Metric Learning: Triplet-Loss

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I. The Triplet-Loss Pipeline

In this supervised similarity (metric learning), the Triplet-Loss pipeline consists of

1) Retrieve images from CUB200_2011 dataset within `TripletCUBDataset` class
2) Transform images into tensors and apply additional augmentations to the training set only
3) Train the model using ResNet18 and ResNet34 pre-trained backbones using the `TripletMarginLoss` function and `Adam` optimizer
4) The training run calculates the loss (or distance) between triplets (anchor, positive, negative) and updates the weights
5) Run the trained model against the test (non-augmented) dataset and observe the loss, cosine similarity and precision and compare to training results

II. Training Hyper-parameters

We conducted 4 experiments using two pre-trained models: ResNet18 and ResNet34
ResNet18 contains approximately 11.4 million parameters
ResNet34 contains approximately 21.5 million parameters

1) epochs: 20, learning rate: 0.001, batch size: 32
2) epochs: 20, learning rate: 0.002, batch size: 32
3) epochs: 20, learning rate: 0.001, batch size: 64
4) epochs: 20, learning rate: 0.002, batch size: 64
   Extended Training with ResNet18
5) epochs: 60, learning rate: 0.001, batch size: 32
6) epochs: 60, learning rate: 0.001, batch size: 64

III. Training Curves

A. ResNet18

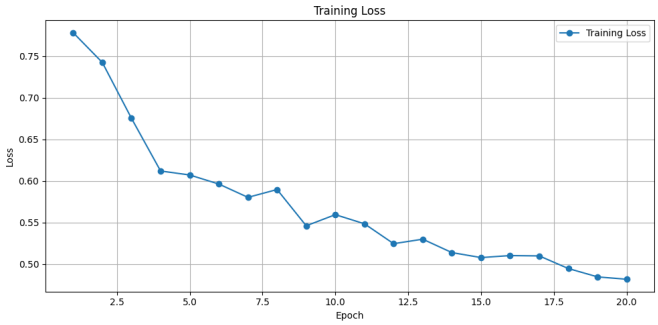

Fig. 1. Experiment 1 with ResNet18

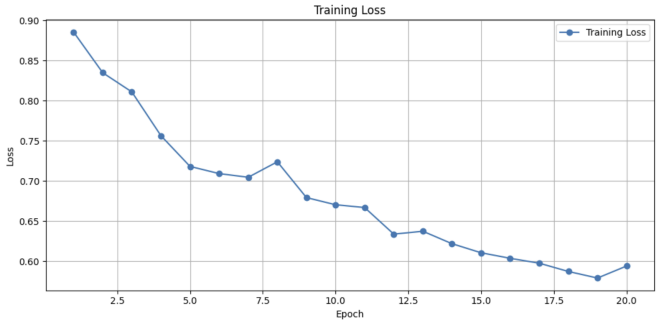

Fig. 2. Experiment 2 with ResNet18

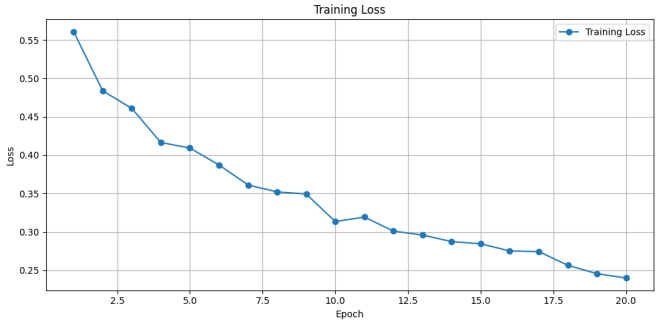

Fig. 3. Experiment 3 with ResNet18

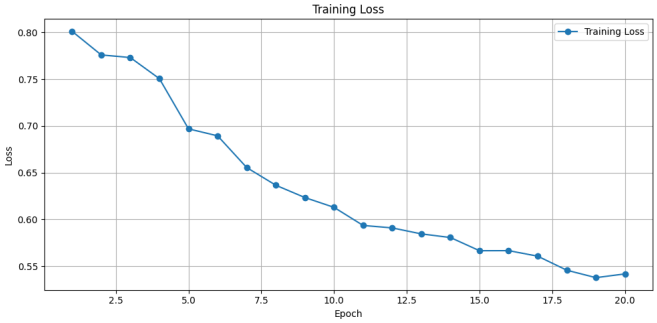

Fig. 4. Experiment 4 with ResNet18

B. *ResNet34*

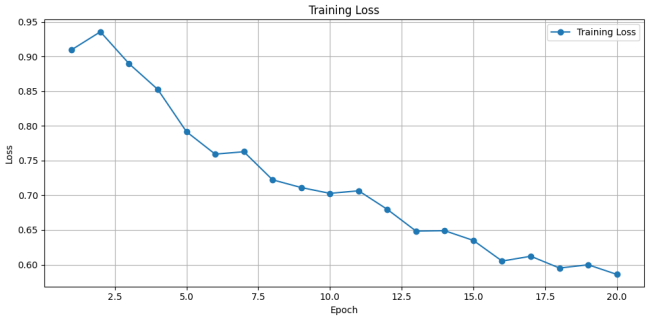

Fig. 5. Experiment 1 with ResNet34

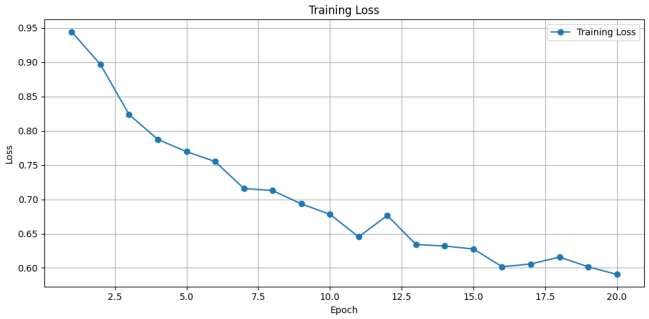

Fig. 6. Experiment 2 with ResNet34

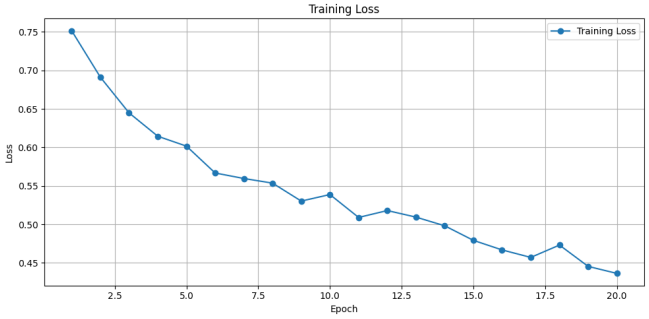

Fig. 7. Experiment 3 with ResNet34

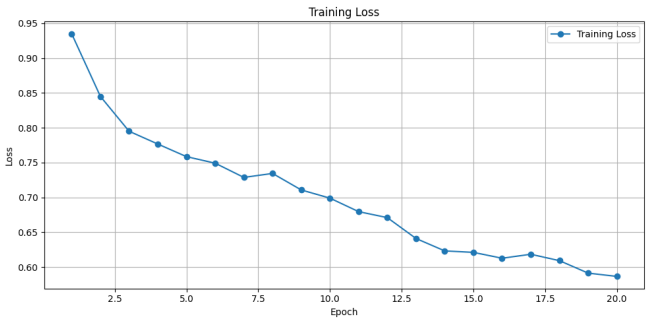

Fig. 8. Experiment 4 with ResNet34

IV. Embedding Visualizations

A. *ResNet18*

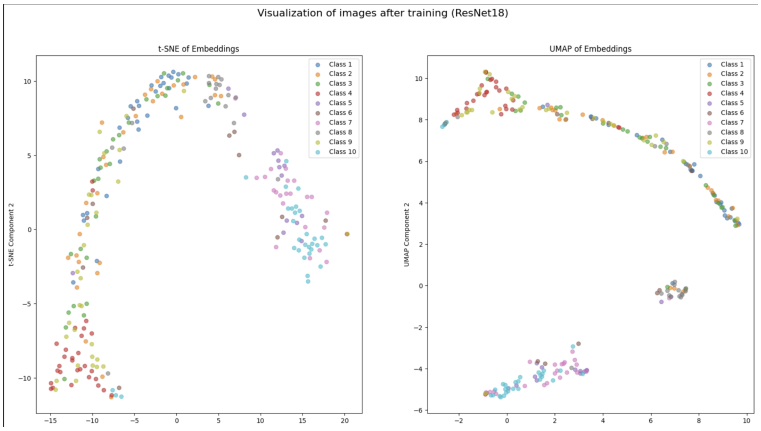

Fig. 9. Experiment 1 with ResNet18

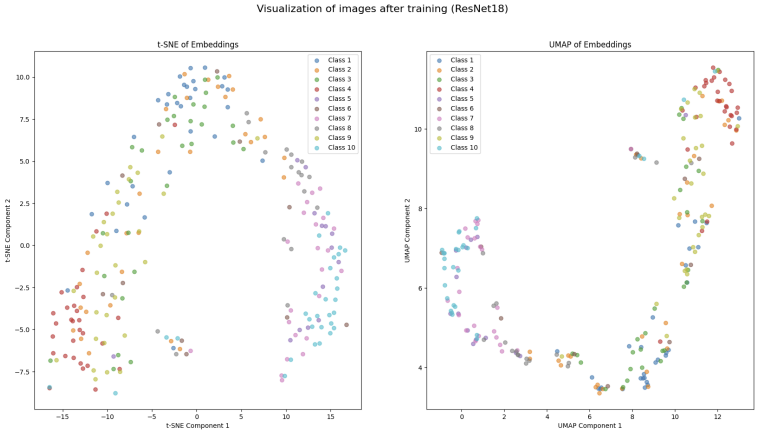

Fig. 10. Experiment 2 with ResNet18

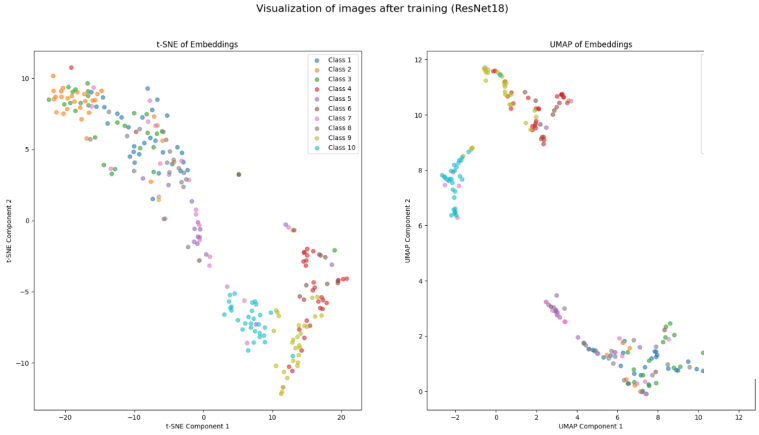

Fig. 11. Experiment 3 with ResNet18

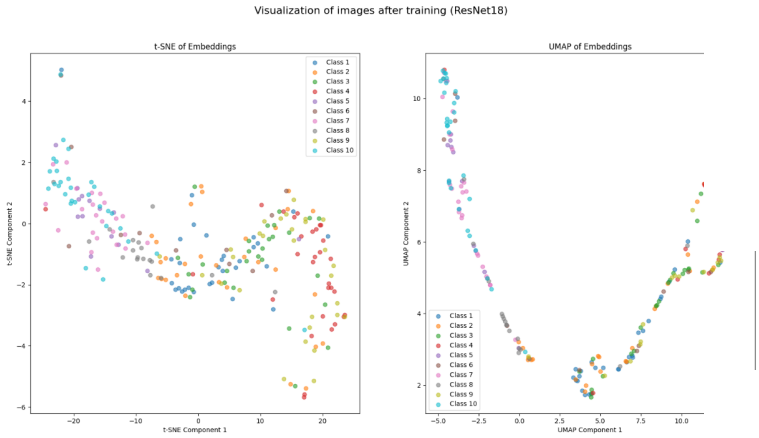

Fig. 12. Experiment 4 with ResNet18

B. ResNet34

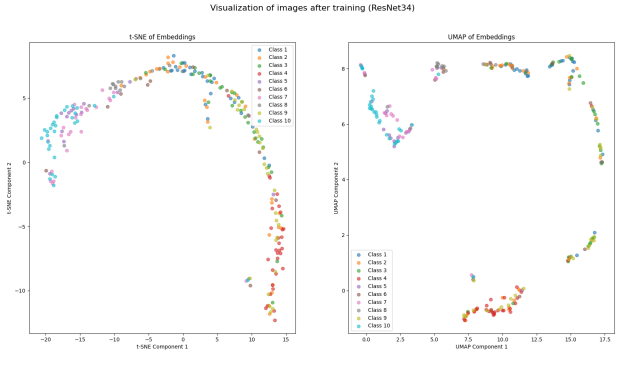

Fig. 13. Experiment 1 with ResNet34

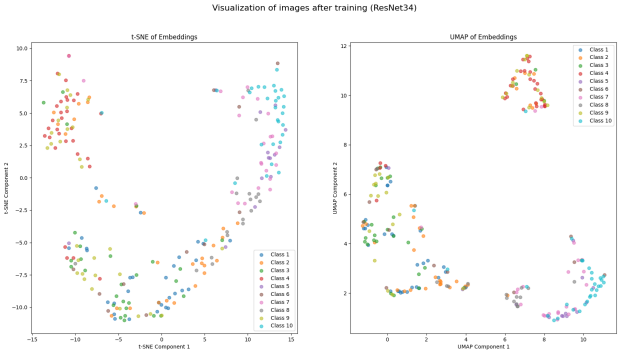

Fig. 14. Experiment 2 with ResNet34

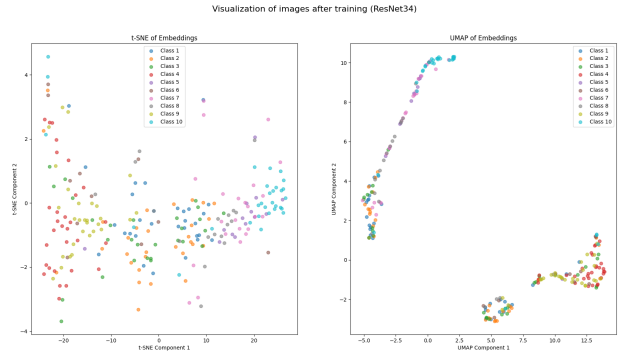

Fig. 15. Experiment 3 with ResNet34

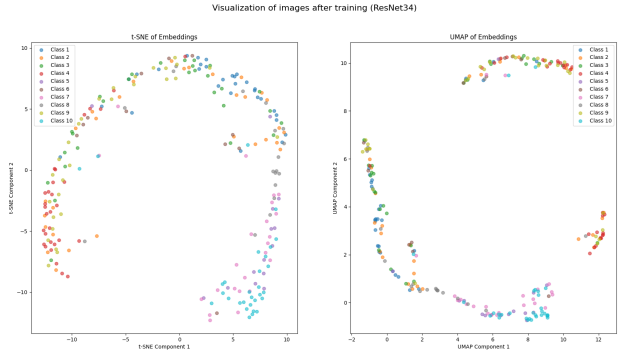

Fig. 16. Experiment 4 with ResNet34

V. Evaluation Results

A. ResNet18

TABLE I
Loss and Accuracy Metrics for Experiment 1

Metric (Average)	Value
Loss	0.5020
Top-1 Accuracy (%)	79.60
Cosine Similarity Anchor-Positive	0.6735
Cosine Similarity Anchor-Negative	0.0359

TABLE II
PRECISION METRICS FOR EXPERIMENT 1

Metric	Value (%)
Precision@1	33.74
Precision@5	33.83
Precision@10	32.55

TABLE III
LOSS AND ACCURACY METRICS FOR EXPERIMENT 2

Metric	Value
Loss	0.5932
Top-1 Accuracy (%)	75.04
Cosine Similarity Anchor-Positive	0.6542
Cosine Similarity Anchor-Negative	0.1330

TABLE IV
PRECISION METRICS FOR EXPERIMENT 2

Metric	Value (%)
Precision@1	25.93
Precision@5	31.28
Precision@10	31.60

TABLE V
LOSS AND ACCURACY METRICS FOR EXPERIMENT 3

Metric (Average)	Value
Loss	0.3277
Top-1 Accuracy (%)	89.11
Cosine Similarity Anchor-Positive	0.7762
Cosine Similarity Anchor-Negative	-0.0004

TABLE VI
PRECISION METRICS FOR EXPERIMENT 3

Metric	Value (%)
Precision@1	39.92
Precision@5	44.03
Precision@10	42.51

TABLE VII
LOSS AND ACCURACY METRICS FOR EXPERIMENT 4

Metric (Average)	Value
Loss	0.5633
Top-1 Accuracy (%)	76.53
Cosine Similarity Anchor-Positive	0.6284
Cosine Similarity Anchor-Negative	0.0632

TABLE VIII
PRECISION METRICS FOR EXPERIMENT 4

Metric	Value (%)
Precision@1	31.69
Precision@5	28.48
Precision@10	27.04

B. ResNet34

TABLE IX
LOSS AND ACCURACY METRICS FOR EXPERIMENT 1

Metric (Average)	Value
Loss	0.5902
Top-1 Accuracy (%)	75.85
Cosine Similarity Anchor-Positive	0.6200
Cosine Similarity Anchor-Negative	0.0994

TABLE X
PRECISION METRICS FOR EXPERIMENT 1

Metric	Value (%)
Precision@1	31.69
Precision@5	30.12
Precision@10	30.37

TABLE XI
LOSS AND ACCURACY METRICS FOR EXPERIMENT 2

Metric (Average)	Value
Loss	0.5829
Top-1 Accuracy (%)	75.63
Cosine Similarity Anchor-Positive	0.6727
Cosine Similarity Anchor-Negative	0.1282

TABLE XII
PRECISION METRICS FOR EXPERIMENT 2

Metric	Value (%)
Precision@1	26.34
Precision@5	29.14
Precision@10	29.42

TABLE XIII
LOSS AND ACCURACY METRICS FOR EXPERIMENT 3

Metric (Average)	Value
Loss	0.4440
Top-1 Accuracy (%)	83.28
Cosine Similarity Anchor-Positive	0.7201
Cosine Similarity Anchor-Negative	0.0272

TABLE XIV
PRECISION METRICS FOR EXPERIMENT 3

Metric	Value (%)
Precision@1	34.98
Precision@5	30.86
Precision@10	29.55

TABLE XV
LOSS AND ACCURACY METRICS FOR EXPERIMENT 4

Metric (Average)	Value
Loss	0.6131
Top-1 Accuracy (%)	73.66
Cosine Similarity Anchor-Positive	0.6504
Cosine Similarity Anchor-Negative	0.1431

TABLE XVI
PRECISION METRICS FOR EXPERIMENT 4

Metric	Value (%)
Precision@1	25.51
Precision@5	28.31
Precision@10	27.08

VI. *Extended Training with ResNet18*

A. epochs: 60, learning rate: 0.001, batch size: 32

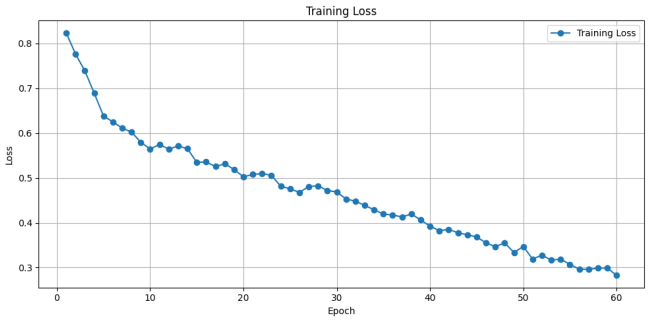

Fig. 17. Experiment 5 with ResNet18

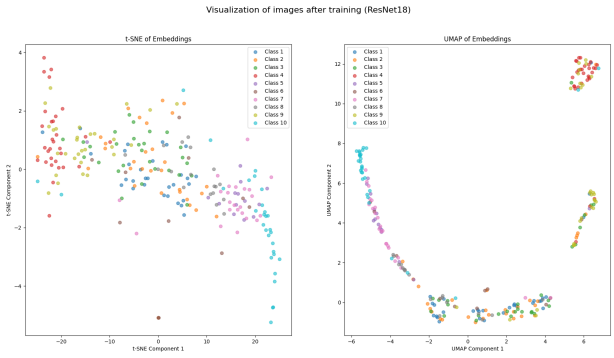

Fig. 18. Experiment 5 with ResNet18

TABLE XVII
LOSS AND ACCURACY METRICS FOR EXPERIMENT 5

Metric (Average)	Value
Loss	0.4344
Top-1 Accuracy (%)	83.53
Cosine Similarity Anchor-Positive	0.7268
Cosine Similarity Anchor-Negative	0.0781

TABLE XVIII
PRECISION METRICS FOR EXPERIMENT 5

Metric	Value (%)
Precision@1	33.74
Precision@5	35.97
Precision@10	34.86

B. epochs: 60, learning rate: 0.001, batch size: 64

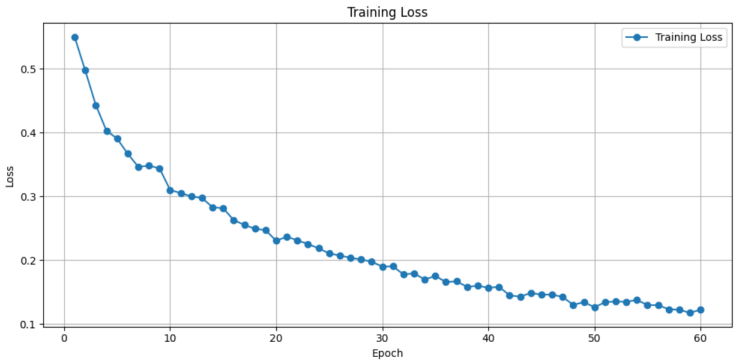

Fig. 19. Experiment 6 with ResNet18

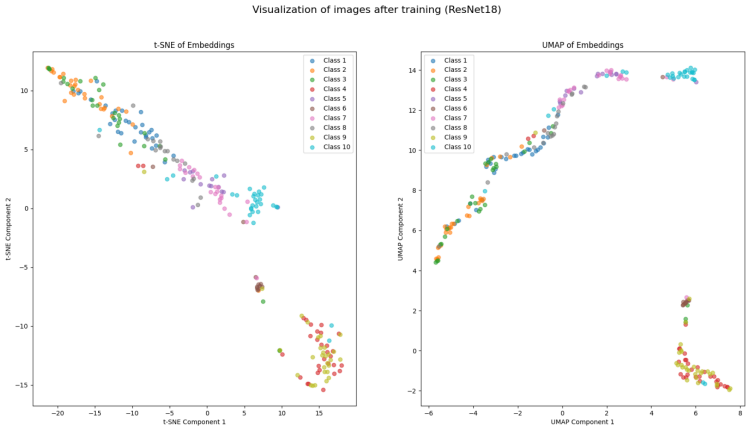

Fig. 20. Experiment 6 with ResNet18

TABLE XIX
LOSS AND ACCURACY METRICS FOR EXPERIMENT 6

Metric (Average)	Value
Loss	0.3081
Top-1 Accuracy (%)	89.61
Cosine Similarity Anchor-Positive	0.7707
Cosine Similarity Anchor-Negative	0.0127

TABLE XX
PRECISION METRICS FOR EXPERIMENT 6

Metric	Value (%)
Precision@1	46.91
Precision@5	44.69
Precision@10	42.84

VII. DISCUSSION