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

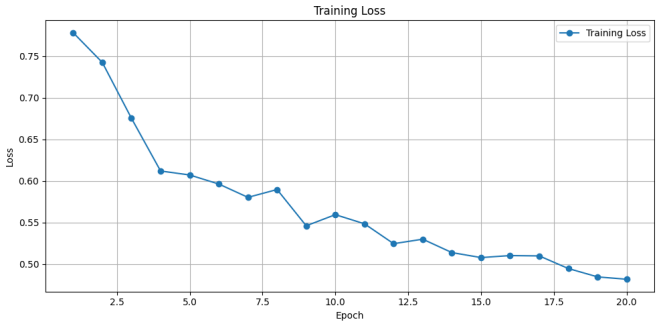

Fig. 1. Experiment 1 with ResNet18

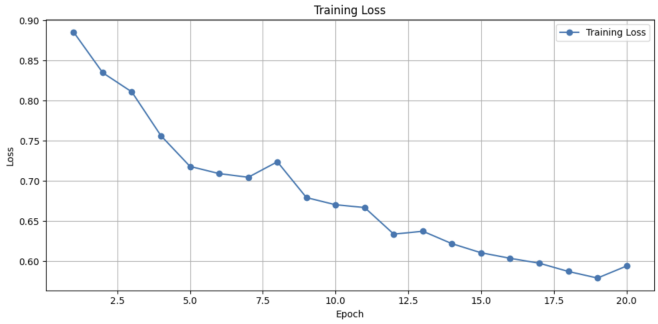

Fig. 2. Experiment 2 with ResNet18

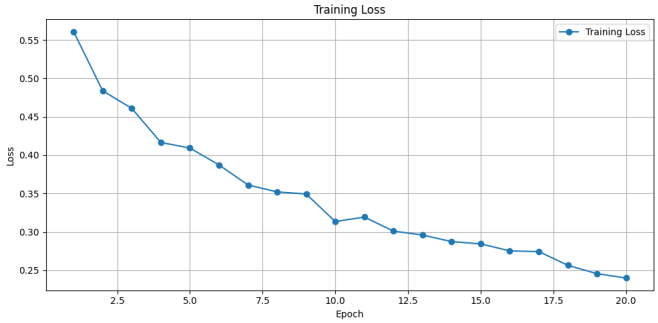

Fig. 3. Experiment 3 with ResNet18

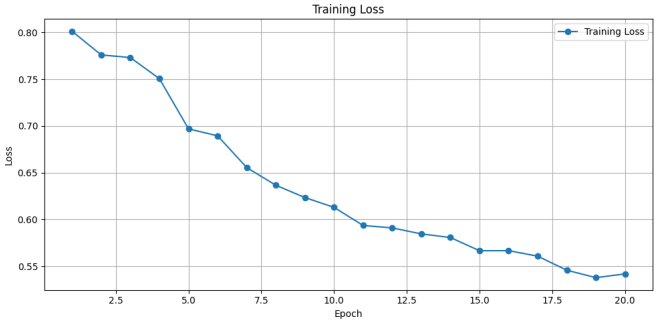

Fig. 4. Experiment 4 with ResNet18

B. *ResNet34*

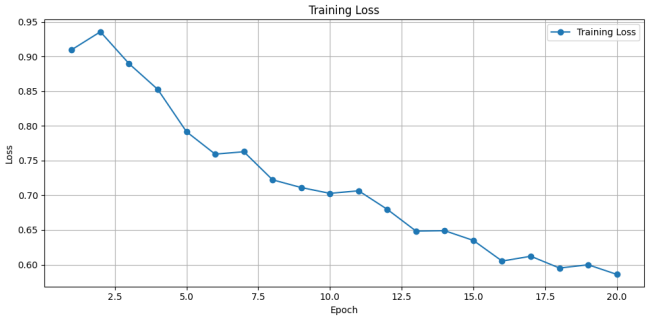

Fig. 5. Experiment 1 with ResNet34

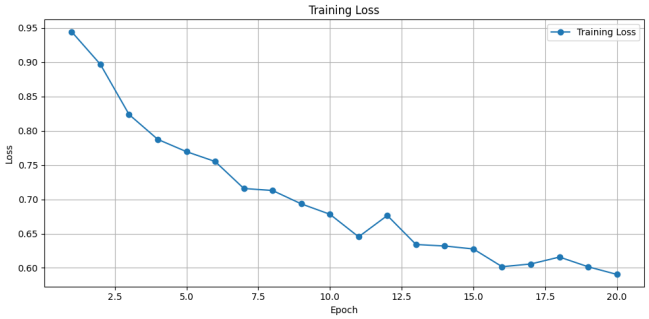

Fig. 6. Experiment 2 with ResNet34

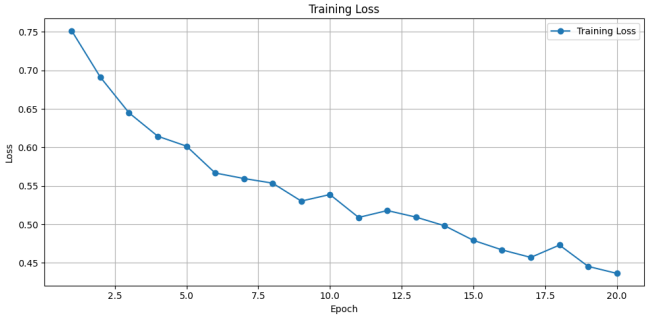

Fig. 7. Experiment 3 with ResNet34

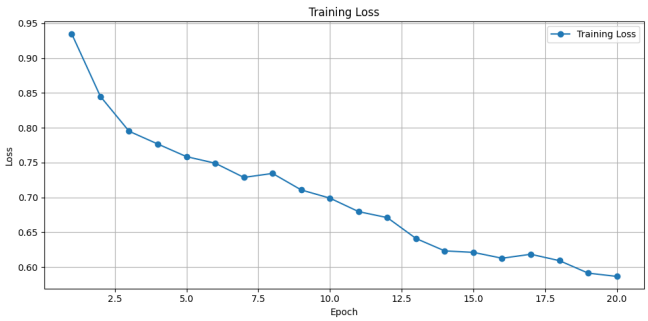

Fig. 8. Experiment 4 with ResNet34

IV. Embedding Visualizations

A. *ResNet18*

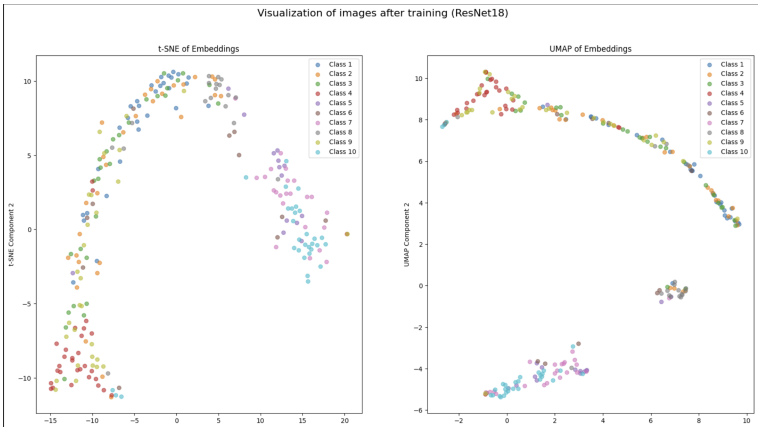

Fig. 9. Experiment 1 with ResNet18

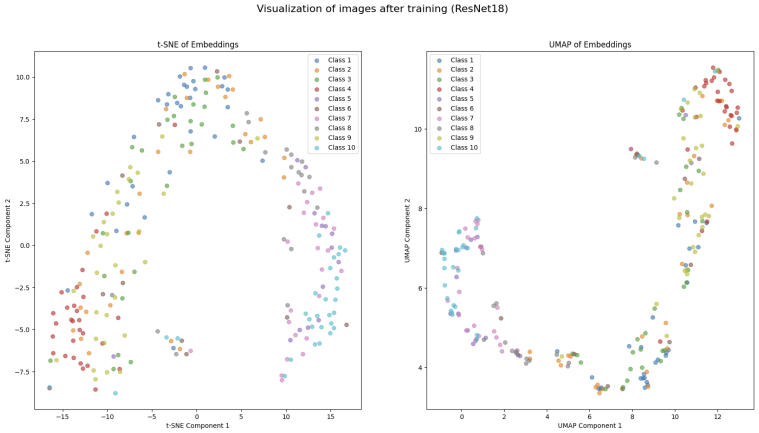

Fig. 10. Experiment 2 with ResNet18

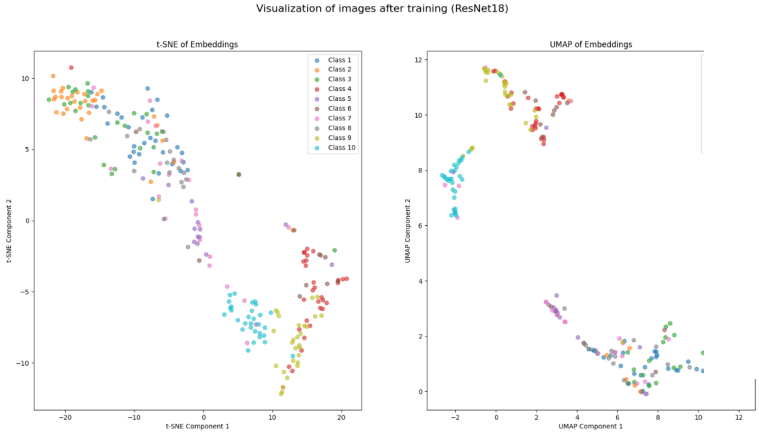

Fig. 11. Experiment 3 with ResNet18

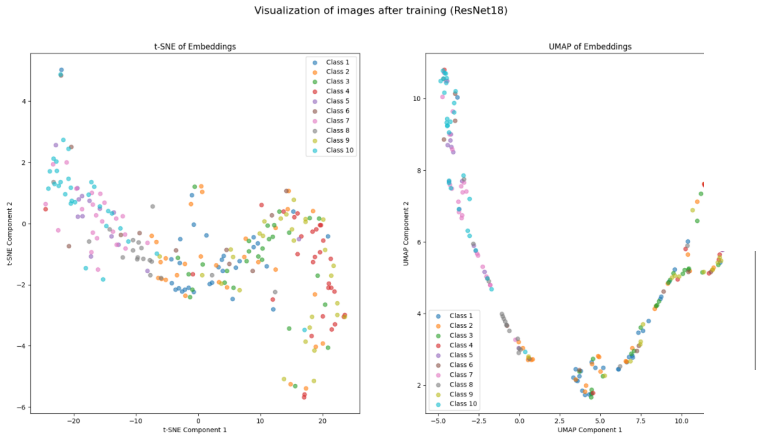

Fig. 12. Experiment 4 with ResNet18

B. ResNet34

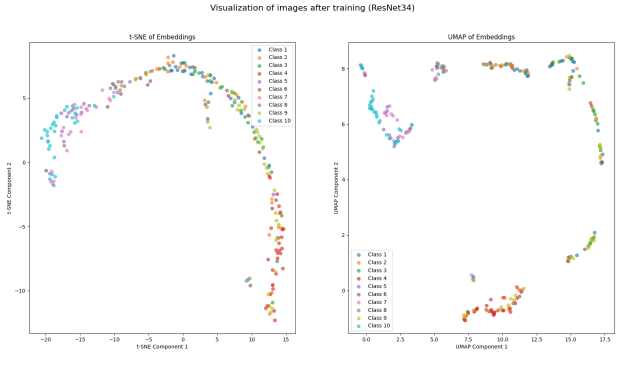

Fig. 13. Experiment 1 with ResNet34

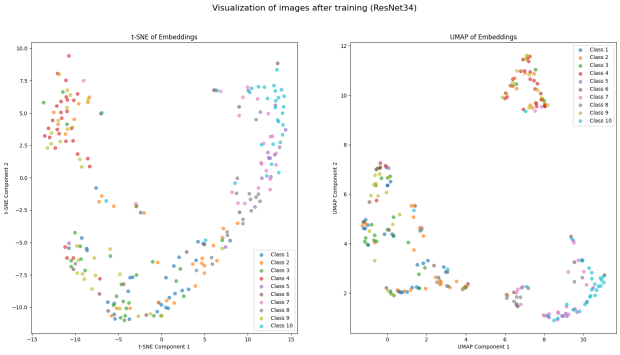

Fig. 14. Experiment 2 with ResNet34

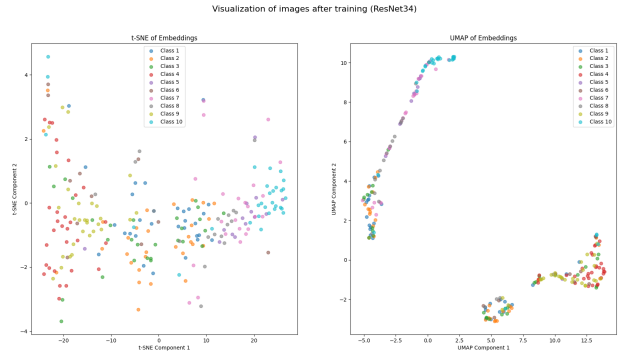

Fig. 15. Experiment 3 with ResNet34

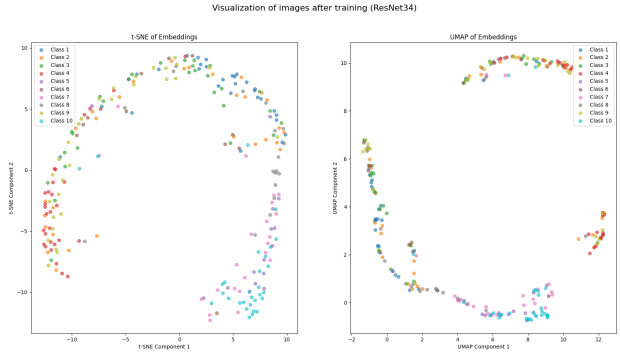

Fig. 16. Experiment 4 with ResNet34

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

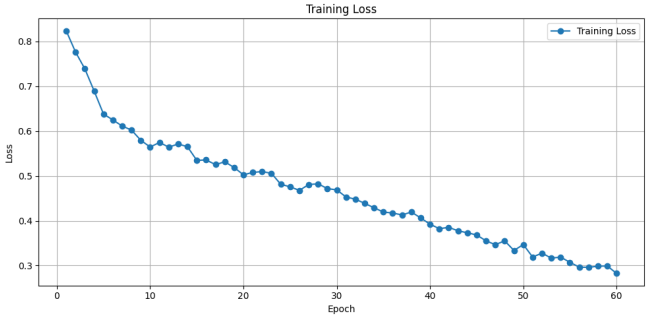

Fig. 17. Experiment 5 with ResNet18

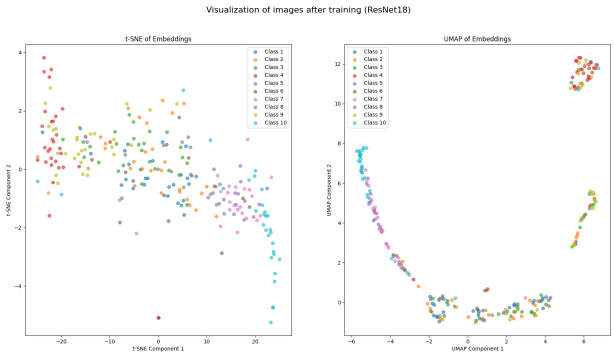

Fig. 18. Experiment 5 with ResNet18

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

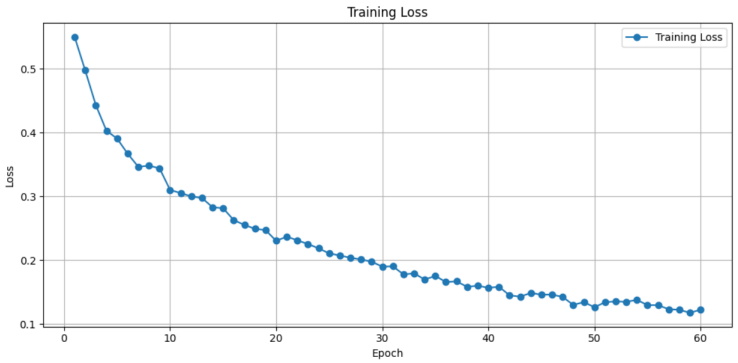

Fig. 19. Experiment 6 with ResNet18

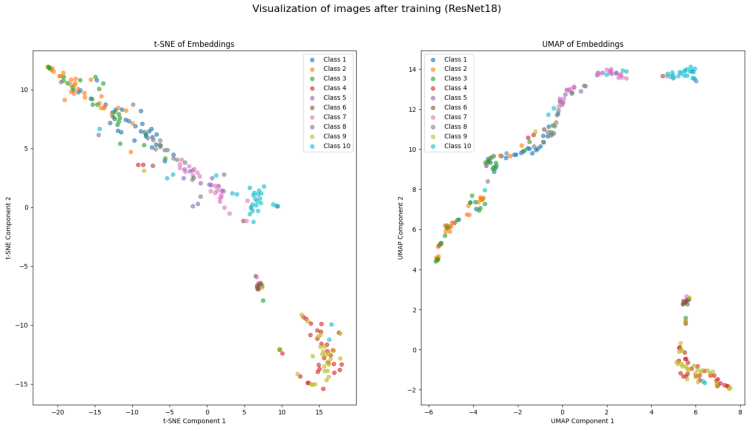

Fig. 20. Experiment 6 with ResNet18

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

In running our experiments (multiple ResNet models and different hyperparameters), we understood the following:

1) The best result was obtained by increasing epoch size from 20 to 60. We began with 20 epochs to better evaluate the final training hyperparameters, consistent

with out understanding that a higher epoch size results in a more accurate prediction model. This can be observed for both Experiments 5 and 6, where the loss was lower and accuracy was higher than in previous experiments.
2) with an epoch size of 60 in experiments 5 and 6, the model with a higher batch size (6) yielded a lower training loss (0.3, XIX), higher accuracy (89%, XIX) and precision metrics.
3) The clustering of the classes (UMAP and T-SNE, 18, 20) did not yield clear differences between the models. However, stronger evidence of clustering is observed in Experiments 5 and 6, which refers to the higher accuracy and precision (XX) of those models.

ACKNOWLEDGMENT

We would like to thank Professor Arash Azarfar and Firat Oncel for their guidance and support throughout this project. Large Language Models, like Google's Gemini were used in an educational context to further understand the resources for this research.

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