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:

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

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:`

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
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	0.001383	1.51E-05	9.60E-05
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	0.009773	0.000295	9.99E-07	0.000593
C:\Users\hp\Downloads\102flowers\jpg\	22	0.000973	8.69E-05	0.000139	4.05E-06	7.99E-07	2.63E-05	2.43E-06	0.063488	1.72E-06	2.35E-05	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
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	0.00094	0.000291	0.000297	4.10E-05	0.01295	0.000449	0.000322	4.37E-06	0.008512
C:\Users\hp\Downloads\102flowers\jpg\	70	1.28E-05	0.000552	3.88E-07	7.57E-08	0.002102	3.75E-05	4.45E-05	9.36E-06	6.81E-08	3.11E-07	4.02E-06	7.59E-05	8.09E-05	3.01E-07	4.56E-05	4.02E-06	0.006343	0.003845	3.23E-05	3.23E-05	6.48E-08
C:\Users\hp\Downloads\102flowers\jpg\	73	0.000107	6.58E-05	0.002875	0.004715	0.000271	0.000899	0.000102	1.10E-05	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
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	0.000704	7.94E-06	7.00E-05	8.76E-07	3.65E-05	0.005739	4.17E-05	1.94E-05	1.76E-08	0.000641	0.001184	6.75E-06	7.56E-09	0.000465
C:\Users\hp\Downloads\102flowers\jpg\	88	0.000636	2.32E-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-08	2.34E-07	1.88E-09	2.08E-05	0.001886	8.22E-08	6.01E-05	0.001131	6.14E-06	0.000214
C:\Users\hp\Downloads\102flowers\jpg\	14	6.31E-06	6.08E-06	1.37E-06	1.29E-07	3.35E-05	1.69E-06	1.66E-07	0.007818	1.39E-09	6.80E-08	3.25E-07	3.33E-05	1.88E-06	1.38E-09	0.891661	0.000201	0.000592	0.000603	5.66E-05	3.68E-05	0.000338
C:\Users\hp\Downloads\102flowers\jpg\	85	0.034726	6.72E-05	0.000309	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	0.008385	0.003481	0.003236	0.000194	4.58E-05
C:\Users\hp\Downloads\102flowers\jpg\	58	0.000293	5.92E-06	5.96E-05	4.01E-07	0.000644	7.65E-06	7.31E-06	9.23E-05	1.47E-06	7.68E-08	1.37E-05	2.58E-05	1.53E-05	5.49E-08	0.000178	3.19E-05	0.000203	0.000462	0.000974	3.42E-05	4.54E-05
C:\Users\hp\Downloads\102flowers\jpg\	32	0.004367	6.81E-06	0.000214	2.76E-05	1.86E-06	1.27E-06	0.000301	2.15E-06	0.000112	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
C:\Users\hp\Downloads\102flowers\jpg\	95	0.003329	0.002828	0.002231	0.001852	6.54E-06	0.000179	0.031761	1.70E-07	0.000417	4.27E-07	0.000571	6.87E-07	8.57E-06	5.86E-08	1.69E-06	1.30E-05	8.22E-05	0.000517	0.000421	0.002113	4.98E-07
C:\Users\hp\Downloads\102flowers\jpg\	6	0.001783	0.001039	0.019597	0.028479	3.65E-05	0.000176	0.09577	4.30E-07	0.011391	1.34E-05	0.004619	2.64E-06	9.95E-06	1.73E-06	8.49E-06	6.06E-06	0.000807	0.012432	0.002238	0.000799	3.39E-06
C:\Users\hp\Downloads\102flowers\jpg\	96	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-08	5.03E-07	1.06E-07	1.79E-06	2.98E-08	0.000909	1.36E-05	8.92E-06	7.39E-06	0.001354	0.000323	0.000103
C:\Users\hp\Downloads\102flowers\jpg\	72	2.25E-07	5.72E-06	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	1.23E-05	3.94E-05	2.22E-08
C:\Users\hp\Downloads\102flowers\jpg\	42	0.003117	1.34E-05	0.000139	2.69E-05	0.002543	2.52E-06	8.30E-05	0.000165	3.99E-06	1.39E-07	0.002397	5.69E-06	1.72E-07	2.28E-09	0.20089	0.050239	0.000195	0.001012	7.32E-05	0.00023	0.001119
C:\Users\hp\Downloads\102flowers\jpg\	22	1.30E-13	9.87E-10	1.12E-12	3.01E-13	1.28E-16	1.42E-07	3.12E-15	4.20E-14	4.01E-12	4.45E-13	2.24E-14	1.39E-14	1.87E-11	4.59E-12	3.58E-16	2.39E-12	1.01E-12	2.66E-13	8.64E-11	3.96E-11	7.67E-13
C:\Users\hp\Downloads\102flowers\jpg\	88	0.000706	2.81E-05	0.006724	0.002831	2.40E-05	2.91E-05	7.24E-05	8.47E-06	0.000165	1.38E-08	0.02305	9.99E-08	2.69E-05	2.99E-07	0.001757	9.00E-05	7.18E-06	0.016817	0.000305	8.67E-06	0.004844
C:\Users\hp\Downloads\102flowers\jpg\	37	0.000484	0.000219	0.000805	8.60E-05	8.24E-06	0.000159	0.001244	9.24E-05	0.000872	0.000513	1.69E-06	0.000244	0.002697	4.08E-05	1.92E-05	1.54E-07	0.006851	0.006412	0.01664	0.000259	3.98E-05
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	0.08645	3.41E-06	2.90E-07	1.48E-05	0.00014	0.000115	2.53E-09	0.166754	0.000328	1.11E-05	0.000108	1.15E-05	0.000298	0.011826
C:\Users\hp\Downloads\102flowers\jpg\	97	0.022098	0.000452	0.021928	0.001393	0.000182	0.000541	0.000315	0.000163	0.008263	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
C:\Users\hp\Downloads\102flowers\jpg\	49	6.96E-06	6.68E-07	0.00016	6.42E-08	0.005442	1.80E-06	6.94E-07	4.34E-06	2.56E-07	3.65E-05	3.42E-07	0.055295	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
C:\Users\hp\Downloads\102flowers\jpg\	79	7.35E-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-07	1.49E-08	9.28E-09	1.72E-06	5.61E-08	4.11E-06	1.45E-07	3.39E-05	1.69E-06
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	0.005107	1.63E-06
C:\Users\hp\Downloads\102flowers\jpg\	101	3.17E-06	0.002	5.95E-05	0.000105	2.14E-06	0.000145	2.18E-05	1.32E-05	2.24E-05	1.41E-07	1.67E-05	6.40E-07	9.24E-05	4.10E-07	0.000133	4.14E-07	0.000968	0.007424	0.000894	1.01E-05	8.94E-06
C:\Users\hp\Downloads\102flowers\jpg\	70	2.84E-06	3.34E-06	1.24E-07	3.06E-09	0.020269	2.03E-06	5.82E-07	3.76E-06	7.81E-09	1.18E-07	2.76E-07	7.41E-05	3.87E-05	5.98E-08	3.56E-06	5.00E-08	0.002876	0.000294	9.06E-07	1.03E-06	1.02E-07
C:\Users\hp\Downloads\102flowers\jpg\	73	0.004583	0.002038	0.045729	0.025406	0.000158	0.000264	0.000427	0.000108	0.005011	2.09E-05	0.020452	1.01E-05	0.000364	0.000183	0.002297	0.001304	0.000378	0.006984	0.0055	0.000707	0.019604
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	0.000718	8.83E-05	0.00031	0.029256	0.00214	3.70E-05
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-05	1.43E-06	1.24E-07	2.65E-05	2.45E-07	0.003231	0.000631	0.003137	4.70E-05	2.50E-08
C:\Users\hp\Downloads\102flowers\jpg\	76	0.00049	0.024091	0.000386	0.000114	0.000165	0.00046	0.000949	7.78E-05	0.000163	8.25E-07	1.64E-05	0.000531	0.002415	1.62E-06	0.000253	6.17E-05	0.000966	0.131861	0.002135	2.06E-05	0.002647

test_probs_vgg19_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.

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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)

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**

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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 (≥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)

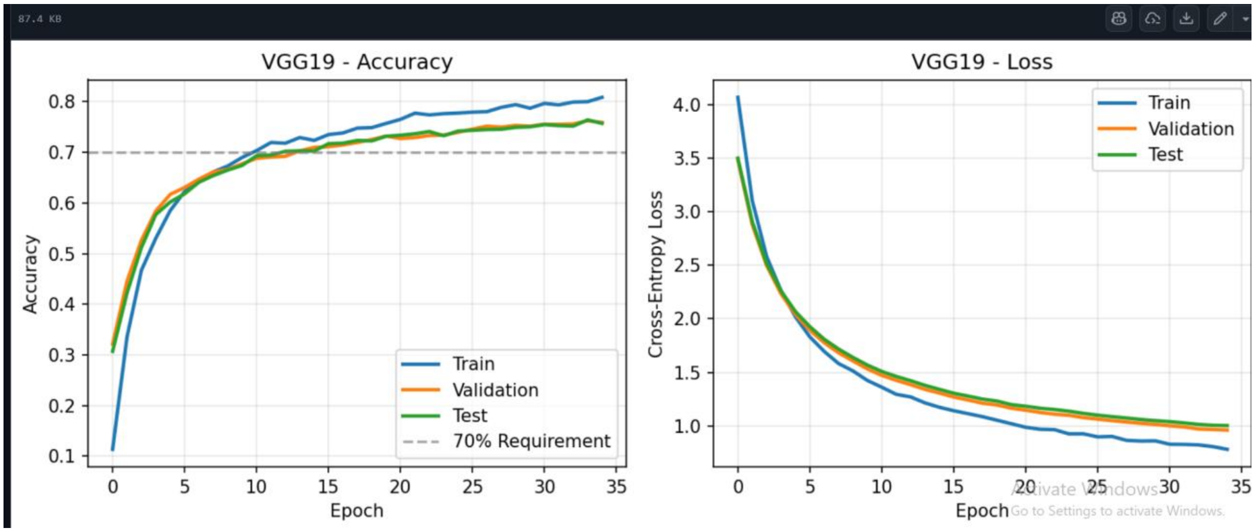
We saved and plotted the training plots per experiment as shown Below.

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

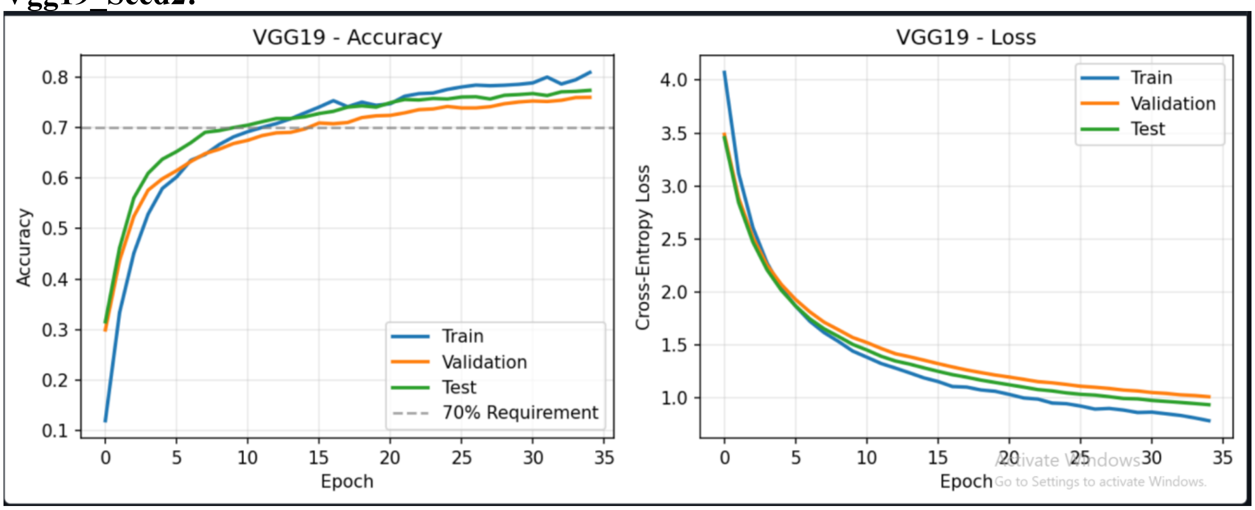
VGG19

- 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:



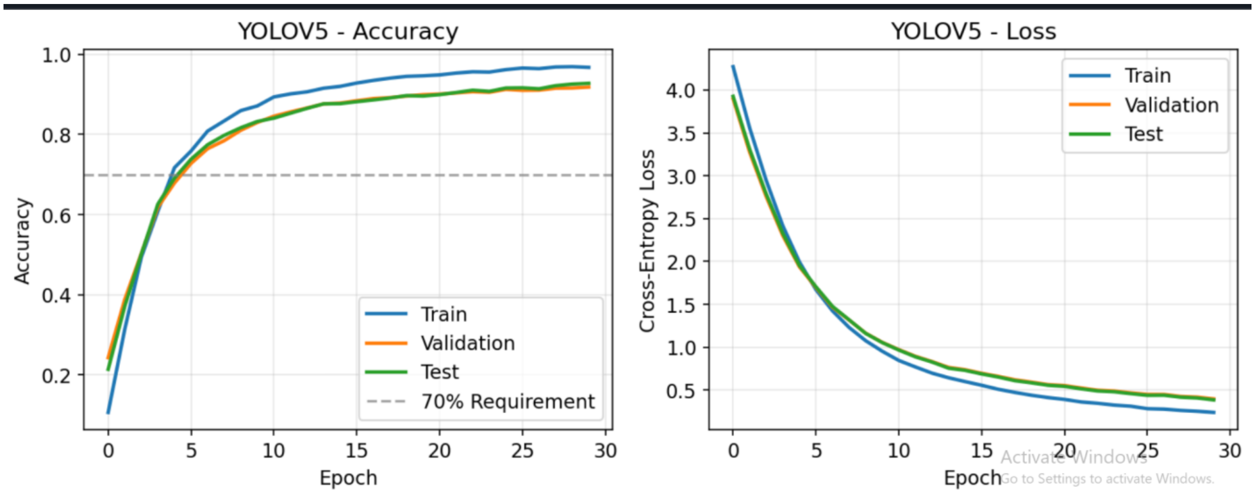
Vgg19_Seed2:



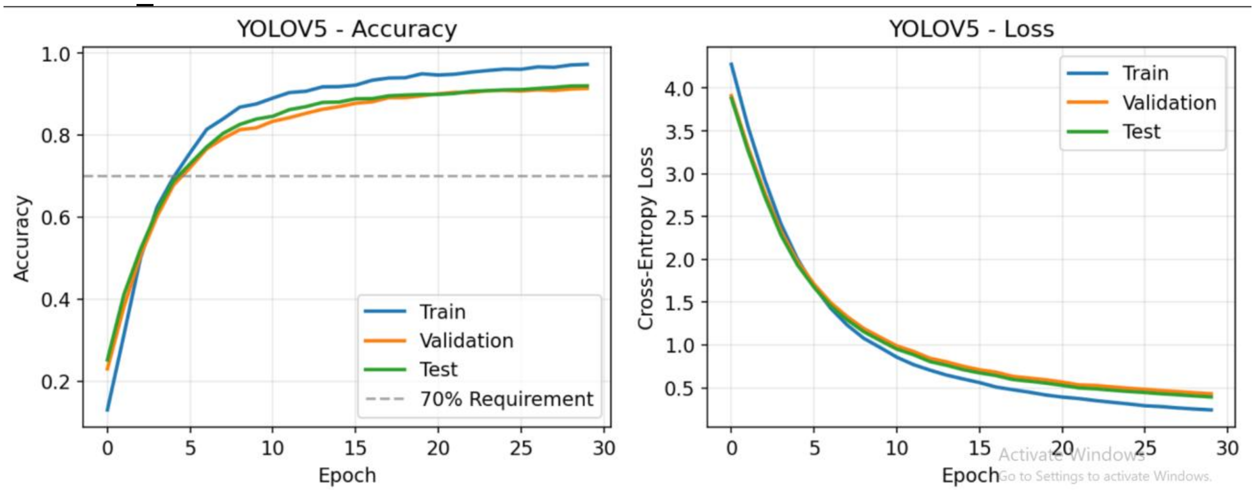
YOLOv5-CLS

- 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 ~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 (≈0.94–1.01) 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.

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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 (≈92% test accuracy). The implementation also exports **class probability outputs** via softmax and produces the required **train/val/test accuracy and cross-entropy curves**.