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# CSCE 636 Deep Learning Project 10-Class Image Classification\*

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## Abstract

ResNet is a technique that solves the degradation of gradient problems by the addition of input into the output of each residual block. ResNet introduces two block formats, standard block and residual block. This project modifies the ResNet by changing the downsampling block. The modified ResNet trains on the CIFAR-10 public dataset with an accuracy of 70% on the testing dataset.

## 1 Introduction

This project is for image classification, which is about clustering images and obtaining information from different images. This classification concept is Computer Vision. Convolutional layers are the major building blocks used in convolutional neural networks. Convolution is the simple application of a filter to an input that results in activation. Repeated application of the same filter to an input results in a map of activations called a feature map, indicating the locations and strength of a detected feature in an input, such as an image. The innovation of convolutional neural networks is the ability to automatically learn a large number of filters in parallel specific to a training dataset under the constraints of a specific predictive modeling problem, such as image classification. The result is highly specific features that can be detected anywhere on input images.

Deep Residual Learning using normalized initialization and intermediate normalization layers solved the problem led by Deep Convolutional Neural Network, which is a vanishing gradient. Many deep learning frameworks are based on ResNet(1). Many researchers have found that increasing the width of the network gives the same or better accuracy with deeper neural networks. Wider networks improve the training time, which deeper neural networks lack and do not affect training accuracy. Other researchers stated that the modification of the ResNet can also improve the network and prevent information loss. This project implements one of the model tweaks, which is a minor adjustment to the network architecture, such as changing the stride of a particular convolution layer (2).

## 2 ResNet-B

ResNet-B is a tweak that first appears in a Torch implementation blog(3), which is a minor modification of the network architecture of ResNet. This section is the introduction to the concept of ResNet-B and its architecture.

### 2.1 Architecture

Figure 1 is the first bottleneck layer version. The bottleneck residual block has a  $1 \times 1$  convolution layer followed by Batch Normalization and then ReLU activation, it is followed by a  $3 \times 3$  convolution

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\*Link to the full project GitHub: [https://github.com/ada0613/Deep\\_Learning\\_Project.git](https://github.com/ada0613/Deep_Learning_Project.git)

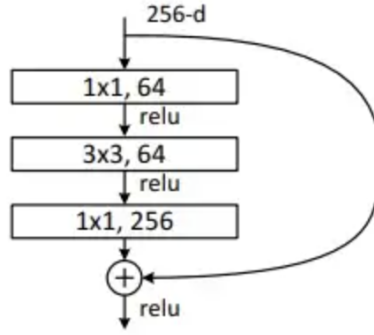


Figure 1: Deep Residual Network: Bottleneck Residual Block. Source: (1)

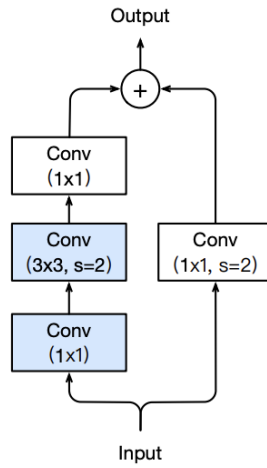


Figure 2: ResNet-B. Source: (2)

layer, followed by Batch Normalization and ReLU, and finally a  $1 \times 1$  convolution layer with a Batch Normalization. This is connected to the skip connection input, and the final ReLU activation is then applied.

This project implemented ResNet-B, as shown in Figure2. This bottleneck residual block is similar to the first version, except it has an extra  $1 \times 1$  convolution layer followed by a Batch Normalization present on the skip connection, which modifies the downsampling block of Resnet. In the left path in Figure2, the convolution ignores three-quarters of the input feature map as it uses kernel size  $1 \times 1$  with stride 2. ResNet-B switches the strides size of the first two convolutions in the left path. No information is ignored because the second convolution has kernel size  $3 \times 3$ , and the output shape of the left path is unchanged.

### 3 Implementation

This section introduces how ResNet-B was implemented in this project, including environment, training, testing data, and hyperparameters.

#### 3.1 Environment

This project uses Pytorch 1.7.0 and Python 3.8.13 for training, testing, and performing predictions on private testing data.

Table 1: CIFAR-10 Classes

Label	airplane	automobile	bird	cat	deer	dog	frog	horse	ship	truck
Classes	0	1	2	3	4	5	6	7	8	9

Table 2: Hyperparameters

Hyperparameters	Value
Activation function	ReLu
Bach Size	128
Epoch	100
First number of filters	32
Learning rate	0.1
Momentum	0.9
Stack layers	4
Weight Decay	0.0005

### 3.2 Data Loading & Processing

The CIFAR-10 dataset(4) consists of 60000 32x32 color images in 10 classes in labels 0 to 9, which are referred to Table 1. 50000 images were used for training, it was split into 45000 images for training and 5000 images for validation in order to get the best model. The 10000 images were used for testing. Each image of CIFAR-10 is in shape  $3 \times 32 \times 32$ . The final private data set for prediction consists of 2000 images in the shape of  $32 \times 32 \times 3$ .

In the preprocessing of the training images, each image was padded with padding 4, randomly cropped into the size of  $32 \times 32$ , and randomly flipped horizontally. Moreover, image normalization with mean and standard deviation was also utilized for the image preprocessing. In the preprocessing of the testing images, each image was normalized with mean and standard deviation.

### 3.3 Hyperparameters

The hyperparameters in the model with the best performance can be referred to Table2

### 3.4 ResNet-B implementation

The ResNet-B is implemented as three stack layers. Each convolutional layer is followed by batch normalization and ReLu. In the output layer, an average pool of kernel size 8 is used, followed by a linear fully connected layer.

### 3.5 Optimizer

The optimizer is SGD with a momentum of 0.9 and weight decay of 0.0005.

Table 3: Bottleneck Residual Block

Epoch	Training Loss	Testing Accuracy	Time per Epoch (seconds)
10	1.69	0.51	135
20	1.75	0.53	182
40	1.68	0.47	95
80	1.71	0.64	95
100	1.68	0.63	96
200	1.65	0.61	94

Table 4: ResNet-B

Epoch	Training Loss	Testing Accuracy	Time per Epoch (seconds)
10	0.51	0.53	148
20	0.22	0.70	149
30	0.005	0.67	149
40	0.002	0.67	149
50	0.003	0.68	149
60	0.003	0.66	149
70	0.002	0.69	149
80	0.002	0.69	148
90	0.003	0.69	149
100	0.003	0.67	149

## 4 Result

This section introduces the training loss and testing accuracy of the Bottleneck Residual Block ran 200 epochs, and ResNet-B ran 100 epochs due to time consumption. Detailed results can be referred to Appendix A and Appendix B.

Table 3 and Table 4 show the epoch, training loss, testing accuracy, and time per epoch for the Bottleneck Residual Block and ResNet-B, respectively. The training loss for Bottleneck Residual Block stays almost the same throughout 200 epochs, while the training loss for ResNet-B decreases from 0.51 to 0.003 in epoch 100 after applying a learning rate decay after 20 epochs.

The testing accuracy for the Bottleneck Residual Block increases to 0.64 at epoch 80 and remains unchanged. Hypothetically, if it runs more epochs, the testing accuracy may increase. The time per epoch for ResNet-B is longer than the first version of the bottleneck because of the extra convolution layer (Figure 2), and it stays the same in the first 100 training epochs. The testing accuracy of ResNet-B reaches 0.7 in epoch 20.

## 5 Conclusion

This project experimented with the modification of the Resnet by adding an extra convolution layer on the skip connection (Figure 2) preventing information loss. Moreover, the data augmentation for data preprocessing helps the better training for the model. Even though the testing accuracy isn't as high as 90%, the result shows ResNet-B performs better than Bottleneck Residual Block within 100 epochs, and the testing accuracy reached 70% in epoch 20.

## References

- [1] K. He, X. Zhang, S. Ren, and J. Sun. Deep residual learning for image recognition, 2015.
- [2] T. He, Z. Zhang, H. Zhang, Z. Zhang, J. Xie, and M. Li. Bag of tricks for image classification with convolutional neural networks, 2019.
- [3] S. Gross and M. Wilber. Training and investigating residual nets. <http://torch.ch/blog/2016/02/04/resnets.html>.
- [4] A. Krizhevsky. Learning Multiple Layers of Features from Tiny Images, 2009.

## A Appendix

Training loss for Bottleneck Residual Block

```
### Training... ###
Epoch 1 Loss 1.997370 Duration 128.675 seconds.
Epoch 2 Loss 2.038549 Duration 127.026 seconds.
```

Epoch 3 Loss 1.952512 Duration 127.227 seconds.  
Epoch 4 Loss 1.860366 Duration 126.861 seconds.  
Epoch 5 Loss 1.867315 Duration 127.538 seconds.  
Epoch 6 Loss 1.838398 Duration 127.151 seconds.  
Epoch 7 Loss 1.856418 Duration 127.133 seconds.  
Epoch 8 Loss 1.789966 Duration 132.509 seconds.  
Epoch 9 Loss 1.722859 Duration 134.624 seconds.  
Epoch 10 Loss 1.693874 Duration 134.692 seconds.  
Checkpoint has been created.  
Epoch 11 Loss 1.798813 Duration 134.620 seconds.  
Epoch 12 Loss 1.748131 Duration 134.383 seconds.  
Epoch 13 Loss 1.743140 Duration 134.704 seconds.  
Epoch 14 Loss 1.785435 Duration 134.602 seconds.  
Epoch 15 Loss 1.761830 Duration 134.597 seconds.  
Epoch 16 Loss 1.745569 Duration 134.629 seconds.  
Epoch 17 Loss 1.683166 Duration 134.350 seconds.  
Epoch 18 Loss 1.715982 Duration 134.656 seconds.  
Epoch 19 Loss 1.706439 Duration 148.786 seconds.  
Epoch 20 Loss 1.749734 Duration 181.917 seconds.  
Checkpoint has been created.  
Epoch 21 Loss 1.703662 Duration 170.265 seconds.  
Epoch 22 Loss 1.724723 Duration 170.474 seconds.  
Epoch 23 Loss 1.712446 Duration 102.113 seconds.  
Epoch 24 Loss 1.696883 Duration 101.826 seconds.  
Epoch 25 Loss 1.690280 Duration 101.680 seconds.  
Epoch 26 Loss 1.687283 Duration 101.861 seconds.  
Epoch 27 Loss 1.715937 Duration 102.117 seconds.  
Epoch 28 Loss 1.786857 Duration 102.205 seconds.  
Epoch 29 Loss 1.736567 Duration 100.223 seconds.  
Epoch 30 Loss 1.786134 Duration 104.526 seconds.  
Checkpoint has been created.  
Epoch 31 Loss 1.685953 Duration 101.933 seconds.  
Epoch 32 Loss 1.736255 Duration 101.686 seconds.  
Epoch 33 Loss 1.649446 Duration 103.270 seconds.  
Epoch 34 Loss 1.766070 Duration 103.973 seconds.  
Epoch 35 Loss 1.727726 Duration 103.642 seconds.  
Epoch 36 Loss 1.717600 Duration 102.282 seconds.  
Epoch 37 Loss 1.665911 Duration 102.657 seconds.  
Epoch 38 Loss 1.670597 Duration 105.036 seconds.  
Epoch 39 Loss 1.730624 Duration 99.547 seconds.  
Epoch 40 Loss 1.676359 Duration 95.473 seconds.  
Checkpoint has been created.  
Epoch 41 Loss 1.673016 Duration 95.138 seconds.  
Epoch 42 Loss 1.748420 Duration 95.572 seconds.  
Epoch 43 Loss 1.760042 Duration 95.278 seconds.  
Epoch 44 Loss 1.800549 Duration 95.671 seconds.  
Epoch 45 Loss 1.681574 Duration 95.509 seconds.  
Epoch 46 Loss 1.750901 Duration 95.438 seconds.  
Epoch 47 Loss 1.759270 Duration 95.290 seconds.  
Epoch 48 Loss 1.698287 Duration 94.798 seconds.  
Epoch 49 Loss 1.690603 Duration 95.461 seconds.  
Epoch 50 Loss 1.652050 Duration 95.457 seconds.  
Checkpoint has been created.  
Epoch 51 Loss 1.748744 Duration 95.143 seconds.  
Epoch 52 Loss 1.664204 Duration 95.185 seconds.  
Epoch 53 Loss 1.721217 Duration 94.782 seconds.  
Epoch 54 Loss 1.735000 Duration 95.019 seconds.  
Epoch 55 Loss 1.733707 Duration 95.093 seconds.  
Epoch 56 Loss 1.718624 Duration 94.882 seconds.

Epoch 57 Loss 1.682994 Duration 94.773 seconds.  
Epoch 58 Loss 1.760963 Duration 95.086 seconds.  
Epoch 59 Loss 1.785629 Duration 94.557 seconds.  
Epoch 60 Loss 1.691675 Duration 94.668 seconds.  
Checkpoint has been created.  
Epoch 61 Loss 1.743364 Duration 94.782 seconds.  
Epoch 62 Loss 1.745736 Duration 95.121 seconds.  
Epoch 63 Loss 1.708296 Duration 95.006 seconds.  
Epoch 64 Loss 1.736557 Duration 95.299 seconds.  
Epoch 65 Loss 1.720004 Duration 94.749 seconds.  
Epoch 66 Loss 1.744494 Duration 94.747 seconds.  
Epoch 67 Loss 1.740485 Duration 94.373 seconds.  
Epoch 68 Loss 1.688853 Duration 94.878 seconds.  
Epoch 69 Loss 1.674425 Duration 94.891 seconds.  
Epoch 70 Loss 1.710384 Duration 94.882 seconds.  
Checkpoint has been created.  
Epoch 71 Loss 1.681930 Duration 95.246 seconds.  
Epoch 72 Loss 1.675672 Duration 95.039 seconds.  
Epoch 73 Loss 1.720593 Duration 94.609 seconds.  
Epoch 74 Loss 1.693539 Duration 94.715 seconds.  
Epoch 75 Loss 1.688610 Duration 94.912 seconds.  
Epoch 76 Loss 1.674830 Duration 94.632 seconds.  
Epoch 77 Loss 1.698468 Duration 95.098 seconds.  
Epoch 78 Loss 1.692740 Duration 94.813 seconds.  
Epoch 79 Loss 1.649389 Duration 95.542 seconds.  
Epoch 80 Loss 1.707424 Duration 95.210 seconds.  
Checkpoint has been created.  
Epoch 81 Loss 1.715847 Duration 95.124 seconds.  
Epoch 82 Loss 1.696532 Duration 95.065 seconds.  
Epoch 83 Loss 1.686250 Duration 95.002 seconds.  
Epoch 84 Loss 1.639218 Duration 102.405 seconds.  
Epoch 85 Loss 1.683416 Duration 101.546 seconds.  
Epoch 86 Loss 1.718550 Duration 103.098 seconds.  
Epoch 87 Loss 1.709079 Duration 103.267 seconds.  
Epoch 88 Loss 1.701370 Duration 102.059 seconds.  
Epoch 89 Loss 1.728400 Duration 104.181 seconds.  
Epoch 90 Loss 1.667134 Duration 101.894 seconds.  
Checkpoint has been created.  
Epoch 91 Loss 1.657640 Duration 97.850 seconds.  
Epoch 92 Loss 1.721572 Duration 102.793 seconds.  
Epoch 93 Loss 1.644660 Duration 101.527 seconds.  
Epoch 94 Loss 1.663152 Duration 99.098 seconds.  
Epoch 95 Loss 1.704944 Duration 99.865 seconds.  
Epoch 96 Loss 1.638471 Duration 99.593 seconds.  
Epoch 97 Loss 1.716068 Duration 99.893 seconds.  
Epoch 98 Loss 1.680885 Duration 100.214 seconds.  
Epoch 99 Loss 1.650818 Duration 94.502 seconds.  
Epoch 100 Loss 1.683068 Duration 94.686 seconds.  
Checkpoint has been created.  
Epoch 101 Loss 1.709160 Duration 94.729 seconds.  
Epoch 102 Loss 1.717804 Duration 94.536 seconds.  
Epoch 103 Loss 1.707152 Duration 94.700 seconds.  
Epoch 104 Loss 1.689312 Duration 94.658 seconds.  
Epoch 105 Loss 1.710769 Duration 94.893 seconds.  
Epoch 106 Loss 1.692937 Duration 94.960 seconds.  
Epoch 107 Loss 1.743447 Duration 94.837 seconds.  
Epoch 108 Loss 1.668307 Duration 94.939 seconds.  
Epoch 109 Loss 1.673443 Duration 94.742 seconds.  
Epoch 110 Loss 1.718888 Duration 94.557 seconds.

Checkpoint has been created.

Epoch 111 Loss 1.688698 Duration 94.205 seconds.  
Epoch 112 Loss 1.736363 Duration 93.989 seconds.  
Epoch 113 Loss 1.749324 Duration 94.141 seconds.  
Epoch 114 Loss 1.643229 Duration 95.290 seconds.  
Epoch 115 Loss 1.713343 Duration 95.215 seconds.  
Epoch 116 Loss 1.638193 Duration 93.217 seconds.  
Epoch 117 Loss 1.650723 Duration 94.496 seconds.  
Epoch 118 Loss 1.700015 Duration 92.972 seconds.  
Epoch 119 Loss 1.712466 Duration 93.039 seconds.  
Epoch 120 Loss 1.708274 Duration 93.442 seconds.  
Checkpoint has been created.

Epoch 121 Loss 1.692642 Duration 94.350 seconds.  
Epoch 122 Loss 1.680777 Duration 94.144 seconds.  
Epoch 123 Loss 1.666398 Duration 94.065 seconds.  
Epoch 124 Loss 1.656645 Duration 94.413 seconds.  
Epoch 125 Loss 1.682365 Duration 94.113 seconds.  
Epoch 126 Loss 1.709246 Duration 93.986 seconds.  
Epoch 127 Loss 1.686799 Duration 93.893 seconds.  
Epoch 128 Loss 1.641454 Duration 94.344 seconds.  
Epoch 129 Loss 1.704138 Duration 94.268 seconds.  
Epoch 130 Loss 1.627378 Duration 96.370 seconds.  
Checkpoint has been created.

Epoch 131 Loss 1.630394 Duration 99.450 seconds.  
Epoch 132 Loss 1.626126 Duration 99.429 seconds.  
Epoch 133 Loss 1.678116 Duration 99.606 seconds.  
Epoch 134 Loss 1.582046 Duration 100.431 seconds.  
Epoch 135 Loss 1.717714 Duration 99.518 seconds.  
Epoch 136 Loss 1.641348 Duration 99.085 seconds.  
Epoch 137 Loss 1.718943 Duration 96.132 seconds.  
Epoch 138 Loss 1.678457 Duration 98.100 seconds.  
Epoch 139 Loss 1.675596 Duration 101.329 seconds.  
Epoch 140 Loss 1.716462 Duration 97.465 seconds.  
Checkpoint has been created.

Epoch 141 Loss 1.728582 Duration 97.322 seconds.  
Epoch 142 Loss 1.643223 Duration 102.391 seconds.  
Epoch 143 Loss 1.714178 Duration 101.840 seconds.  
Epoch 144 Loss 1.669827 Duration 102.487 seconds.  
Epoch 145 Loss 1.669674 Duration 101.261 seconds.  
Epoch 146 Loss 1.695178 Duration 99.636 seconds.  
Epoch 147 Loss 1.672853 Duration 99.818 seconds.  
Epoch 148 Loss 1.692376 Duration 95.897 seconds.  
Epoch 149 Loss 1.712232 Duration 91.743 seconds.  
Epoch 150 Loss 1.716954 Duration 98.410 seconds.  
Checkpoint has been created.

Epoch 151 Loss 1.698011 Duration 97.894 seconds.  
Epoch 152 Loss 1.671428 Duration 97.116 seconds.  
Epoch 153 Loss 1.644054 Duration 96.942 seconds.  
Epoch 154 Loss 1.711297 Duration 90.633 seconds.  
Epoch 155 Loss 1.684206 Duration 91.583 seconds.  
Epoch 156 Loss 1.669461 Duration 91.956 seconds.  
Epoch 157 Loss 1.693763 Duration 91.763 seconds.  
Epoch 158 Loss 1.739948 Duration 94.906 seconds.  
Epoch 159 Loss 1.663999 Duration 93.478 seconds.  
Epoch 160 Loss 1.667747 Duration 92.255 seconds.  
Checkpoint has been created.

Epoch 161 Loss 1.684448 Duration 92.550 seconds.  
Epoch 162 Loss 1.715983 Duration 91.935 seconds.  
Epoch 163 Loss 1.719768 Duration 92.601 seconds.

Epoch 164 Loss 1.711896 Duration 92.852 seconds.  
 Epoch 165 Loss 1.678590 Duration 92.680 seconds.  
 Epoch 166 Loss 1.633449 Duration 92.333 seconds.  
 Epoch 167 Loss 1.617714 Duration 96.151 seconds.  
 Epoch 168 Loss 1.685222 Duration 98.450 seconds.  
 Epoch 169 Loss 1.703202 Duration 98.432 seconds.  
 Epoch 170 Loss 1.694694 Duration 98.378 seconds.  
 Checkpoint has been created.  
 Epoch 171 Loss 1.649729 Duration 98.277 seconds.  
 Epoch 172 Loss 1.727990 Duration 98.236 seconds.  
 Epoch 173 Loss 1.666174 Duration 98.201 seconds.  
 Epoch 174 Loss 1.710297 Duration 97.898 seconds.  
 Epoch 175 Loss 1.700603 Duration 98.033 seconds.  
 Epoch 176 Loss 1.745156 Duration 98.416 seconds.  
 Epoch 177 Loss 1.628908 Duration 95.447 seconds.  
 Epoch 178 Loss 1.657946 Duration 91.949 seconds.  
 Epoch 179 Loss 1.679477 Duration 92.296 seconds.  
 Epoch 180 Loss 1.665162 Duration 92.198 seconds.  
 Checkpoint has been created.  
 Epoch 181 Loss 1.645265 Duration 92.814 seconds.  
 Epoch 182 Loss 1.662404 Duration 92.135 seconds.  
 Epoch 183 Loss 1.722891 Duration 92.426 seconds.  
 Epoch 184 Loss 1.610835 Duration 92.628 seconds.  
 Epoch 185 Loss 1.704155 Duration 92.572 seconds.  
 Epoch 186 Loss 1.729048 Duration 92.817 seconds.  
 Epoch 187 Loss 1.707020 Duration 92.225 seconds.  
 Epoch 188 Loss 1.651891 Duration 92.682 seconds.  
 Epoch 189 Loss 1.656192 Duration 92.623 seconds.  
 Epoch 190 Loss 1.733911 Duration 92.626 seconds.  
 Checkpoint has been created.  
 Epoch 191 Loss 1.633651 Duration 92.420 seconds.  
 Epoch 192 Loss 1.678530 Duration 92.532 seconds.  
 Epoch 193 Loss 1.632002 Duration 92.751 seconds.  
 Epoch 194 Loss 1.719390 Duration 92.604 seconds.  
 Epoch 195 Loss 1.626907 Duration 92.669 seconds.  
 Epoch 196 Loss 1.681161 Duration 92.726 seconds.  
 Epoch 197 Loss 1.722104 Duration 92.371 seconds.  
 Epoch 198 Loss 1.732533 Duration 93.378 seconds.  
 Epoch 199 Loss 1.689982 Duration 93.284 seconds.  
 Epoch 200 Loss 1.652457 Duration 94.748 seconds.  
 Checkpoint has been created.

#### Testing accuracy for Bottleneck Residual Block

```

### Test or Validation ###
Restored model parameters from saved_models\model-bottleneck_res-10.ckpt
100%| 10000/10000 [01:34<00:00, 105.48it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.5111
Restored model parameters from saved_models\model-bottleneck_res-20.ckpt
100%| 10000/10000 [01:28<00:00, 112.58it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.5248
Restored model parameters from saved_models\model-bottleneck_res-40.ckpt
100%| 10000/10000 [01:28<00:00, 112.50it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.4626
Restored model parameters from saved_models\model-bottleneck_res-80.ckpt
100%| 10000/10000 [01:31<00:00, 109.69it/s]
  
```



```

torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6385
Restored model parameters from saved_models\model-bottleneck_res-100.ckpt
100%| 10000/10000 [01:38<00:00, 101.72it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6245
Restored model parameters from saved_models\model-bottleneck_res-120.ckpt
100%| 10000/10000 [01:34<00:00, 105.39it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6191
Restored model parameters from saved_models\model-bottleneck_res-160.ckpt
100%| 10000/10000 [01:30<00:00, 110.28it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6294
Restored model parameters from saved_models\model-bottleneck_res-180.ckpt
100%| 10000/10000 [01:35<00:00, 104.62it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.5400
Restored model parameters from saved_models\model-bottleneck_res-200.ckpt
100%| 10000/10000 [01:44<00:00, 96.11it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6108

```

## B Appendix

Training loss for ResNet-B

```

### Training... ###
Epoch-1 lr: 0.1
Epoch 1 Loss 1.213185 Duration 148.193 seconds.
Epoch-2 lr: 0.1
Epoch 2 Loss 1.055650 Duration 147.678 seconds.
Epoch-3 lr: 0.1
Epoch 3 Loss 0.717960 Duration 148.166 seconds.
Epoch-4 lr: 0.1
Epoch 4 Loss 0.798185 Duration 148.332 seconds.
Epoch-5 lr: 0.1
Epoch 5 Loss 0.642246 Duration 148.521 seconds.
Checkpoint has been created.
Epoch-6 lr: 0.1
Epoch 6 Loss 0.852025 Duration 148.668 seconds.
Epoch-7 lr: 0.1
Epoch 7 Loss 0.489399 Duration 148.685 seconds.
Epoch-8 lr: 0.1
Epoch 8 Loss 0.579551 Duration 148.671 seconds.
Epoch-9 lr: 0.1
Epoch 9 Loss 0.583394 Duration 148.710 seconds.
Epoch-10 lr: 0.1
Epoch 10 Loss 0.509069 Duration 148.744 seconds.
Checkpoint has been created.
Epoch-11 lr: 0.1
Epoch 11 Loss 0.547181 Duration 148.789 seconds.
Epoch-12 lr: 0.1
Epoch 12 Loss 0.517088 Duration 148.871 seconds.
Epoch-13 lr: 0.1
Epoch 13 Loss 0.494798 Duration 148.755 seconds.
Epoch-14 lr: 0.1
Epoch 14 Loss 0.499049 Duration 148.743 seconds.
Epoch-15 lr: 0.1

```

Epoch 15 Loss 0.502697 Duration 148.722 seconds.  
 Checkpoint has been created.  
 Epoch-16 lr: 0.1  
 Epoch 16 Loss 0.393377 Duration 148.717 seconds.  
 Epoch-17 lr: 0.1  
 Epoch 17 Loss 0.524652 Duration 148.671 seconds.  
 Epoch-18 lr: 0.1  
 Epoch 18 Loss 0.449361 Duration 148.881 seconds.  
 Epoch-19 lr: 0.1  
 Epoch 19 Loss 0.529273 Duration 148.822 seconds.  
 Epoch-20 lr: 0.010000000000000002  
  
 Epoch 20 Loss 0.223757 Duration 148.814 seconds.  
 Checkpoint has been created.  
 Epoch-21 lr: 0.010000000000000002  
 Epoch 21 Loss 0.110726 Duration 148.833 seconds.  
 Epoch-22 lr: 0.010000000000000002  
 Epoch 22 Loss 0.153483 Duration 148.747 seconds.  
 Epoch-23 lr: 0.010000000000000002  
 Epoch 23 Loss 0.147353 Duration 148.617 seconds.  
 Epoch-24 lr: 0.010000000000000002  
 Epoch 24 Loss 0.051436 Duration 148.729 seconds.  
 Epoch-25 lr: 0.010000000000000002  
 Epoch 25 Loss 0.061751 Duration 148.786 seconds.  
 Checkpoint has been created.  
 Epoch-26 lr: 0.010000000000000002  
 Epoch 26 Loss 0.040777 Duration 148.659 seconds.  
 Epoch-27 lr: 0.010000000000000002  
 Epoch 27 Loss 0.046030 Duration 148.740 seconds.  
 Epoch-28 lr: 0.010000000000000002  
 Epoch 28 Loss 0.013239 Duration 148.732 seconds.  
 Epoch-29 lr: 0.010000000000000002  
 Epoch 29 Loss 0.010425 Duration 148.530 seconds.  
 Epoch-30 lr: 0.010000000000000002  
 Epoch 30 Loss 0.005237 Duration 148.641 seconds.  
 Checkpoint has been created.  
 Epoch-31 lr: 0.010000000000000002  
 Epoch 31 Loss 0.005403 Duration 148.510 seconds.  
 Epoch-32 lr: 0.010000000000000002  
 Epoch 32 Loss 0.005575 Duration 148.455 seconds.  
 Epoch-33 lr: 0.010000000000000002  
 Epoch 33 Loss 0.008746 Duration 148.495 seconds.  
 Epoch-34 lr: 0.010000000000000002  
 Epoch 34 Loss 0.011342 Duration 148.405 seconds.  
 Epoch-35 lr: 0.010000000000000002  
 Epoch 35 Loss 0.004760 Duration 148.487 seconds.  
 Checkpoint has been created.  
 Epoch-36 lr: 0.010000000000000002  
 Epoch 36 Loss 0.003072 Duration 148.606 seconds.  
 Epoch-37 lr: 0.010000000000000002  
 Epoch 37 Loss 0.006412 Duration 148.570 seconds.  
 Epoch-38 lr: 0.010000000000000002  
 Epoch 38 Loss 0.002278 Duration 148.631 seconds.  
 Epoch-39 lr: 0.010000000000000002  
 Epoch 39 Loss 0.003292 Duration 148.824 seconds.  
 Epoch-40 lr: 0.0010000000000000002  
  
 Epoch 40 Loss 0.002343 Duration 148.705 seconds.  
 Checkpoint has been created.

Epoch-41 lr: 0.00100000000000000002  
 Epoch 41 Loss 0.003839 Duration 148.542 seconds.  
 Epoch-42 lr: 0.00100000000000000002  
 Epoch 42 Loss 0.003474 Duration 148.563 seconds.  
 Epoch-43 lr: 0.00100000000000000002  
 Epoch 43 Loss 0.002261 Duration 148.472 seconds.  
 Epoch-44 lr: 0.00100000000000000002  
 Epoch 44 Loss 0.002582 Duration 148.440 seconds.  
 Epoch-45 lr: 0.00100000000000000002  
 Epoch 45 Loss 0.002398 Duration 148.520 seconds.  
 Checkpoint has been created.  
 Epoch-46 lr: 0.00100000000000000002  
 Epoch 46 Loss 0.003266 Duration 148.458 seconds.  
 Epoch-47 lr: 0.00100000000000000002  
 Epoch 47 Loss 0.002682 Duration 148.472 seconds.  
 Epoch-48 lr: 0.00100000000000000002  
 Epoch 48 Loss 0.003025 Duration 148.615 seconds.  
 Epoch-49 lr: 0.00100000000000000002  
 Epoch 49 Loss 0.002161 Duration 148.531 seconds.  
 Epoch-50 lr: 0.00100000000000000002  
 Epoch 50 Loss 0.002801 Duration 148.553 seconds.  
 Checkpoint has been created.  
 Epoch-51 lr: 0.00100000000000000002  
 Epoch 51 Loss 0.001982 Duration 148.440 seconds.  
 Epoch-52 lr: 0.00100000000000000002  
 Epoch 52 Loss 0.003092 Duration 148.325 seconds.  
 Epoch-53 lr: 0.00100000000000000002  
 Epoch 53 Loss 0.002640 Duration 148.395 seconds.  
 Epoch-54 lr: 0.00100000000000000002  
 Epoch 54 Loss 0.003569 Duration 148.485 seconds.  
 Epoch-55 lr: 0.00100000000000000002  
 Epoch 55 Loss 0.003126 Duration 148.546 seconds.  
 Checkpoint has been created.  
 Epoch-56 lr: 0.00100000000000000002  
 Epoch 56 Loss 0.002280 Duration 148.530 seconds.  
 Epoch-57 lr: 0.00100000000000000002  
 Epoch 57 Loss 0.002211 Duration 148.468 seconds.  
 Epoch-58 lr: 0.00100000000000000002  
 Epoch 58 Loss 0.001942 Duration 148.530 seconds.  
 Epoch-59 lr: 0.00100000000000000002  
 Epoch 59 Loss 0.002019 Duration 148.509 seconds.  
 Epoch-60 lr: 0.00010000000000000003  
 Epoch 60 Loss 0.003347 Duration 148.512 seconds.  
 Checkpoint has been created.  
 Epoch-61 lr: 0.00010000000000000003  
 Epoch 61 Loss 0.003242 Duration 148.530 seconds.  
 Epoch-62 lr: 0.00010000000000000003  
 Epoch 62 Loss 0.003352 Duration 148.362 seconds.  
 Epoch-63 lr: 0.00010000000000000003  
 Epoch 63 Loss 0.001909 Duration 148.283 seconds.  
 Epoch-64 lr: 0.00010000000000000003  
 Epoch 64 Loss 0.002155 Duration 148.433 seconds.  
 Epoch-65 lr: 0.00010000000000000003  
 Epoch 65 Loss 0.003752 Duration 148.488 seconds.  
 Checkpoint has been created.  
 Epoch-66 lr: 0.00010000000000000003  
 Epoch 66 Loss 0.002751 Duration 148.501 seconds.  
 Epoch-67 lr: 0.00010000000000000003

Epoch 67 Loss 0.004042 Duration 148.574 seconds.  
 Epoch-68 lr: 0.00010000000000000003  
 Epoch 68 Loss 0.003811 Duration 148.438 seconds.  
 Epoch-69 lr: 0.00010000000000000003  
 Epoch 69 Loss 0.002547 Duration 148.508 seconds.  
 Epoch-70 lr: 0.00010000000000000003  
 Epoch 70 Loss 0.001697 Duration 148.560 seconds.  
 Checkpoint has been created.  
 Epoch-71 lr: 0.00010000000000000003  
 Epoch 71 Loss 0.002429 Duration 148.487 seconds.  
 Epoch-72 lr: 0.00010000000000000003  
 Epoch 72 Loss 0.002799 Duration 148.457 seconds.  
 Epoch-73 lr: 0.00010000000000000003  
 Epoch 73 Loss 0.002346 Duration 148.402 seconds.  
 Epoch-74 lr: 0.00010000000000000003  
 Epoch 74 Loss 0.002827 Duration 148.240 seconds.  
 Epoch-75 lr: 0.00010000000000000003  
 Epoch 75 Loss 0.002068 Duration 148.375 seconds.  
 Checkpoint has been created.  
 Epoch-76 lr: 0.00010000000000000003  
 Epoch 76 Loss 0.001627 Duration 148.393 seconds.  
 Epoch-77 lr: 0.00010000000000000003  
 Epoch 77 Loss 0.002167 Duration 148.508 seconds.  
 Epoch-78 lr: 0.00010000000000000003  
 Epoch 78 Loss 0.002423 Duration 148.474 seconds.  
 Epoch-79 lr: 0.00010000000000000003  
 Epoch 79 Loss 0.002909 Duration 148.467 seconds.  
 Epoch-80 lr: 1.0000000000000004e-05  
  
 Epoch 80 Loss 0.002392 Duration 148.496 seconds.  
 Checkpoint has been created.  
 Epoch-81 lr: 1.0000000000000004e-05  
 Epoch 81 Loss 0.002791 Duration 148.484 seconds.  
 Epoch-82 lr: 1.0000000000000004e-05  
 Epoch 82 Loss 0.001660 Duration 148.528 seconds.  
 Epoch-83 lr: 1.0000000000000004e-05  
 Epoch 83 Loss 0.002247 Duration 148.512 seconds.  
 Epoch-84 lr: 1.0000000000000004e-05  
 Epoch 84 Loss 0.002926 Duration 149.111 seconds.  
 Epoch-85 lr: 1.0000000000000004e-05  
 Epoch 85 Loss 0.002145 Duration 148.415 seconds.  
 Checkpoint has been created.  
 Epoch-86 lr: 1.0000000000000004e-05  
 Epoch 86 Loss 0.002191 Duration 148.545 seconds.  
 Epoch-87 lr: 1.0000000000000004e-05  
 Epoch 87 Loss 0.006555 Duration 148.605 seconds.  
 Epoch-88 lr: 1.0000000000000004e-05  
 Epoch 88 Loss 0.004280 Duration 148.547 seconds.  
 Epoch-89 lr: 1.0000000000000004e-05  
 Epoch 89 Loss 0.002668 Duration 148.565 seconds.  
 Epoch-90 lr: 1.0000000000000004e-05  
 Epoch 90 Loss 0.002502 Duration 148.531 seconds.  
 Checkpoint has been created.  
 Epoch-91 lr: 1.0000000000000004e-05  
 Epoch 91 Loss 0.001420 Duration 148.482 seconds.  
 Epoch-92 lr: 1.0000000000000004e-05  
 Epoch 92 Loss 0.002198 Duration 148.306 seconds.  
 Epoch-93 lr: 1.0000000000000004e-05  
 Epoch 93 Loss 0.002594 Duration 148.413 seconds.

Epoch-94 lr: 1.0000000000000004e-05  
Epoch 94 Loss 0.002691 Duration 148.475 seconds.  
Epoch-95 lr: 1.0000000000000004e-05  
Epoch 95 Loss 0.002177 Duration 148.355 seconds.  
Checkpoint has been created.  
Epoch-96 lr: 1.0000000000000004e-05  
Epoch 96 Loss 0.005524 Duration 148.467 seconds.  
Epoch-97 lr: 1.0000000000000004e-05  
Epoch 97 Loss 0.001451 Duration 148.402 seconds.  
Epoch-98 lr: 1.0000000000000004e-05  
Epoch 98 Loss 0.002055 Duration 148.355 seconds.  
Epoch-99 lr: 1.0000000000000004e-05  
Epoch 99 Loss 0.001959 Duration 148.391 seconds.  
Epoch-100 lr: 1.0000000000000004e-06

Epoch 100 Loss 0.002904 Duration 148.517 seconds.  
Checkpoint has been created.

Testing accuracy for ResNet-B

```
### Test or Validation ###
Restored model parameters from saved_models\model-bottleneck_res-10.ckpt
100%| 10000/10000 [01:12<00:00, 137.40it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.5337
Restored model parameters from saved_models\model-bottleneck_res-20.ckpt
100%| 10000/10000 [01:11<00:00, 139.95it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.7010
Restored model parameters from saved_models\model-bottleneck_res-30.ckpt
100%| 10000/10000 [01:11<00:00, 139.19it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6690
Restored model parameters from saved_models\model-bottleneck_res-40.ckpt
100%| 10000/10000 [01:11<00:00, 140.23it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6704
Restored model parameters from saved_models\model-bottleneck_res-50.ckpt
100%| 10000/10000 [01:11<00:00, 140.72it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6790
Restored model parameters from saved_models\model-bottleneck_res-60.ckpt
100%| 10000/10000 [01:11<00:00, 140.18it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6611
Restored model parameters from saved_models\model-bottleneck_res-70.ckpt
100%| 10000/10000 [01:11<00:00, 140.42it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6879
Restored model parameters from saved_models\model-bottleneck_res-80.ckpt
100%| 10000/10000 [01:11<00:00, 139.87it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6871
Restored model parameters from saved_models\model-bottleneck_res-90.ckpt
100%| 10000/10000 [01:13<00:00, 136.87it/s]
torch.Size([10000]) torch.Size([10000])
Test accuracy: 0.6908
Restored model parameters from saved_models\model-bottleneck_res-100.ckpt
100%| 10000/10000 [01:12<00:00, 137.94it/s]
```

```
torch.Size([10000]) torch.Size([10000])  
Test accuracy: 0.6697
```