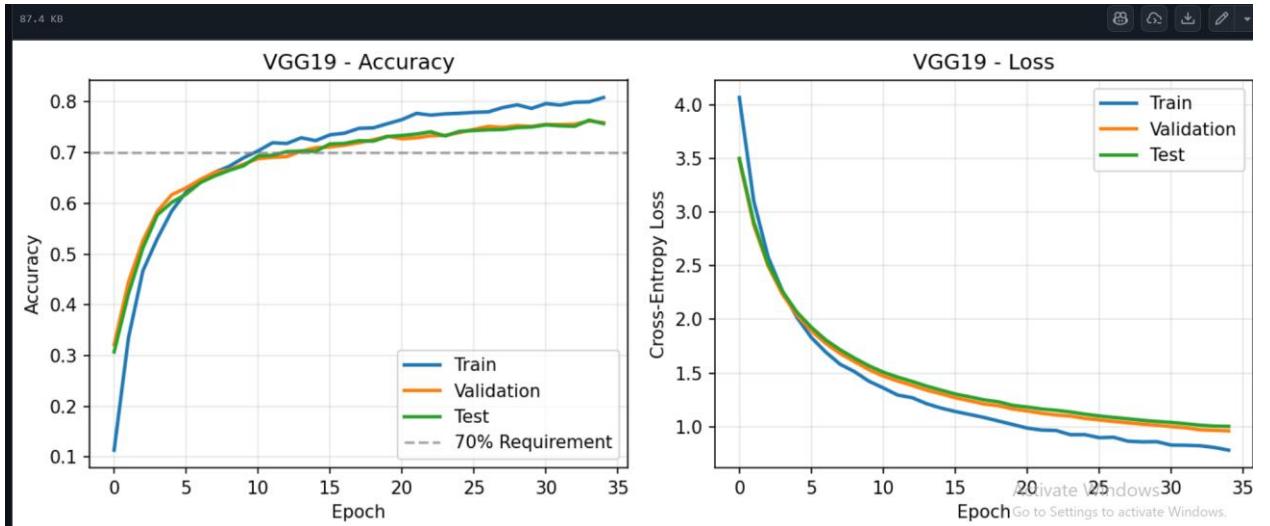
We saved and plotted the training plots per experiment as shown Below.

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

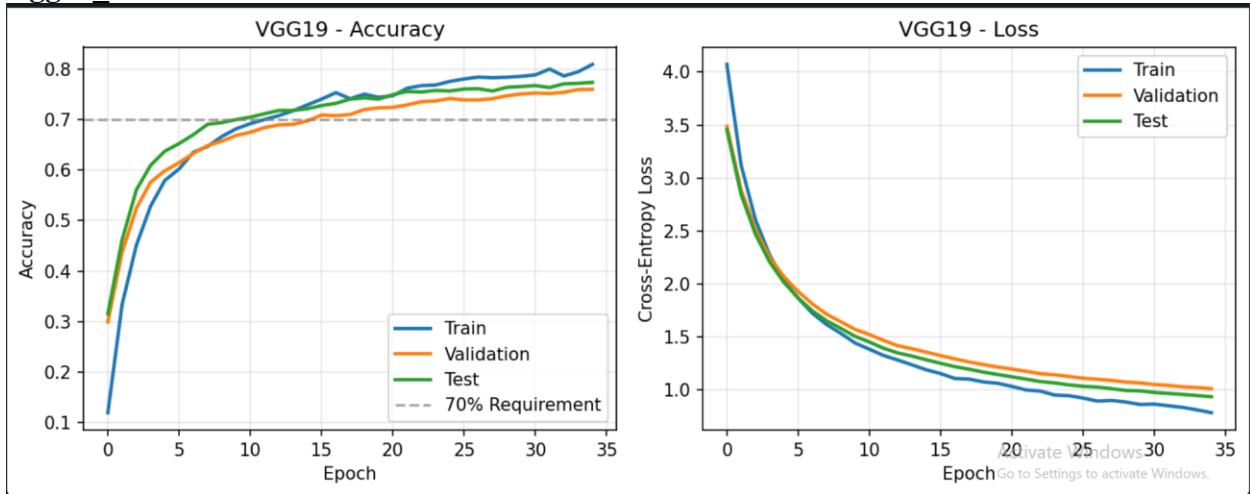
#### VGG19

- 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:



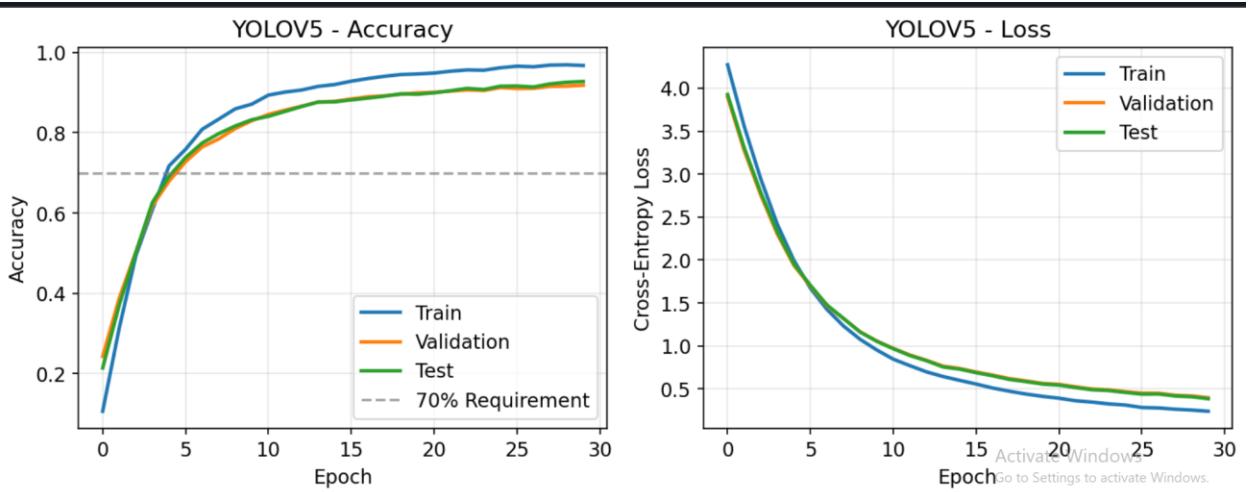
**Vgg19\_Seed2:**



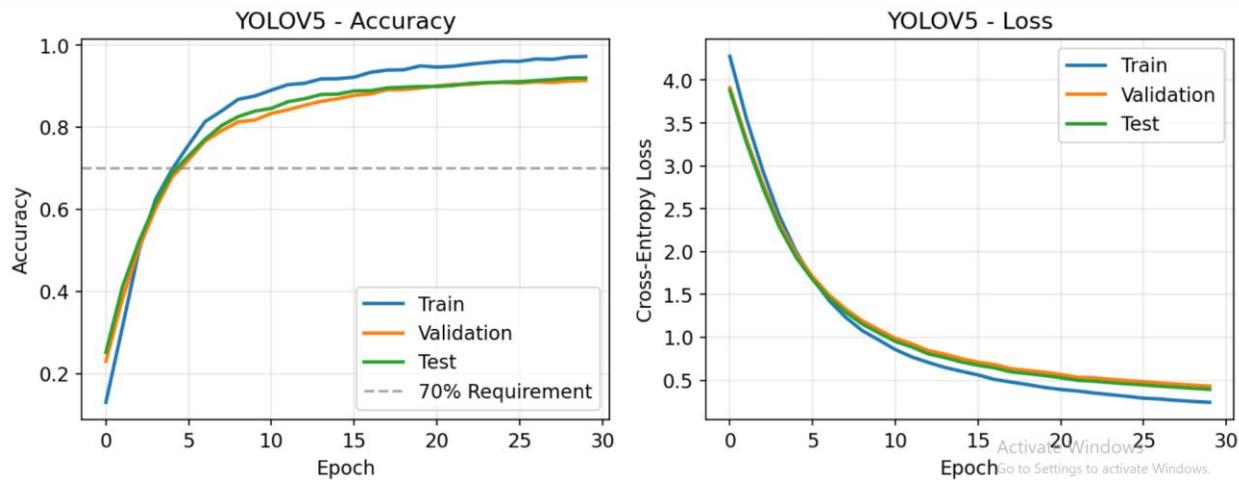
## YOLOv5-CLS

- **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 ~0.9% absolute test accuracy between seeds (0.7642 → 0.7734).
- YOLOv5-CLS varies by ~0.8% absolute test accuracy between seeds (0.9277 → 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 ( $\approx 0.39$ ) alongside high accuracy, indicating both strong correctness and stronger probability concentration on correct classes.
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## 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**.