AMS 691.05: Deep Learning (Fall 2025)
Midterm Report

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1. Implementation Details

1.1 DataReader.py

File Loading: A helper function, unpickle, was used to load data from a file path using pickle.load(fo, encoding='bytes').

Training Data: The code iterates through the 5 training batches (data_batch_1 to data_batch_5), unpickles each one, and appends the b'data' and b'labels' to separate lists.

Test Data: The test_batch file is loaded similarly.

Final Arrays: np.concatenate is used to combine the 5 training batches into a single training set. All data is then converted to the required np.float32 (for images) and np.int32 (for labels) types.

1.2 ImageUtils.py

Training Augmentation:

- Padding: The 32x32 image is padded to 40x40 using np.pad with mode='reflect'.
- Random Crop: A 32x32 crop is randomly selected. This is achieved by generating a random top and left offset between 0 and 8.
- Random Flip: The image is horizontally flipped (np.fliplr) with a 50% probability.

Normalization: For both training and testing, the image is normalized per-image. The mean (np.mean) and standard deviation (np.std) of the image's pixels are calculated, and the image is standardized using (image - mean) / (std + epsilon).

1.3 NetWork.py

ResNet v1 (standard_block): This block consists of two 3x3 nn.Conv2d layers. Each is followed by nn.BatchNorm2d and nn.ReLU (except for the final activation, which comes after adding the shortcut).

ResNet v2 (bottleneck_block): This block (used when resnet_version=2) implements the full pre-activation design. It consists of a 1x1, 3x3, and 1x1 convolution sequence. Each nn.Conv2d is preceded by nn.BatchNorm2d and nn.ReLU.

Projection Shortcuts: In stack_layer, projection shortcuts (1x1 convolutions) are correctly added when the stride is > 1 (downsampling) or when input/output channels do not match.

Output Layer: The output_layer performs global average pooling (nn.AdaptiveAvgPool2d), flattens the result, and passes it to a final nn.Linear layer to produce logits for the 10 classes.

1.4 Model.py

Loss & Optimizer: The model uses nn.CrossEntropyLoss() as the criterion and torch.optim.SGD with momentum and weight decay as the optimizer.

Training Loop:

- LR Decay: The learning rate is decayed by lr_decay_factor at epochs specified in lr_decay_epochs.
- Batch Processing: The training loop iterates through batches, applies parse_record for augmentation, and moves tensors to the GPU.
- Backpropagation: The standard optimizer.zero_grad(), loss.backward(), and optimizer.step() process is implemented to update network weights.

Evaluation:

- It loops through all test/validation images one by one, performs inference within a torch.no_grad() block, and calculates accuracy by comparing the torch.argmax of the output to the ground-truth labels.

2. Hyperparameters and Results

2.1 Hyperparameters

Parameter	Value
resnet_version	1
resnet_size	3 (Resulting in ResNet-20)
batch_size	128
learning_rate	0.1
momentum	0.9
weight_decay	2e-4
lr_decay_epochs	[100, 150]
lr_decay_factor	0.1

2.2 Results and Analysis

Step 1: Hyperparameter Tuning (200 Epochs)

The model was trained for 200 epochs on the 45,000-image training split (x_train_new) and evaluated on the 5,000-image validation set (x_valid). The console log shows the loss decreasing over 200 epochs, with learning rate decays at epochs 100 and 150.

The validation accuracy tested on the final checkpoints:

Checkpoint (Epoch)	Validation Accuracy
160	92.84%
170	92.68%
180	92.62%
190	92.52%
200	92.64%

Analysis: The validation accuracy was highest at 92.84% at epoch 160, suggesting that epoch 160 was the optimal model.

Step 2 & 3: Final Training and Testing

The model was then re-trained for 10 epochs on the full 50,000-image training set (x_train). This 10-epoch model was then evaluated on the 10,000-image test set (x_test).

Final Test Accuracy: 92.16%

2.3 Output Images

```
--- Preparing Data ---
### Training... ###
Epoch 1 Loss 1.418317 Duration 24.079 seconds.
Epoch 2 Loss 1.045104 Duration 24.153 seconds.
Epoch 3 Loss 0.913229 Duration 24.034 seconds.
Epoch 4 Loss 0.742231 Duration 24.068 seconds.
Epoch 5 Loss 0.828165 Duration 24.059 seconds.
Epoch 6 Loss 0.574925 Duration 23.704 seconds.
Epoch 7 Loss 0.564323 Duration 24.168 seconds.
Epoch 8 Loss 0.571572 Duration 24.026 seconds.
Epoch 9 Loss 0.453988 Duration 24.088 seconds.
Epoch 10 Loss 0.371135 Duration 24.115 seconds.
Checkpoint has been created.
Epoch 11 Loss 0.390138 Duration 23.786 seconds.
Epoch 12 Loss 0.354278 Duration 23.945 seconds.
Epoch 13 Loss 0.331997 Duration 24.036 seconds.
Epoch 14 Loss 0.470163 Duration 24.060 seconds.
Epoch 15 Loss 0.521359 Duration 24.011 seconds.
Epoch 16 Loss 0.639423 Duration 23.981 seconds.
Epoch 17 Loss 0.371543 Duration 23.586 seconds.
Epoch 18 Loss 0.328672 Duration 23.924 seconds.
Epoch 19 Loss 0.630650 Duration 24.019 seconds.
Epoch 20 Loss 0.491445 Duration 24.080 seconds.
Checkpoint has been created.
Epoch 21 Loss 0.616137 Duration 24.079 seconds.
Epoch 22 Loss 0.357310 Duration 23.814 seconds.
Epoch 23 Loss 0.507063 Duration 23.825 seconds.
Epoch 24 Loss 0.406305 Duration 24.093 seconds.
Epoch 25 Loss 0.592081 Duration 24.197 seconds.
Epoch 26 Loss 0.424619 Duration 24.175 seconds.
Epoch 27 Loss 0.397105 Duration 24.116 seconds.
Epoch 28 Loss 0.523609 Duration 23.576 seconds.
Epoch 29 Loss 0.302736 Duration 23.954 seconds.
Epoch 30 Loss 0.290708 Duration 24.297 seconds.
Checkpoint has been created.
Epoch 31 Loss 0.267978 Duration 24.092 seconds.
Epoch 32 Loss 0.367224 Duration 24.113 seconds.
Epoch 33 Loss 0.386285 Duration 23.851 seconds.
Epoch 34 Loss 0.407861 Duration 23.569 seconds.
Epoch 35 Loss 0.378124 Duration 24.000 seconds.
Epoch 36 Loss 0.373603 Duration 23.957 seconds.
Epoch 37 Loss 0.314042 Duration 24.001 seconds.
Epoch 38 Loss 0.349788 Duration 23.949 seconds.
Epoch 39 Loss 0.362820 Duration 23.738 seconds.
Epoch 40 Loss 0.457716 Duration 23.854 seconds.
Checkpoint has been created.
Epoch 41 Loss 0.274843 Duration 23.947 seconds.
Epoch 42 Loss 0.251708 Duration 24.103 seconds.
Epoch 43 Loss 0.394343 Duration 24.192 seconds.
Epoch 44 Loss 0.300614 Duration 23.832 seconds.
Epoch 45 Loss 0.324391 Duration 23.589 seconds.
Epoch 46 Loss 0.322002 Duration 24.080 seconds.
Epoch 47 Loss 0.362995 Duration 23.913 seconds.
Epoch 48 Loss 0.413384 Duration 24.023 seconds.
Epoch 49 Loss 0.369471 Duration 24.057 seconds.
Epoch 50 Loss 0.360871 Duration 23.616 seconds.
Checkpoint has been created.
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Epoch 51 Loss 0.319028 Duration 23.858 seconds.
Epoch 52 Loss 0.414226 Duration 23.963 seconds.
Epoch 53 Loss 0.229316 Duration 24.038 seconds.
Epoch 54 Loss 0.373267 Duration 23.996 seconds.
Epoch 55 Loss 0.241538 Duration 23.720 seconds.
Epoch 56 Loss 0.388046 Duration 23.723 seconds.
Epoch 57 Loss 0.348649 Duration 23.834 seconds.
Epoch 58 Loss 0.296313 Duration 24.021 seconds.
Epoch 59 Loss 0.400567 Duration 24.010 seconds.
Epoch 60 Loss 0.310735 Duration 23.872 seconds.
Checkpoint has been created.
Epoch 61 Loss 0.266818 Duration 23.571 seconds.
Epoch 62 Loss 0.493677 Duration 24.001 seconds.
Epoch 63 Loss 0.241938 Duration 24.020 seconds.
Epoch 64 Loss 0.217383 Duration 24.021 seconds.
Epoch 65 Loss 0.305171 Duration 24.039 seconds.
Epoch 66 Loss 0.237547 Duration 23.755 seconds.
Epoch 67 Loss 0.283753 Duration 23.716 seconds.
Epoch 68 Loss 0.374431 Duration 24.034 seconds.
Epoch 69 Loss 0.265424 Duration 24.121 seconds.
Epoch 70 Loss 0.252049 Duration 24.088 seconds.
Checkpoint has been created.
Epoch 71 Loss 0.346323 Duration 24.000 seconds.
Epoch 72 Loss 0.248614 Duration 23.568 seconds.
Epoch 73 Loss 0.238905 Duration 24.004 seconds.
Epoch 74 Loss 0.184915 Duration 24.030 seconds.
Epoch 75 Loss 0.227223 Duration 24.078 seconds.
Epoch 76 Loss 0.322716 Duration 24.187 seconds.
Epoch 77 Loss 0.350674 Duration 23.626 seconds.
Epoch 78 Loss 0.407350 Duration 23.549 seconds.
Epoch 79 Loss 0.374390 Duration 23.920 seconds.
Epoch 80 Loss 0.417837 Duration 24.367 seconds.
Checkpoint has been created.
Epoch 81 Loss 0.384133 Duration 24.100 seconds.
Epoch 82 Loss 0.270687 Duration 24.205 seconds.
Epoch 83 Loss 0.278354 Duration 23.684 seconds.
Epoch 84 Loss 0.276585 Duration 23.900 seconds.
Epoch 85 Loss 0.271324 Duration 23.932 seconds.
Epoch 86 Loss 0.390842 Duration 24.112 seconds.
Epoch 87 Loss 0.330958 Duration 23.985 seconds.
Epoch 88 Loss 0.193271 Duration 23.597 seconds.
Epoch 89 Loss 0.332966 Duration 23.646 seconds.
Epoch 90 Loss 0.263957 Duration 24.005 seconds.
Checkpoint has been created.
Epoch 91 Loss 0.342784 Duration 23.997 seconds.
Epoch 92 Loss 0.300897 Duration 23.922 seconds.
Epoch 93 Loss 0.422641 Duration 24.137 seconds.
Epoch 94 Loss 0.412924 Duration 23.721 seconds.
Epoch 95 Loss 0.408305 Duration 24.296 seconds.
Epoch 96 Loss 0.309980 Duration 24.330 seconds.
Epoch 97 Loss 0.222800 Duration 24.270 seconds.
Epoch 98 Loss 0.323622 Duration 24.253 seconds.
Epoch 99 Loss 0.434142 Duration 24.094 seconds.

--- Decaying learning rate at epoch 100 ---
Epoch 100 Loss 0.163684 Duration 23.853 seconds.
Checkpoint has been created.
```

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Epoch 101 Loss 0.154581 Duration 24.270 seconds.
Epoch 102 Loss 0.152436 Duration 24.078 seconds.
Epoch 103 Loss 0.136543 Duration 24.168 seconds.
Epoch 104 Loss 0.156872 Duration 23.996 seconds.
Epoch 105 Loss 0.095828 Duration 23.668 seconds.
Epoch 106 Loss 0.098195 Duration 23.832 seconds.
Epoch 107 Loss 0.095478 Duration 24.033 seconds.
Epoch 108 Loss 0.125584 Duration 24.167 seconds.
Epoch 109 Loss 0.141043 Duration 24.097 seconds.
Epoch 110 Loss 0.065858 Duration 23.878 seconds.
Checkpoint has been created.
Epoch 111 Loss 0.070336 Duration 23.700 seconds.
Epoch 112 Loss 0.093515 Duration 24.008 seconds.
Epoch 113 Loss 0.107535 Duration 24.093 seconds.
Epoch 114 Loss 0.071373 Duration 24.034 seconds.
Epoch 115 Loss 0.127833 Duration 23.962 seconds.
Epoch 116 Loss 0.031959 Duration 23.444 seconds.
Epoch 117 Loss 0.121042 Duration 23.872 seconds.
Epoch 118 Loss 0.094411 Duration 24.031 seconds.
Epoch 119 Loss 0.047410 Duration 23.991 seconds.
Epoch 120 Loss 0.051175 Duration 23.990 seconds.
Checkpoint has been created.
Epoch 121 Loss 0.061615 Duration 23.724 seconds.
Epoch 122 Loss 0.060628 Duration 23.712 seconds.
Epoch 123 Loss 0.076169 Duration 24.133 seconds.
Epoch 124 Loss 0.066697 Duration 24.035 seconds.
Epoch 125 Loss 0.090890 Duration 24.050 seconds.
Epoch 126 Loss 0.046205 Duration 23.848 seconds.
Epoch 127 Loss 0.081232 Duration 23.686 seconds.
Epoch 128 Loss 0.091611 Duration 23.919 seconds.
Epoch 129 Loss 0.059307 Duration 24.078 seconds.
Epoch 130 Loss 0.065887 Duration 24.092 seconds.
Checkpoint has been created.
Epoch 131 Loss 0.045594 Duration 24.106 seconds.
Epoch 132 Loss 0.059898 Duration 23.558 seconds.
Epoch 133 Loss 0.080034 Duration 23.970 seconds.
Epoch 134 Loss 0.052059 Duration 24.149 seconds.
Epoch 135 Loss 0.092964 Duration 24.079 seconds.
Epoch 136 Loss 0.044506 Duration 24.006 seconds.
Epoch 137 Loss 0.080181 Duration 23.689 seconds.
Epoch 138 Loss 0.068506 Duration 23.744 seconds.
Epoch 139 Loss 0.077689 Duration 24.188 seconds.
Epoch 140 Loss 0.100184 Duration 24.732 seconds.
Checkpoint has been created.
Epoch 141 Loss 0.035610 Duration 24.743 seconds.
Epoch 142 Loss 0.043537 Duration 24.559 seconds.
Epoch 143 Loss 0.088510 Duration 24.290 seconds.
Epoch 144 Loss 0.033610 Duration 24.115 seconds.
Epoch 145 Loss 0.073792 Duration 24.205 seconds.
Epoch 146 Loss 0.021386 Duration 24.558 seconds.
Epoch 147 Loss 0.037875 Duration 24.344 seconds.
Epoch 148 Loss 0.048553 Duration 24.211 seconds.
Epoch 149 Loss 0.066284 Duration 23.804 seconds.

--- Decaying learning rate at epoch 150 ---
Epoch 150 Loss 0.013161 Duration 23.795 seconds.
Checkpoint has been created.
```

```
Epoch 151 Loss 0.045182 Duration 24.126 seconds.
Epoch 152 Loss 0.010791 Duration 24.119 seconds.
Epoch 153 Loss 0.025245 Duration 24.226 seconds.
Epoch 154 Loss 0.015755 Duration 24.191 seconds.
Epoch 155 Loss 0.033268 Duration 23.677 seconds.
Epoch 156 Loss 0.018797 Duration 23.964 seconds.
Epoch 157 Loss 0.013463 Duration 24.157 seconds.
Epoch 158 Loss 0.020589 Duration 24.139 seconds.
Epoch 159 Loss 0.056612 Duration 24.230 seconds.
Epoch 160 Loss 0.023853 Duration 23.853 seconds.
Checkpoint has been created.
Epoch 161 Loss 0.023657 Duration 23.810 seconds.
Epoch 162 Loss 0.030640 Duration 24.103 seconds.
Epoch 163 Loss 0.017847 Duration 24.131 seconds.
Epoch 164 Loss 0.030402 Duration 24.125 seconds.
Epoch 165 Loss 0.047854 Duration 24.152 seconds.
Epoch 166 Loss 0.021464 Duration 23.761 seconds.
Epoch 167 Loss 0.050606 Duration 24.062 seconds.
Epoch 168 Loss 0.020088 Duration 24.192 seconds.
Epoch 169 Loss 0.015531 Duration 24.065 seconds.
Epoch 170 Loss 0.013655 Duration 24.169 seconds.
Checkpoint has been created.
Epoch 171 Loss 0.033339 Duration 24.082 seconds.
Epoch 172 Loss 0.008319 Duration 23.728 seconds.
Epoch 173 Loss 0.013577 Duration 23.953 seconds.
Epoch 174 Loss 0.031715 Duration 23.959 seconds.
Epoch 175 Loss 0.036139 Duration 24.109 seconds.
Epoch 176 Loss 0.012550 Duration 24.135 seconds.
Epoch 177 Loss 0.044357 Duration 23.921 seconds.
Epoch 178 Loss 0.033321 Duration 23.698 seconds.
Epoch 179 Loss 0.023525 Duration 24.058 seconds.
Epoch 180 Loss 0.015788 Duration 24.026 seconds.
Checkpoint has been created.
Epoch 181 Loss 0.031066 Duration 24.081 seconds.
Epoch 182 Loss 0.021784 Duration 23.995 seconds.
Epoch 183 Loss 0.036476 Duration 23.584 seconds.
Epoch 184 Loss 0.010176 Duration 23.916 seconds.
Epoch 185 Loss 0.024318 Duration 24.202 seconds.
Epoch 186 Loss 0.037234 Duration 24.068 seconds.
Epoch 187 Loss 0.042249 Duration 24.022 seconds.
Epoch 188 Loss 0.018222 Duration 23.884 seconds.
Epoch 189 Loss 0.029953 Duration 23.748 seconds.
Epoch 190 Loss 0.048854 Duration 23.949 seconds.
Checkpoint has been created.
Epoch 191 Loss 0.007794 Duration 24.056 seconds.
Epoch 192 Loss 0.028504 Duration 24.052 seconds.
Epoch 193 Loss 0.020591 Duration 24.182 seconds.
Epoch 194 Loss 0.060414 Duration 23.785 seconds.
Epoch 195 Loss 0.031727 Duration 23.951 seconds.
Epoch 196 Loss 0.016263 Duration 24.169 seconds.
Epoch 197 Loss 0.025561 Duration 24.245 seconds.
Epoch 198 Loss 0.015576 Duration 24.218 seconds.
Epoch 199 Loss 0.020006 Duration 23.986 seconds.
Epoch 200 Loss 0.027026 Duration 23.607 seconds.
Checkpoint has been created.
```

```
### Test or Validation ###
Restored model parameters from model_v1/model-160.ckpt
100%|██████████| 5000/5000 [00:12<00:00, 390.12it/s]
Test accuracy: 0.9284
Restored model parameters from model_v1/model-170.ckpt
100%|██████████| 5000/5000 [00:12<00:00, 390.98it/s]
/tmp/ipython-input-1238540060.py:121: UserWarning: To copy construct from a tensor, it is recommended to use sourceTensor.detach().clone() or sourceTenso
  y = torch.tensor(y)
Test accuracy: 0.9268
Restored model parameters from model_v1/model-180.ckpt
100%|██████████| 5000/5000 [00:12<00:00, 389.27it/s]
Test accuracy: 0.9262
Restored model parameters from model_v1/model-190.ckpt
100%|██████████| 5000/5000 [00:12<00:00, 392.64it/s]
Test accuracy: 0.9252
Restored model parameters from model_v1/model-200.ckpt
100%|██████████| 5000/5000 [00:12<00:00, 390.48it/s]
Test accuracy: 0.9264
### Training... ###
Epoch 1 Loss 0.032380 Duration 26.789 seconds.
Epoch 2 Loss 0.046825 Duration 26.380 seconds.
Epoch 3 Loss 0.062061 Duration 26.365 seconds.
Epoch 4 Loss 0.025574 Duration 26.366 seconds.
Epoch 5 Loss 0.026148 Duration 26.467 seconds.
Epoch 6 Loss 0.054615 Duration 26.459 seconds.
Epoch 7 Loss 0.036988 Duration 26.561 seconds.
Epoch 8 Loss 0.164093 Duration 26.826 seconds.
Epoch 9 Loss 0.016625 Duration 26.508 seconds.
Epoch 10 Loss 0.060841 Duration 26.456 seconds.
Checkpoint has been created.
### Test or Validation ###
Restored model parameters from model_v1/model-10.ckpt
100%|██████████| 10000/10000 [00:25<00:00, 392.48it/s]Test accuracy: 0.9216
```