Lab 3: Gesture Recognition using Convolutional Neural Networks

Deadlines:

- Lab 3 Part A: February 6, 11:59pm
- Lab 3 Part B: February 13, 11:59pm

Late Penalty: There is a penalty-free grace period of one hour past the deadline. Any work that is submitted between 1 hour and 24 hours past the deadline will receive a 20% grade deduction. No other late work is accepted. Quercus submission time will be used, not your local computer time. You can submit your labs as many times as you want before the deadline, so please submit often and early.

Grading TAs:

- Lab 3 Part A: Geoff Donoghue
- Lab 3 Part B: Tianshi Cao

This lab is based on an assignment developed by Prof. Lisa Zhang.

This lab will be completed in two parts. In Part A you will you will gain experience gathering your own data set (specifically images of hand gestures), and understand the challenges involved in the data cleaning process. In Part B you will train a convolutional neural network to make classifications on different hand gestures. By the end of the lab, you should be able to:

1. Generate and preprocess your own data
2. Load and split data for training, validation and testing
3. Train a Convolutional Neural Network
4. Apply transfer learning to improve your model

Note that for this lab we will not be providing you with any starter code. You should be able to take the code used in previous labs, tutorials and lectures and modify it accordingly to complete the tasks outlined below.

What to submit

Submission for Part A:

Submit a zip file containing your images. Three images each of American Sign Language gestures for letters A - I (total of 27 images). You will be required to clean the images before submitting them. Details are provided under Part A of the handout.

Individual image file names should follow the convention of student-number_Alphabet_file-number.jpg (e.g. 100343434_A_1.jpg).

Submission for Part B:

Submit a PDF file containing all your code, outputs, and write-up from parts 1-5. You can produce a PDF of your Google Colab file by going to **File > Print** and then save as PDF. The Colab instructions has more information. Make sure to review the PDF submission to ensure that your answers are easy to read. Make sure that your text is not cut off at the margins.

Do not submit any other files produced by your code.

Include a link to your colab file in your submission.

Please use Google Colab to complete this assignment. If you want to use Jupyter Notebook, please complete the assignment and upload your Jupyter Notebook file to Google Colab for submission.

Colab Link

Include a link to your colab file here

Colab Link: https://colab.research.google.com/drive/1icVDsN8AcLJfh5tZgUXYMb3QvFkeVwbY

Part A. Data Collection [10 pt]

So far, we have worked with data sets that have been collected, cleaned, and curated by machine learning researchers and practitioners. Datasets like MNIST and CIFAR are often used as toy examples, both by students and by researchers testing new machine learning models.

In the real world, getting a clean data set is never that easy. More than half the work in applying machine learning is finding, gathering, cleaning, and formatting your data set.

The purpose of this lab is to help you gain experience gathering your own data set, and understand the challenges involved in the data cleaning process.

American Sign Language

American Sign Language (ASL) is a complete, complex language that employs signs made by moving the hands combined with facial expressions and postures of the body. It is the primary language of many North Americans who are deaf and is one of several communication options used by people who are deaf or hard-of-hearing.

The hand gestures representing English alphabet are shown below. This lab focuses on classifying a subset of these hand gesture images using convolutional neural networks. Specifically, given an image of a hand showing one of the letters A-I, we want to detect which letter is being represented.

Generating Data

We will produce the images required for this lab by ourselves. Each student will collect, clean and submit three images each of Americal Sign Language gestures for letters A - I (total of 27 images) Steps involved in data collection

1. Familiarize yourself with American Sign Language gestures for letters from A - I (9 letters).
2. Ask your friend to take three pictures at slightly different orientation for each letter gesture using your mobile phone.
    - Ensure adequate lighting while you are capturing the images.
    - Use a white wall as your background.
    - Use your right hand to create gestures (for consistency).
    - Keep your right hand fairly apart from your body and any other obstructions.
    - Avoid having shadows on parts of your hand.
3. Transfer the images to your laptop for cleaning.

Cleaning Data

To simplify the machine learning the task, we will standardize the training images. We will make sure that all our images are of the same size (224 x 224 pixels RGB), and have the hand in the center of the cropped regions.

You may use the following applications to crop and resize your images:

Mac

- Use Preview: – Holding down CMD + Shift will keep a square aspect ratio while selecting the hand area. – Resize to 224x224 pixels.

Windows 10

- Use Photos app to edit and crop the image and keep the aspect ratio a square.
- Use Paint to resize the image to the final image size of 224x224 pixels.

Linux

- You can use GIMP, imagemagick, or other tools of your choosing. You may also use online tools such as http://picresize.com All the above steps are illustrative only. You need not follow these steps but following these will ensure that you produce a good quality dataset. You

will be judged based on the quality of the images alone. Please do not edit your photos in any other way. You should not need to change the aspect ratio of your image. You also should not digitally remove the background or shadows—instead, take photos with a white background and minimal shadows.

Accepted Images

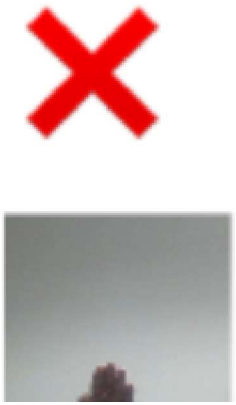
Images will be accepted and graded based on the criteria below

1. The final image should be size 224x224 pixels (RGB).
2. The file format should be a .jpg file.
3. The hand should be approximately centered on the frame.
4. The hand should not be obscured or cut off.
5. The photos follows the ASL gestures posted earlier.
6. The photos were not edited in any other way (e.g. no electronic removal of shadows or background).

Submission

Submit a zip file containing your images. There should be a total of 27 images (3 for each category)

1. Individual image file names should follow the convention of student-number_Alphabet_file-number.jpg (e.g. 100343434_A_1.jpg)
2. Zip all the images together and name it with the following convention: last-name_student-number.zip (e.g. last-name_100343434.zip).
3. Submit the zipped folder. We will be anonymizing and combining the images that everyone submits. We will announce when the combined data set will be available for download.

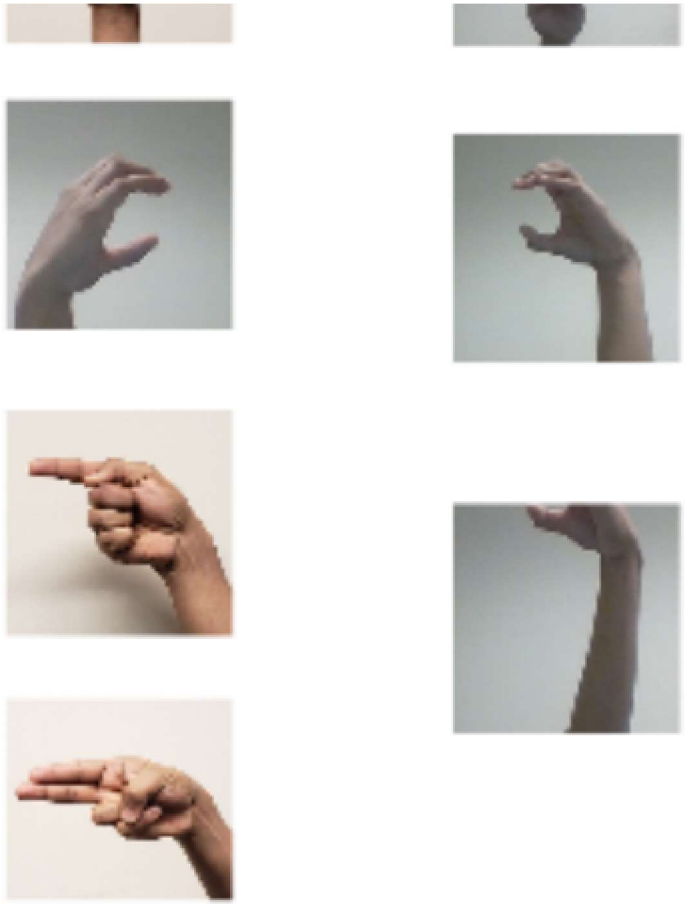


Figure 1: Acceptable Images (left) and Unacceptable Images (right)

Part B. Building a CNN [50 pt]

For this lab, we are not going to give you any starter code. You will be writing a convolutional neural network from scratch. You are welcome to use any code from previous labs, lectures and tutorials. You should also write your own code.

You may use the PyTorch documentation freely. You might also find online tutorials helpful. However, all code that you submit must be your own.

Make sure that your code is vectorized, and does not contain obvious inefficiencies (for example, unecessary for loops, or unnecessary calls to unsqueeze()). Ensure enough comments are included in the code so that your TA can understand what you are doing. It is your responsibility to show that you understand what you write.

This is much more challenging and time-consuming than the previous labs. Make sure that you give yourself plenty of time by starting early. In particular, the earlier questions can be completed even if you do not yet have the full data set.

1. Data Loading and Splitting [10 pt]

Download the anonymized data provided from Quercus. Split the data into training, validation, and test sets.

Note: Data splitting is not as trivial in this lab. We want our test set to closely resemble the setting in which our model will be used. In particular, our test set should contain hands that are never seen in training!

Explain how you split the data, either by describing what you did, or by showing the code that you used. Justify your choice of splitting strategy. How many training, validation, and test images do you have?

For loading the data, you can use plt.imread as in Lab 1, or any other method that you choose. You may find torchvision.datasets.ImageFolder helpful. (see https://pytorch.org/docs/master/torchvision/datasets.html#imagefolder)

```
# Imports
import numpy as np
import matplotlib.pyplot as plt
import time
import torch
import torch.nn as nn
import torch.nn.functional as F
import torch.optim as optim
import torchvision
from torch.utils.data.sampler import SubsetRandomSampler
import torchvision.transforms as transforms
```

```
import torch.utils.data as data_utils


use_cuda=True
torch.backends.cudnn.deterministic = True
torch.backends.cudnn.benchmark = False


# Mount Google Drive

from google.colab import drive
drive.mount('/content/gdrive')
```

```
Go to this URL in a browser: https://accounts.google.com/o/oauth2/auth?client_id=947318989803-6bn6qk8qdgf4n4g3pfee6491hc0brc4i.a

Enter your authorization code:
··········
Mounted at /content/gdrive
```

```
# Data loading functions

# Load Image Folder
def get_img_folder(data_dir):
  root_dir = "/content/gdrive/My Drive/APS360/Datasets/"
  transform = transforms.Compose([transforms.CenterCrop((224,224)), transforms.ToTensor(), transforms.Normalize((0.5,0.5,0.5), (0.5,0
  return torchvision.datasets.ImageFolder(root_dir + data_dir, transform)

# Get Training, Validation and Test Datasets
def get_data_loader(dataset, batch_size=64):
  np.random.seed(1000) # Fixed numpy random seed for reproducible shuffling
  torch.manual_seed(1000)

  num_samples = len(dataset.samples)

  # Randomize indices list
  indices = list(range(num_samples))
  np.random.shuffle(indices)
```

```
    # Allocate relevant loaders
    num_train = int(num_samples * 0.6) # 60% of total
    num_val = int(num_samples * 0.2) # 20% of total
    # test is the remaining 20%

    split1, split2 = num_train, num_train + num_val
    train_indices, val_indices, test_indices = indices[:split1], indices[split1:split2], indices[split2:]

    train_sampler = SubsetRandomSampler(train_indices)
    val_sampler = SubsetRandomSampler(val_indices)
    test_sampler = SubsetRandomSampler(test_indices)

    train_loader = torch.utils.data.DataLoader(dataset, batch_size=batch_size,
                                               num_workers=1, sampler=train_sampler)
    val_loader = torch.utils.data.DataLoader(dataset, batch_size=batch_size,
                                             num_workers=1, sampler=val_sampler)
    test_loader = torch.utils.data.DataLoader(dataset, batch_size=batch_size,
                                              num_workers=1, sampler=test_sampler)
    return train_loader, val_loader, test_loader


# Helper Functions (Copied from Lab 2)

def get_model_name(name, batch_size, learning_rate, epoch):
    """ Generate a name for the model consisting of all the hyperparameter values

    Args:
        config: Configuration object containing the hyperparameters
    Returns:
        path: A string with the hyperparameter name and value concatenated
    """
    path = "model_{0}_bs{1}_lr{2}_epoch{3}".format(name,
                                                   batch_size,
                                                   learning_rate,
                                                   epoch)
    return path

def evaluate(net, loader, criterion, enable_cuda=True):
```

```
        """ Evaluate the network on the validation set.

         Args:
             net: PyTorch neural network object
             loader: PyTorch data loader for the validation set
             criterion: The loss function
         Returns:
             err: A scalar for the avg classification error over the validation set
             loss: A scalar for the average loss function over the validation set
         """
        total_loss = 0.0
        total_err = 0.0
        total_epoch = 0
        for i, data in enumerate(loader, 0):
            inputs, labels = data
            if use_cuda and enable_cuda and torch.cuda.is_available():
                inputs = inputs.cuda()
                labels = labels.cuda()
            outputs = net(inputs)
            loss = criterion(outputs, labels)
            corr = outputs.max(1)[1] != labels
            total_err += int(corr.sum())
            total_loss += loss.item()
            total_epoch += len(labels)
        err = float(total_err) / total_epoch
        loss = float(total_loss) / (i + 1)
        return err, loss

    def plot_training_curve(path):
        """ Plots the training curve for a model run, given the csv files
        containing the train/validation error/loss.

        Args:
            path: The base path of the csv files produced during training
        """
        train_err = np.loadtxt("{}_train_err.csv".format(path))
        val_err = np.loadtxt("{}_val_err.csv".format(path))
        train_loss = np.loadtxt("{}_train_loss.csv".format(path))
```

```
    val_loss = np.loadtxt("{}_val_loss.csv".format(path))
    params = path.split("_")
    for param in params:
      if param.startswith("bs"):
        bs = param[2:]
      if param.startswith("lr"):
        lr = param[2:]
    title = "Train vs Validation Error (bs = " + bs + ", lr = " + lr + ")"
    plt.title(title)
    n = len(train_err) # number of epochs
    plt.plot(range(1,n+1), train_err, label="Train")
    plt.plot(range(1,n+1), val_err, label="Validation")
    plt.xlabel("Epoch")
    plt.ylabel("Error")
    plt.legend(loc='best')
    plt.show()
    title = "Train vs Validation Loss (bs = " + bs + ", lr = " + lr + ")"
    plt.title(title)
    plt.plot(range(1,n+1), train_loss, label="Train")
    plt.plot(range(1,n+1), val_loss, label="Validation")
    plt.xlabel("Epoch")
    plt.ylabel("Loss")
    plt.legend(loc='best')
    plt.show()


# Load the data into training/validation/test datasets

dataset = "Lab_3_Gesture_Dataset_W2020"
img_folder = get_img_folder(dataset)

train_loader, val_loader, test_loader = get_data_loader(img_folder, batch_size=1)


# Check loaded data

print("Number of training examples:", len(train_loader))
print("Number of validation examples:", len(val_loader))
print("Number of test examples:", len(test_loader))
```

```
print("Total:", len(train_loader) + len(val_loader) + len(test_loader), "samples out of", len(img_folder.samples))

k = 0
for images, labels in train_loader:
    # since batch_size = 1, there is only 1 image in `images`
    image = images[0]
    # place the colour channel at the end, instead of at the beginning
    img = np.transpose(image, [1,2,0])
    # normalize pixel intensity values to [0, 1]
    img = img / 2 + 0.5
    plt.subplot(3, 5, k+1)
    plt.axis('off')
    plt.imshow(img)

    k += 1
    if k > 14:
        print(img.size())
        break
```

```
Number of training examples: 2712
Number of validation examples: 904
Number of test examples: 905
Total: 4521 samples out of 4521
torch.Size([224, 224, 3])
```

2. Model Building and Sanity Checking [15 pt]

Part (a) Convolutional Network - 5 pt

Build a convolutional neural network model that takes the (224x224 RGB) image as input, and predicts the gesture letter. Your model should be a subclass of nn.Module. Explain your choice of neural network architecture: how many layers did you choose? What types of layers did you use? Were they fully-connected or convolutional? What about other decisions like pooling layers, activation functions, number of channels / hidden units?

```
class ConvNet(nn.Module):
    def __init__(self, name="cnn"):
        super(ConvNet,self).__init__()
        self.name = name

        in_ch1 = 3
        out_ch1 = 5
        kern_sz1 = 5
        stride1 = 1
        padding1 = 0

        pool1_kern_sz = 4
        pool1_stride = 4
        pool1_padding = 0

        in_ch2 = out_ch1
        out_ch2 = 10
        kern_sz2 = 5
        stride2 = 1
        padding2 = 0

        pool2_kern_sz = 2
        pool2_stride = 2
        pool2_padding = 0

        in_ch3 = out_ch2
```

```
        in_ch3 = out_ch2
        out_ch3 = 20
        kern_sz3 = 4
        stride3 = 1
        padding3 = 0

        # Calculate size of output after convolution layers
        fc1_in_sz = 1 + int((224 + 2*padding1 - kern_sz1)/stride1)
        fc1_in_sz = 1 + int((fc1_in_sz + 2*pool1_padding - pool1_kern_sz) / pool1_stride)
        fc1_in_sz = 1 + int((fc1_in_sz + 2*padding2 - kern_sz2)/stride2)
        fc1_in_sz = 1 + int((fc1_in_sz + 2*pool2_padding - pool2_kern_sz) / pool2_stride)
        fc1_in_sz = 1 + int((fc1_in_sz + 2*padding3 - kern_sz3)/stride3)
        fc1_in_sz = 1 + int((fc1_in_sz + 2*pool2_padding - pool2_kern_sz) / pool2_stride)
        self.fc1_in_sz = out_ch3 * fc1_in_sz * fc1_in_sz # need to store on self for use in forward

        fc1_out_sz = 27

        fc2_in_sz = fc1_out_sz
        fc2_out_sz = 9 # 9 classes from 'A' to 'I'

        # Three convolution layers (+ max pool)
        self.conv1 = nn.Conv2d(in_ch1, out_ch1, kern_sz1, stride1, padding1)
        self.pool1 = nn.MaxPool2d(pool1_kern_sz, pool1_stride, pool1_padding)
        self.conv2 = nn.Conv2d(in_ch2, out_ch2, kern_sz2, stride2, padding2)
        self.pool2 = nn.MaxPool2d(pool2_kern_sz, pool2_stride, pool2_padding)
        self.conv3 = nn.Conv2d(in_ch3, out_ch3, kern_sz3, stride3, padding3)

        # Two fully connected layers
        self.fc1 = nn.Linear(self.fc1_in_sz, fc1_out_sz)
        self.fc2 = nn.Linear(fc2_in_sz, fc2_out_sz)

    def forward(self, x): # start with 3x224x224 image
        x = self.pool1(F.relu(self.conv1(x)))
        x = self.pool2(F.relu(self.conv2(x)))
        x = self.pool2(F.relu(self.conv3(x)))
        x = x.view(-1, self.fc1_in_sz)
        x = F.relu(self.fc1(x))
        x = self.fc2(x)
```

```
        x = x.squeeze(1)
        return x
```

Part (b) Training Code - 5 pt

Write code that trains your neural network given some training data. Your training code should make it easy to tweak the usual hyperparameters, like batch size, learning rate, and the model object itself. Make sure that you are checkpointing your models from time to time (the frequency is up to you). Explain your choice of loss function and optimizer.

```
def train_net(net, train_loader, val_loader, batch_size=64, learning_rate=0.01, num_epochs=30):
    np.random.seed(1000) # Fixed numpy random seed for reproducible shuffling
    torch.manual_seed(1000)

    criterion = nn.CrossEntropyLoss()
    optimizer = optim.Adam(net.parameters(), lr=learning_rate)

    if use_cuda and torch.cuda.is_available():
      net.cuda()

    # Set up some numpy arrays to store the training/test loss/erruracy
    train_err = np.zeros(num_epochs)
    train_loss = np.zeros(num_epochs)
    val_err = np.zeros(num_epochs)
    val_loss = np.zeros(num_epochs)

    ################################################################################
    # Train the network
    # Loop over the data iterator and sample a new batch of training data
    # Get the output from the network, and optimize our loss function.
    start_time = time.time()
    for epoch in range(num_epochs):  # loop over the dataset multiple times
        total_train_loss = 0.0
        total_train_err = 0.0
        total_epoch = 0

        for i, data in enumerate(train_loader, 0):
```

```
            # Get the inputs
            inputs, labels = data
            if use_cuda and torch.cuda.is_available():
              inputs = inputs.cuda()
              labels = labels.cuda()
            # Zero the parameter gradients
            optimizer.zero_grad()
            # Forward pass, backward pass, and optimize
            outputs = net(inputs)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()
            # Calculate the statistics
            corr = outputs.max(1)[1] != labels
            total_train_err += int(corr.sum())
            total_train_loss += loss.item()
            total_epoch += len(labels)

        train_err[epoch] = float(total_train_err) / total_epoch
        train_loss[epoch] = float(total_train_loss) / (i+1)
        val_err[epoch], val_loss[epoch] = evaluate(net, val_loader, criterion)
        print(("Epoch {}: Train err: {}, Train loss: {} |"+
               "Validation err: {}, Validation loss: {}").format(
                   epoch + 1,
                   train_err[epoch],
                   train_loss[epoch],
                   val_err[epoch],
                   val_loss[epoch]))
        # Save the current model (checkpoint) to a file every 5 epochs (and the last epoch)
        if epoch % 5 == 0 or epoch == num_epochs-1:
          model_path = get_model_name(net.name, batch_size, learning_rate, epoch)
          torch.save(net.state_dict(), model_path)
    print('Finished Training')
    end_time = time.time()
    elapsed_time = end_time - start_time
    print("Total time elapsed: {:.2f} seconds".format(elapsed_time))
    # Write the train/test loss/err into CSV file for plotting later
    epochs = np.arange(1, num_epochs + 1)
```

```
    epochs = np.arange(1, num_epochs + 1)
    np.savetxt("{}_train_err.csv".format(model_path), train_err)
    np.savetxt("{}_train_loss.csv".format(model_path), train_loss)
    np.savetxt("{}_val_err.csv".format(model_path), val_err)
    np.savetxt("{}_val_loss.csv".format(model_path), val_loss)
```

Part (c) “Overfit” to a Small Dataset - 5 pt

One way to sanity check our neural network model and training code is to check whether the model is capable of “overfitting” or “memorizing” a small dataset. A properly constructed CNN with correct training code should be able to memorize the answers to a small number of images quickly.

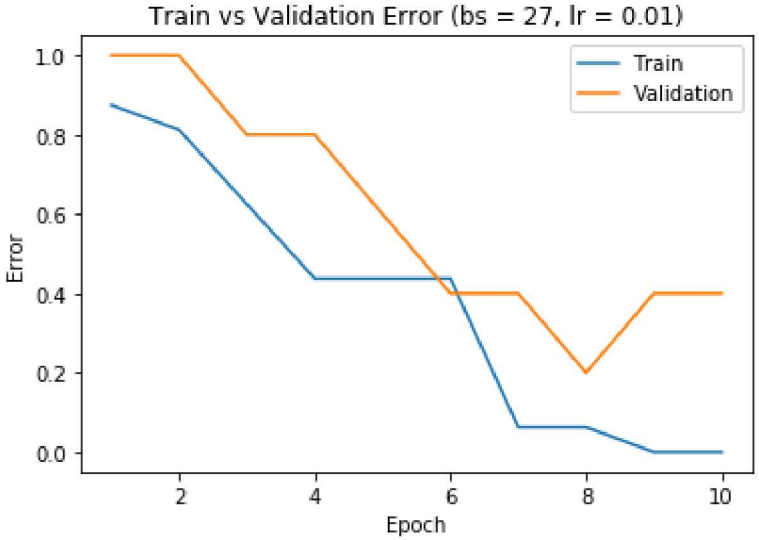
Construct a small dataset (e.g. just the images that you have collected). Then show that your model and training code is capable of memorizing the labels of this small data set.

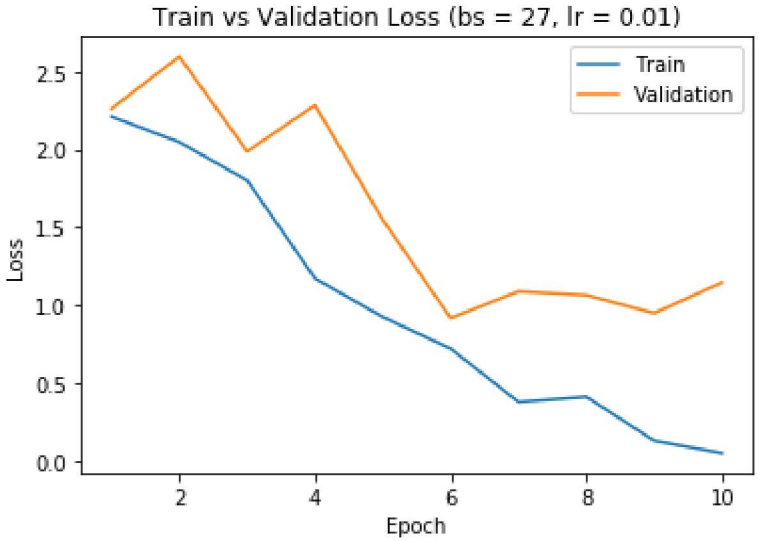
With a large batch size (e.g. the entire small dataset) and learning rate that is not too high, You should be able to obtain a 100% training accuracy on that small dataset relatively quickly (within 200 iterations).

```
# Load small dataset
small_dataset = "Lab_3_Gesture_Dataset_Small"
small_img_folder = get_img_folder(small_dataset)

sm_train_loader, sm_val_loader, sm_test_loader = get_data_loader(small_img_folder, len(small_img_folder.samples))


# Train net
net = ConvNet("sm_net")
train_net(net, sm_train_loader, sm_val_loader, len(small_img_folder.samples), num_epochs=10)
```

```
Epoch 1: Train err: 0.875, Train loss: 2.2107186317443848 |Validation err: 1.0, Validation loss: 2.261265993118286
Epoch 2: Train err: 0.8125, Train loss: 2.0471889972686768 |Validation err: 1.0, Validation loss: 2.5964102745056152
Epoch 3: Train err: 0.625, Train loss: 1.8018001317977905 |Validation err: 0.8, Validation loss: 1.9870370626449585
Epoch 4: Train err: 0.4375, Train loss: 1.1725926399230957 |Validation err: 0.8, Validation loss: 2.2840206623077393
Epoch 5: Train err: 0.4375, Train loss: 0.9247167110443115 |Validation err: 0.6, Validation loss: 1.5480233430862427
Epoch 6: Train err: 0.4375, Train loss: 0.7219251990318298 |Validation err: 0.4, Validation loss: 0.917380690574646
Epoch 7: Train err: 0.0625, Train loss: 0.3791523575782776 |Validation err: 0.4, Validation loss: 1.0892759561538696
Epoch 8: Train err: 0.0625, Train loss: 0.4127773642539978 |Validation err: 0.2, Validation loss: 1.0649678707122803
Epoch 9: Train err: 0.0, Train loss: 0.13091637194156647 |Validation err: 0.4, Validation loss: 0.9497539401054382
Epoch 10: Train err: 0.0, Train loss: 0.05143043398857117 |Validation err: 0.4, Validation loss: 1.146304726600647
Finished Training
Total time elapsed: 2.66 seconds
```

```
#Print Training Data
model_path = get_model_name("sm_net", batch_size=len(small_img_folder.samples), learning_rate=0.01, epoch=9)
plot_training_curve(model_path)
```





3. Hyperparameter Search [10 pt]

Part (a) - 1 pt

List 3 hyperparameters that you think are most worth tuning. Choose at least one hyperparameter related to the model architecture.

Parameters to tune: `batch_size`, `learning_rate` and kernel parameters (size, stride, padding)

Part (b) - 6 pt

Tune the hyperparameters you listed in Part (a), trying as many values as you need to until you feel satisfied that you are getting a good model. Plot the training curve of at least 4 different hyperparameter settings.

```
# Setup Training

dataset = "Lab_3_Gesture_Dataset_W2020"
img_folder = get_img_folder(dataset)

batch_sizes = [16, 32, 64, 128]
learning_rates = [0.01, 0.005, 0.05, 0.03]
models = []

num_epochs = 30


# Execute Training
# NOTE: THIS TAKES A LONG TIME TO FINISH EXECUTING

for bs in batch_sizes:
  train_loader, val_loader, test_loader = get_data_loader(img_folder, bs)
  for lr in learning_rates:
    net = ConvNet("hpsearch")   # Create new net to refresh weights
    print("Training with batch_size =", bs, "and learning rate =", lr)
    train_net(net, train_loader, val_loader, bs, lr, num_epochs)
    models.append(get_model_name(net.name, bs, lr, num_epochs-1))
```

```
Training with batch_size = 16 and learning rate = 0.01
Epoch 1: Train err: 0.5136430678466076, Train loss: 1.495493676907876 |Validation err: 0.3307522123893805, Validation loss: 0.99
Epoch 2: Train err: 0.3056784660766962, Train loss: 0.9141136930269353 |Validation err: 0.27101769911504425, Validation loss: 0.
Epoch 3: Train err: 0.2603244837758112, Train loss: 0.7694134056568146 |Validation err: 0.2555309734513274, Validation loss: 0.7
Epoch 4: Train err: 0.20907079646017698, Train loss: 0.6149381751523298 |Validation err: 0.21460176991150443, Validation loss: 0
Epoch 5: Train err: 0.1898967551622419, Train loss: 0.540360965623575 |Validation err: 0.2168141592920354, Validation loss: 0.74
Epoch 6: Train err: 0.168141592920354, Train loss: 0.49704674578764857 |Validation err: 0.19690265486725664, Validation loss: 0.
Epoch 7: Train err: 0.16297935103244837, Train loss: 0.53237043847056 |Validation err: 0.3506637168141593, Validation loss: 1.29
Epoch 8: Train err: 0.21865781710914453, Train loss: 0.6907448202371598 |Validation err: 0.21238938053097345, Validation loss: 0
Epoch 9: Train err: 0.13274336283185842, Train loss: 0.3900964939418961 |Validation err: 0.19911504424778761, Validation loss: 0
Epoch 10: Train err: 0.1415929203539823, Train loss: 0.4096322601332384 |Validation err: 0.21349557522123894, Validation loss: 0
Epoch 11: Train err: 0.12426253687315635, Train loss: 0.377618886881014 86 |Validation err: 0.20575221238938052, Validation loss:
Epoch 12: Train err: 0.12426253687315635, Train loss: 0.360529167468056 97 |Validation err: 0.2179203539823009, Validation loss:
Epoch 13: Train err: 0.11246312684365782, Train loss: 0.3439634522532716 |Validation err: 0.2002212389380531, Validation loss: 0
Epoch 14: Train err: 0.10435103244837758, Train loss: 0.3118366843637298 |Validation err: 0.1847345132743363, Validation loss: 0
Epoch 15: Train err: 0.096976401179941, Train loss: 0.2864284062210251 |Validation err: 0.19469026548672566, Validation loss: 0.
Epoch 16: Train err: 0.09513274336283185, Train loss: 0.276197567100034 |Validation err: 0.20243362831858408, Validation loss: 1
Epoch 17: Train err: 0.10582595870206489, Train loss: 0.31799158914124265 |Validation err: 0.17035398230088494, Validation loss:
Epoch 18: Train err: 0.08997050147492626, Train loss: 0.2913773989852737 |Validation err: 0.17588495575221239, Validation loss:
Epoch 19: Train err: 0.10029498525073746, Train loss: 0.31376061229144825 |Validation err: 0.17588495575221239, Validation loss:
Epoch 20: Train err: 0.08591445427728614, Train loss: 0.27587432274047063 |Validation err: 0.17256637168141592, Validation loss:
Epoch 21: Train err: 0.11578171091445427, Train loss: 0.3844343143350938 |Validation err: 0.18915929203539822, Validation loss:
Epoch 22: Train err: 0.07042772861356932, Train loss: 0.21336544033359078 |Validation err: 0.16592920353982302, Validation loss:
Epoch 23: Train err: 0.09292035398230089, Train loss: 0.28110116676372643 |Validation err: 0.20243362831858408, Validation loss:
Epoch 24: Train err: 0.06858407079646017, Train loss: 0.19166504666209222 |Validation err: 0.16592920353982302, Validation loss:
Epoch 25: Train err: 0.08333333333333333, Train loss: 0.2810688847128083 |Validation err: 0.2002212389380531, Validation loss: 1
Epoch 26: Train err: 0.06342182890855458, Train loss: 0.17713066389893783 |Validation err: 0.17146017699115043, Validation loss:
Epoch 27: Train err: 0.07558997050147492, Train loss: 0.2355128716896562 |Validation err: 0.2079646017699115, Validation loss: 1
Epoch 28: Train err: 0.0700589970501475, Train loss: 0.22833677780102282 |Validation err: 0.2002212389380531, Validation loss: 1
Epoch 29: Train err: 0.08849557522123894, Train loss: 0.2702477087869364 |Validation err: 0.2002212389380531, Validation loss: 1
Epoch 30: Train err: 0.07374631268436578, Train loss: 0.22305534736198537 |Validation err: 0.17588495575221239, Validation loss:
Finished Training
Total time elapsed: 747.63 seconds
Training with batch_size = 16 and learning rate = 0.005
Epoch 1: Train err: 0.5066371681415929, Train loss: 1.4055667805321077 |Validation err: 0.336283185840708, Validation loss: 1.00
Epoch 2: Train err: 0.2448377581120944, Train loss: 0.7382355992408359 |Validation err: 0.23893805309734514, Validation loss: 0.
Epoch 3: Train err: 0.16556047197640117, Train loss: 0.5048989814432229 |Validation err: 0.16924778761061948, Validation loss: 0
Epoch 4: Train err: 0.13126843657817108, Train loss: 0.39729192357729465 |Validation err: 0.17146017699115043, Validation loss:
Epoch 5: Train err: 0.1161504424778761, Train loss: 0.3475052402738263 |Validation err: 0.15597345132743362, Validation loss: 0.
Epoch 6: Train err: 0.07890855457227139, Train loss: 0.2471700333935373 |Validation err: 0.15597345132743362, Validation loss: 0
Epoch 7: Train err: 0.0752212389380531, Train loss: 0.21891452753368545 |Validation err: 0.14491150442477876, Validation loss: 0
Epoch 8: Train err: 0.061946902654867256, Train loss: 0.1827480040709762 |Validation err: 0.1581858407079646, Validation loss: 0
```

```
Epoch 9: Train err: 0.06305309734513274, Train loss: 0.2035635675139287 |Validation err: 0.20243362831858408, Validation loss: 0
Epoch 10: Train err: 0.07964601769911504, Train loss: 0.2306052842122667 |Validation err: 0.16592920353982302, Validation loss:
Epoch 11: Train err: 0.0612094395280236, Train loss: 0.1690829038619995 |Validation err: 0.14933628318584072, Validation loss: 0
Epoch 12: Train err: 0.06231563421828908, Train loss: 0.19467614639331313 |Validation err: 0.1592920353982301, Validation loss:
Epoch 13: Train err: 0.049778761061946904, Train loss: 0.14207707424374189 |Validation err: 0.1415929203539823, Validation loss:
Epoch 14: Train err: 0.04019174041297935, Train loss: 0.11998161629718893 |Validation err: 0.1404867256637168, Validation loss:
Epoch 15: Train err: 0.044616519174041296, Train loss: 0.14651381507077638 |Validation err: 0.1592920353982301, Validation loss:
Epoch 16: Train err: 0.03650442477876106, Train loss: 0.10855091748868718 |Validation err: 0.1426991150442478, Validation loss:
Epoch 17: Train err: 0.04498525073746313, Train loss: 0.15102747845299103 |Validation err: 0.20575221238938052, Validation loss:
Epoch 18: Train err: 0.08296460176991151, Train loss: 0.29174726907821263 |Validation err: 0.14933628318584072, Validation loss:
Epoch 19: Train err: 0.03908554572271387, Train loss: 0.11815984744359465 |Validation err: 0.15265486725663716, Validation loss:
Epoch 20: Train err: 0.031342182890855455, Train loss: 0.0867130255436196 |Validation err: 0.12721238938053098, Validation loss:
Epoch 21: Train err: 0.025811209439528023, Train loss: 0.0877696532098686 |Validation err: 0.14380530973451328, Validation loss:
Epoch 22: Train err: 0.03797935103244838, Train loss: 0.1153874681714703 |Validation err: 0.14933628318584072, Validation loss:
Epoch 23: Train err: 0.0357669616519174, Train loss: 0.11508494054569918 |Validation err: 0.15376106194690264, Validation loss:
Epoch 24: Train err: 0.05309734513274336, Train loss: 0.19484049430226577 |Validation err: 0.13938053097345132, Validation loss:
Epoch 25: Train err: 0.03761061946902655, Train loss: 0.1108285108471618 |Validation err: 0.1504424778761062, Validation loss: 0
Epoch 26: Train err: 0.022492625368731565, Train loss: 0.07174840865328032 |Validation err: 0.11504424778761062, Validation loss
Epoch 27: Train err: 0.02691740412979351, Train loss: 0.08714583082234158 |Validation err: 0.17809734513274336, Validation loss:
Epoch 28: Train err: 0.057890855457227136, Train loss: 0.2083722274093067 |Validation err: 0.13606194690265486, Validation loss:
Epoch 29: Train err: 0.035398230088495575, Train loss: 0.09434825330972671 |Validation err: 0.15597345132743362, Validation loss
Epoch 30: Train err: 0.03502949852507375, Train loss: 0.11896271780133247 |Validation err: 0.14380530973451328, Validation loss:
Finished Training
Total time elapsed: 510.68 seconds
Training with batch_size = 16 and learning rate = 0.05
Epoch 1: Train err: 0.907448377581121, Train loss: 2.457940912246704 |Validation err: 0.8926991150442478, Validation loss: 2.214
Epoch 2: Train err: 0.8963864306784661, Train loss: 2.207165304352255 |Validation err: 0.8893805309734514, Validation loss: 2.21
Epoch 3: Train err: 0.8967551622418879, Train loss: 2.2060939872966094 |Validation err: 0.8595132743362832, Validation loss: 2.1
Epoch 4: Train err: 0.8886430678466076, Train loss: 2.2075796057196224 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 5: Train err: 0.8867994100294986, Train loss: 2.204498077841366 |Validation err: 0.8993362831858407, Validation loss: 2.21
Epoch 6: Train err: 0.8845870206489675, Train loss: 2.2066155728171855 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 7: Train err: 0.8908554572271387, Train loss: 2.2059467483969297 |Validation err: 0.8904867256637168, Validation loss: 2.2
Epoch 8: Train err: 0.8923303834808259, Train loss: 2.20589934797848 |Validation err: 0.8926991150442478, Validation loss: 2.207
Epoch 9: Train err: 0.8738938053097345, Train loss: 2.2029466110117295 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 10: Train err: 0.8875368731563422, Train loss: 2.2061327667797315 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 11: Train err: 0.8845870206489675, Train loss: 2.2076237285838407 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 12: Train err: 0.8867994100294986, Train loss: 2.2060497087590836 |Validation err: 0.8904867256637168, Validation loss: 2.
Epoch 13: Train err: 0.9089233038348082, Train loss: 2.208239465601304 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 14: Train err: 0.8864306784660767, Train loss: 2.2062162721858307 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 15: Train err: 0.8897492625368731, Train loss: 2.2089222571429086 |Validation err: 0.8926991150442478, Validation loss: 2.
Epoch 16: Train err: 0.894542772861357, Train loss: 2.205687769721536 |Validation err: 0.8893805309734514, Validation loss: 2.20
Epoch 17: Train err: 0.8912241887905604, Train loss: 2.2038559548995074 |Validation err: 0.8926991150442478, Validation loss: 2.
```

```
Epoch 18: Train err: 0.8997050147492626, Train loss: 2.207139754295349 |Validation err: 0.8904867256637168, Validation loss: 2.2
Epoch 19: Train err: 0.8867994100294986, Train loss: 2.206518633225385 |Validation err: 0.8838495575221239, Validation loss: 2.2
Epoch 20: Train err: 0.8893805309734514, Train loss: 2.206442588918349 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 21: Train err: 0.8956489675516224, Train loss: 2.206147184091456 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 22: Train err: 0.8956489675516224, Train loss: 2.207776573125054 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 23: Train err: 0.8908554572271387, Train loss: 2.2038717648562263 |Validation err: 0.9070796460176991, Validation loss: 2.
Epoch 24: Train err: 0.8993362831858407, Train loss: 2.2067614120595596 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 25: Train err: 0.8875368731563422, Train loss: 2.204099928631502 |Validation err: 0.8838495575221239, Validation loss: 2.1
Epoch 26: Train err: 0.890117994100295, Train loss: 2.2090624051935532 |Validation err: 0.8904867256637168, Validation loss: 2.2
Epoch 27: Train err: 0.8952802359882006, Train loss: 2.209577465057373 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 28: Train err: 0.8871681415929203, Train loss: 2.2079987553989184 |Validation err: 0.8926991150442478, Validation loss: 2.
Epoch 29: Train err: 0.887905604719764, Train loss: 2.209084221896003 |Validation err: 0.8816371681415929, Validation loss: 2.20
Epoch 30: Train err: 0.8978613569321534, Train loss: 2.2079321230159086 |Validation err: 0.8960176991150443, Validation loss: 2.
Finished Training
Total time elapsed: 514.30 seconds
Training with batch_size = 16 and learning rate = 0.03
Epoch 1: Train err: 0.8993362831858407, Train loss: 2.241053227817311 |Validation err: 0.8926991150442478, Validation loss: 2.21
Epoch 2: Train err: 0.8978613569321534, Train loss: 2.203884645069347 |Validation err: 0.8960176991150443, Validation loss: 2.21
Epoch 3: Train err: 0.8938053097345132, Train loss: 2.2026368660085343 |Validation err: 0.8595132743362832, Validation loss: 2.1
Epoch 4: Train err: 0.8963864306784661, Train loss: 2.2038505890790154 |Validation err: 0.8926991150442478, Validation loss: 2.2
Epoch 5: Train err: 0.8849557522123894, Train loss: 2.2018154116237865 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 6: Train err: 0.8860619469026548, Train loss: 2.2030841588973997 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 7: Train err: 0.8831120943952803, Train loss: 2.203174755152534 |Validation err: 0.8904867256637168, Validation loss: 2.20
Epoch 8: Train err: 0.8926991150442478, Train loss: 2.202150183565476 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 9: Train err: 0.8790560471976401, Train loss: 2.200976411034079 |Validation err: 0.8960176991150443, Validation loss: 2.20
Epoch 10: Train err: 0.8816371681415929, Train loss: 2.2021765428430893 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 11: Train err: 0.8967551622418879, Train loss: 2.203975631208981 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 12: Train err: 0.8897492625368731, Train loss: 2.2029061555862426 |Validation err: 0.8904867256637168, Validation loss: 2.
Epoch 13: Train err: 0.9067109144542773, Train loss: 2.203824988533469 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 14: Train err: 0.8864306784660767, Train loss: 2.2025452122968785 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 15: Train err: 0.8930678466076696, Train loss: 2.2047550720327043 |Validation err: 0.8926991150442478, Validation loss: 2.
Epoch 16: Train err: 0.8941740412979351, Train loss: 2.202219101961921 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 17: Train err: 0.8871681415929203, Train loss: 2.20079048240886 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 18: Train err: 0.8989675516224189, Train loss: 2.203515309445998 |Validation err: 0.8904867256637168, Validation loss: 2.2
Epoch 19: Train err: 0.8886430678466076, Train loss: 2.203175194123212 |Validation err: 0.8838495575221239, Validation loss: 2.2
Epoch 20: Train err: 0.8890117994100295, Train loss: 2.203209435238558 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 21: Train err: 0.8960176991150443, Train loss: 2.2022818831836477 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 22: Train err: 0.8930678466076696, Train loss: 2.2038548455518834 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 23: Train err: 0.8923303834808259, Train loss: 2.2017493893118467 |Validation err: 0.9070796460176991, Validation loss: 2.
Epoch 24: Train err: 0.8941740412979351, Train loss: 2.203146784445819 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 25: Train err: 0.8930678466076696, Train loss: 2.2016106212840363 |Validation err: 0.8838495575221239, Validation loss: 2.
Epoch 26: Train err: 0.890117994100295, Train loss: 2.204498591142542 |Validation err: 0.8904867256637168, Validation loss: 2.20
```

```
Epoch 27: Train err: 0.8978613569321534, Train loss: 2.2053093223010793 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 28: Train err: 0.8867994100294986, Train loss: 2.2040506278767307 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 29: Train err: 0.8853244837758112, Train loss: 2.2040027211694158 |Validation err: 0.8816371681415929, Validation loss: 2.
Epoch 30: Train err: 0.8926991150442478, Train loss: 2.2036255780388325 |Validation err: 0.8960176991150443, Validation loss: 2.
Finished Training
Total time elapsed: 511.16 seconds
Training with batch_size = 32 and learning rate = 0.01
Epoch 1: Train err: 0.5881268436578171, Train loss: 1.6590176350930157 |Validation err: 0.38716814159292035, Validation loss: 1.
Epoch 2: Train err: 0.30715339233038347, Train loss: 0.9412334876901963 |Validation err: 0.24668141592920353, Validation loss: 0
Epoch 3: Train err: 0.2193952802359882, Train loss: 0.6650073244291194 |Validation err: 0.20464601769911506, Validation loss: 0.
Epoch 4: Train err: 0.18325958702064896, Train loss: 0.543996008178767 |Validation err: 0.21349557522123894, Validation loss: 0.
Epoch 5: Train err: 0.15781710914454278, Train loss: 0.4618127670358209 |Validation err: 0.21902654867256638, Validation loss: 0
Epoch 6: Train err: 0.14859882005899705, Train loss: 0.42161248291240017 |Validation err: 0.20464601769911506, Validation loss:
Epoch 7: Train err: 0.14564896755162243, Train loss: 0.4384390513686573 |Validation err: 0.17809734513274336, Validation loss: 0
Epoch 8: Train err: 0.12536873156342182, Train loss: 0.368023698294864 |Validation err: 0.17920353982300885, Validation loss: 0.
Epoch 9: Train err: 0.11025073746312684, Train loss: 0.3192440103082096 |Validation err: 0.1913716814159292, Validation loss: 0.
Epoch 10: Train err: 0.11283185840707964, Train loss: 0.3413578903850387 |Validation err: 0.19247787610619468, Validation loss:
Epoch 11: Train err: 0.09918879056047197, Train loss: 0.28453443693352196 |Validation err: 0.17920353982300885, Validation loss:
Epoch 12: Train err: 0.08480825958702065, Train loss: 0.2517604876967037 |Validation err: 0.18030973451327434, Validation loss:
Epoch 13: Train err: 0.08370206489675516, Train loss: 0.23733703949872184 |Validation err: 0.19358407079646017, Validation loss:
Epoch 14: Train err: 0.08960176991150443, Train loss: 0.2630133633227909 |Validation err: 0.18584070796460178, Validation loss:
Epoch 15: Train err: 0.07558997050147492, Train loss: 0.2122318990966853 |Validation err: 0.19469026548672566, Validation loss:
Epoch 16: Train err: 0.08333333333333333, Train loss: 0.25083279039929895 |Validation err: 0.18584070796460178, Validation loss:
Epoch 17: Train err: 0.11836283185840708, Train loss: 0.34880134366890964 |Validation err: 0.19690265486725664, Validation loss:
Epoch 18: Train err: 0.07853982300884955, Train loss: 0.22955578098840573 |Validation err: 0.18584070796460178, Validation loss:
Epoch 19: Train err: 0.06526548672566372, Train loss: 0.18605996002169217 |Validation err: 0.18141592920353983, Validation loss:
Epoch 20: Train err: 0.06526548672566372, Train loss: 0.1830247939509504 |Validation err: 0.18805309734513273, Validation loss:
Epoch 21: Train err: 0.06415929203539823, Train loss: 0.18078901789644186 |Validation err: 0.19690265486725664, Validation loss:
Epoch 22: Train err: 0.04904129793510324, Train loss: 0.1469327070257243 |Validation err: 0.1747787610619469, Validation loss: 1
Epoch 23: Train err: 0.05715339233038348, Train loss: 0.17054249021936865 |Validation err: 0.18030973451327434, Validation loss:
Epoch 24: Train err: 0.06674041297935103, Train loss: 0.1862673777867766 |Validation err: 0.16924778761061948, Validation loss:
Epoch 25: Train err: 0.052728613569321535, Train loss: 0.15677758547313073 |Validation err: 0.1847345132743363, Validation loss:
Epoch 26: Train err: 0.05715339233038348, Train loss: 0.16975725897971322 |Validation err: 0.19690265486725664, Validation loss:
Epoch 27: Train err: 0.05235988200589971, Train loss: 0.14806292153456632 |Validation err: 0.17146017699115043, Validation loss:
Epoch 28: Train err: 0.07374631268436578, Train loss: 0.2444835619014852 |Validation err: 0.22898230088495575, Validation loss:
Epoch 29: Train err: 0.08886430678466077, Train loss: 0.2638001881101552 |Validation err: 0.1747787610619469, Validation loss: 1
Epoch 30: Train err: 0.05752212389380531, Train loss: 0.18415317894781338 |Validation err: 0.17035398230088494, Validation loss:
Finished Training
Total time elapsed: 506.48 seconds
Training with batch_size = 32 and learning rate = 0.005
Epoch 1: Train err: 0.5291297935103245, Train loss: 1.5128792426165412 |Validation err: 0.3307522123893805, Validation loss: 1.0
Epoch 2: Train err: 0.2617994100294985, Train loss: 0.799053878994549 |Validation err: 0.24668141592920353, Validation loss: 0.7
```

```
Epoch 3: Train err: 0.17994100294985252, Train loss: 0.5458785197314094 |Validation err: 0.17588495575221239, Validation loss: 0
Epoch 4: Train err: 0.12721238938053098, Train loss: 0.3655709460377693 |Validation err: 0.1515486725663717, Validation loss: 0.
Epoch 5: Train err: 0.10471976401179942, Train loss: 0.29427821101511226 |Validation err: 0.15265486725663716, Validation loss:
Epoch 6: Train err: 0.08370206489675516, Train loss: 0.2378694630721036 |Validation err: 0.1670353982300885, Validation loss: 0.
Epoch 7: Train err: 0.0586283185840708, Train loss: 0.16525548021582998 |Validation err: 0.17035398230088494, Validation loss: 0
Epoch 8: Train err: 0.049778761061946904, Train loss: 0.14284518880440908 |Validation err: 0.168141592920354, Validation loss: 0
Epoch 9: Train err: 0.054941002949852505, Train loss: 0.1427218707607073 |Validation err: 0.15486725663716813, Validation loss:
Epoch 10: Train err: 0.03761061946902655, Train loss: 0.10364945502403905 |Validation err: 0.14491150442477876, Validation loss:
Epoch 11: Train err: 0.03466076696165192, Train loss: 0.0981118656694889 |Validation err: 0.14601769911504425, Validation loss:
Epoch 12: Train err: 0.036135693215339236, Train loss: 0.10307676020790549 |Validation err: 0.14712389380530974, Validation loss
Epoch 13: Train err: 0.03761061946902655, Train loss: 0.10053999445894185 |Validation err: 0.16371681415929204, Validation loss:
Epoch 14: Train err: 0.05088495575221239, Train loss: 0.15326147613060825 |Validation err: 0.18141592920353983, Validation loss:
Epoch 15: Train err: 0.04793510324483776, Train loss: 0.14507004474015797 |Validation err: 0.15486725663716813, Validation loss:
Epoch 16: Train err: 0.03171091445427729, Train loss: 0.09187279525486862 |Validation err: 0.13716814159292035, Validation loss:
Epoch 17: Train err: 0.01696165191740413, Train loss: 0.045399460547110616 |Validation err: 0.12389380530973451, Validation loss
Epoch 18: Train err: 0.01733038348082596, Train loss: 0.05608959545694661 |Validation err: 0.12831858407079647, Validation loss:
Epoch 19: Train err: 0.011061946902654867, Train loss: 0.030002918565536246 |Validation err: 0.12168141592920353, Validation los
Epoch 20: Train err: 0.016592920353982302, Train loss: 0.05249299954842119 |Validation err: 0.1415929203539823, Validation loss:
Epoch 21: Train err: 0.03797935103244838, Train loss: 0.1168724246103974 |Validation err: 0.12389380530973451, Validation loss:
Epoch 22: Train err: 0.030973451327433628, Train loss: 0.0919064253787784 |Validation err: 0.125, Validation loss: 0.96711226270
Epoch 23: Train err: 0.016224188790560472, Train loss: 0.039778621100327545 |Validation err: 0.12831858407079647, Validation los
Epoch 24: Train err: 0.025073746312684365, Train loss: 0.08241784506860901 |Validation err: 0.13827433628318583, Validation loss
Epoch 25: Train err: 0.018436578171091445, Train loss: 0.058892600939554327 |Validation err: 0.15265486725663716, Validation los
Epoch 26: Train err: 0.022492625368731565, Train loss: 0.07101012389449513 |Validation err: 0.14933628318584072, Validation loss
Epoch 27: Train err: 0.017699115044247787, Train loss: 0.05320286216104732 |Validation err: 0.15486725663716813, Validation loss
Epoch 28: Train err: 0.025073746312684365, Train loss: 0.07277025672442773 |Validation err: 0.16261061946902655, Validation loss
Epoch 29: Train err: 0.032448377581120944, Train loss: 0.10758089909658712 |Validation err: 0.13274336283185842, Validation loss
Epoch 30: Train err: 0.015855457227138645, Train loss: 0.054923284198979246 |Validation err: 0.1338495575221239, Validation loss
Finished Training
Total time elapsed: 504.34 seconds
Training with batch_size = 32 and learning rate = 0.05
Epoch 1: Train err: 0.8934365781710915, Train loss: 2.8283925645491657 |Validation err: 0.8926991150442478, Validation loss: 2.2
Epoch 2: Train err: 0.900811209439528, Train loss: 2.2038281300488642 |Validation err: 0.8993362831858407, Validation loss: 2.21
Epoch 3: Train err: 0.883480825958702, Train loss: 2.20310479332419 |Validation err: 0.9070796460176991, Validation loss: 2.1983
Epoch 4: Train err: 0.8978613569321534, Train loss: 2.204823106877944 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 5: Train err: 0.8831120943952803, Train loss: 2.2027039836434756 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 6: Train err: 0.8890117994100295, Train loss: 2.2041041626649744 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 7: Train err: 0.8875368731563422, Train loss: 2.204933724683874 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 8: Train err: 0.8904867256637168, Train loss: 2.2018025875091554 |Validation err: 0.8926991150442478, Validation loss: 2.2
Epoch 9: Train err: 0.8886430678466076, Train loss: 2.202449344186222 |Validation err: 0.8960176991150443, Validation loss: 2.20
Epoch 10: Train err: 0.875, Train loss: 2.2029989158405976 |Validation err: 0.8893805309734514, Validation loss: 2.1994082434424
Epoch 11: Train err: 0.8978613569321534, Train loss: 2.205414895450368 |Validation err: 0.8960176991150443, Validation loss: 2.2
```

```
Epoch 12: Train err: 0.8919616519174042, Train loss: 2.2041288207559027 |Validation err: 0.8904867256637168, Validation loss: 2.
Epoch 13: Train err: 0.8989675516224189, Train loss: 2.203412036334767 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 14: Train err: 0.8842182890855457, Train loss: 2.202833579568302 |Validation err: 0.8960176991150443, Validation loss: 2.1
Epoch 15: Train err: 0.8963864306784661, Train loss: 2.206242297677433 |Validation err: 0.8926991150442478, Validation loss: 2.2
Epoch 16: Train err: 0.8923303834808259, Train loss: 2.202781391143799 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 17: Train err: 0.8827433628318584, Train loss: 2.200912534489351 |Validation err: 0.8926991150442478, Validation loss: 2.1
Epoch 18: Train err: 0.8971238938053098, Train loss: 2.204090628904455 |Validation err: 0.8904867256637168, Validation loss: 2.2
Epoch 19: Train err: 0.8912241887905604, Train loss: 2.2042087751276354 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 20: Train err: 0.8949115044247787, Train loss: 2.204789630104514 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 21: Train err: 0.8956489675516224, Train loss: 2.2021164613611557 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 22: Train err: 0.8860619469026548, Train loss: 2.2056611509884103 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 23: Train err: 0.8912241887905604, Train loss: 2.2036510888267964 |Validation err: 0.9070796460176991, Validation loss: 2.
Epoch 24: Train err: 0.9000737463126843, Train loss: 2.203789259405697 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 25: Train err: 0.8915929203539823, Train loss: 2.2024689057294062 |Validation err: 0.8838495575221239, Validation loss: 2.
Epoch 26: Train err: 0.8941740412979351, Train loss: 2.2052822702071246 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 27: Train err: 0.9022861356932154, Train loss: 2.20697559188394 |Validation err: 0.8960176991150443, Validation loss: 2.19
Epoch 28: Train err: 0.8871681415929203, Train loss: 2.2051951857174146 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 29: Train err: 0.8915929203539823, Train loss: 2.2039756718803853 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 30: Train err: 0.8882743362831859, Train loss: 2.2038519354427564 |Validation err: 0.8960176991150443, Validation loss: 2.
Finished Training
Total time elapsed: 503.29 seconds
Training with batch_size = 32 and learning rate = 0.03
Epoch 1: Train err: 0.8864306784660767, Train loss: 2.280852836721084 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 2: Train err: 0.8915929203539823, Train loss: 2.2009917792151956 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 3: Train err: 0.8867994100294986, Train loss: 2.200918862398933 |Validation err: 0.9070796460176991, Validation loss: 2.19
Epoch 4: Train err: 0.9041297935103245, Train loss: 2.201799342211555 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 5: Train err: 0.8827433628318584, Train loss: 2.2005616075852337 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 6: Train err: 0.887905604719764, Train loss: 2.201609664804795 |Validation err: 0.8993362831858407, Validation loss: 2.203
Epoch 7: Train err: 0.8853244837758112, Train loss: 2.2019156708436856 |Validation err: 0.8926991150442478, Validation loss: 2.1
Epoch 8: Train err: 0.8934365781710915, Train loss: 2.20039462482228 |Validation err: 0.8926991150442478, Validation loss: 2.202
Epoch 9: Train err: 0.8915929203539823, Train loss: 2.2011978710398954 |Validation err: 0.8816371681415929, Validation loss: 2.1
Epoch 10: Train err: 0.8827433628318584, Train loss: 2.200589698903701 |Validation err: 0.8893805309734514, Validation loss: 2.1
Epoch 11: Train err: 0.8890117994100295, Train loss: 2.2028878071728877 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 12: Train err: 0.8989675516224189, Train loss: 2.201190990560195 |Validation err: 0.8595132743362832, Validation loss: 2.1
Epoch 13: Train err: 0.8967551622418879, Train loss: 2.2006611459395464 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 14: Train err: 0.8886430678466076, Train loss: 2.200366642895867 |Validation err: 0.8960176991150443, Validation loss: 2.1
Epoch 15: Train err: 0.894542772861357, Train loss: 2.202913719065049 |Validation err: 0.8960176991150443, Validation loss: 2.20
Epoch 16: Train err: 0.8941740412979351, Train loss: 2.201200336568496 |Validation err: 0.8893805309734514, Validation loss: 2.1
Epoch 17: Train err: 0.8820058997050148, Train loss: 2.1997709358439725 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 18: Train err: 0.8890117994100295, Train loss: 2.2019152613247144 |Validation err: 0.8904867256637168, Validation loss: 2.
Epoch 19: Train err: 0.8971238938053098, Train loss: 2.2011139448951274 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 20: Train err: 0.8963864306784661, Train loss: 2.2020137169781853 |Validation err: 0.8893805309734514, Validation loss: 2.
```

```
Epoch 21: Train err: 0.8915929203539823, Train loss: 2.199956175860237 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 22: Train err: 0.890117994100295, Train loss: 2.2021578059476963 |Validation err: 0.8960176991150443, Validation loss: 2.2
Epoch 23: Train err: 0.8989675516224189, Train loss: 2.201449887892779 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 24: Train err: 0.8971238938053098, Train loss: 2.2008554346421185 |Validation err: 0.8960176991150443, Validation loss: 2.
Epoch 25: Train err: 0.8893805309734514, Train loss: 2.200606003929587 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 26: Train err: 0.8967551622418879, Train loss: 2.201787306280697 |Validation err: 0.8893805309734514, Validation loss: 2.2
Epoch 27: Train err: 0.9026548672566371, Train loss: 2.202686374327716 |Validation err: 0.8960176991150443, Validation loss: 2.1
Epoch 28: Train err: 0.8882743362831859, Train loss: 2.2018510145299577 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 29: Train err: 0.8963864306784661, Train loss: 2.20083114119137 |Validation err: 0.8893805309734514, Validation loss: 2.20
Epoch 30: Train err: 0.8893805309734514, Train loss: 2.201193562675925 |Validation err: 0.8960176991150443, Validation loss: 2.1
Finished Training
Total time elapsed: 505.43 seconds
Training with batch_size = 64 and learning rate = 0.01
Epoch 1: Train err: 0.6194690265486725, Train loss: 1.702245875846508 |Validation err: 0.33185840707964603, Validation loss: 1.0
Epoch 2: Train err: 0.30162241887905605, Train loss: 0.8855212129825769 |Validation err: 0.24557522123893805, Validation loss: 0
Epoch 3: Train err: 0.19063421828908556, Train loss: 0.5782621204853058 |Validation err: 0.2002212389380531, Validation loss: 0.
Epoch 4: Train err: 0.14896755162241887, Train loss: 0.4442015934822171 |Validation err: 0.18915929203539822, Validation loss: 0
Epoch 5: Train err: 0.11283185840707964, Train loss: 0.32655876545712004 |Validation err: 0.1570796460176991, Validation loss: 0
Epoch 6: Train err: 0.09144542772861357, Train loss: 0.2628434884340264 |Validation err: 0.17809734513274336, Validation loss: 0
Epoch 7: Train err: 0.08923303834808259, Train loss: 0.2510267818389937 |Validation err: 0.16261061946902655, Validation loss: 0
Epoch 8: Train err: 0.07190265486725664, Train loss: 0.2028010782114295 |Validation err: 0.16150442477876106, Validation loss: 0
Epoch 9: Train err: 0.06858407079646017, Train loss: 0.18791086460615314 |Validation err: 0.16261061946902655, Validation loss:
Epoch 10: Train err: 0.05014749262536873, Train loss: 0.1400015243264132 |Validation err: 0.15376106194690264, Validation loss:
Epoch 11: Train err: 0.061946902654867256, Train loss: 0.18587512245704962 |Validation err: 0.16482300884955753, Validation loss
Epoch 12: Train err: 0.059734513274336286, Train loss: 0.17743326775556387 |Validation err: 0.15597345132743362, Validation loss
Epoch 13: Train err: 0.04904129793510324, Train loss: 0.12862160697925923 |Validation err: 0.16371681415929204, Validation loss:
Epoch 14: Train err: 0.05125368731563422, Train loss: 0.1262446416671886 |Validation err: 0.16150442477876106, Validation loss:
Epoch 15: Train err: 0.05014749262536873, Train loss: 0.14636415858254875 |Validation err: 0.13606194690265486, Validation loss:
Epoch 16: Train err: 0.03724188790560472, Train loss: 0.10795398166289466 |Validation err: 0.17146017699115043, Validation loss:
Epoch 17: Train err: 0.052728613569321535, Train loss: 0.1587226411630941 |Validation err: 0.15486725663716813, Validation loss:
Epoch 18: Train err: 0.030973451327433628, Train loss: 0.08973911517234735 |Validation err: 0.14491150442477876, Validation loss
Epoch 19: Train err: 0.02654867256637168, Train loss: 0.06934237969649393 |Validation err: 0.1515486725663717, Validation loss:
Epoch 20: Train err: 0.03908554572271387, Train loss: 0.12930720927583617 |Validation err: 0.14712389380530974, Validation loss:
Epoch 21: Train err: 0.030973451327433628, Train loss: 0.09024192457802074 |Validation err: 0.16150442477876106, Validation loss
Epoch 22: Train err: 0.03871681415929203, Train loss: 0.12497170676672181 |Validation err: 0.13938053097345132, Validation loss:
Epoch 23: Train err: 0.04609144542772861, Train loss: 0.15799886759283932 |Validation err: 0.16592920353982302, Validation loss:
Epoch 24: Train err: 0.022492625368731565, Train loss: 0.06197847192024076 |Validation err: 0.16261061946902655, Validation loss
Epoch 25: Train err: 0.03761061946902655, Train loss: 0.14000927215052206 |Validation err: 0.16592920353982302, Validation loss:
Epoch 26: Train err: 0.038348082595870206, Train loss: 0.12497353198569874 |Validation err: 0.15265486725663716, Validation loss
Epoch 27: Train err: 0.03023598820058997, Train loss: 0.10065288807070533 |Validation err: 0.1404867256637168, Validation loss:
Epoch 28: Train err: 0.035398230088495575, Train loss: 0.09844286809133929 |Validation err: 0.1592920353982301, Validation loss:
Epoch 29: Train err: 0.02064896755162242, Train loss: 0.06718434107511542 |Validation err: 0.13495575221238937, Validation loss:
```

```
Epoch 30: Train err: 0.015855457227138645, Train loss: 0.062028787467022 8|Validation err: 0.14159292035398 23, Validation loss:
Finished Training
Total time elapsed: 502.41 seconds
Training with batch_size = 64 and learning rate = 0.005
Epoch 1: Train err: 0.5770648967551623, Train loss: 1.6229655299075814 |Validation err: 0.3573008849557522, Validation loss: 1.1
Epoch 2: Train err: 0.2853982300884956, Train loss: 0.9045193264650744 |Validation err: 0.27101769911504425, Validation loss: 0.
Epoch 3: Train err: 0.21497050147492625, Train loss: 0.6472296298936356 |Validation err: 0.20353982300884957, Validation loss: 0
Epoch 4: Train err: 0.16002949852507375, Train loss: 0.5018246281285619 |Validation err: 0.20575221238938052, Validation loss: 0
Epoch 5: Train err: 0.137905604719764, Train loss: 0.4057937368404034 |Validation err: 0.17809734513274336, Validation loss: 0.7
Epoch 6: Train err: 0.10140117994100295, Train loss: 0.2918593893910563 |Validation err: 0.19800884955752213, Validation loss: 0
Epoch 7: Train err: 0.07706489675516225, Train loss: 0.22962858267994815 |Validation err: 0.15597345132743362, Validation loss:
Epoch 8: Train err: 0.061946902654867256, Train loss: 0.1795414765040542 |Validation err: 0.1504424778761062, Validation loss: 0
Epoch 9: Train err: 0.05383480825958702, Train loss: 0.15490653209908065 |Validation err: 0.15265486725663716, Validation loss:
Epoch 10: Train err: 0.06821533923303835, Train loss: 0.21057882090640623 |Validation err: 0.15486725663716813, Validation loss:
Epoch 11: Train err: 0.03650442477876106, Train loss: 0.11036975109993025 |Validation err: 0.14823008849557523, Validation loss:
Epoch 12: Train err: 0.03761061946902655, Train loss: 0.115157735425719 |Validation err: 0.1515486725663717, Validation loss: 0.
Epoch 13: Train err: 0.03687315634218289, Train loss: 0.11453173110304876 |Validation err: 0.13827433628318583, Validation loss:
Epoch 14: Train err: 0.029498525073746312, Train loss: 0.08847960526513499 |Validation err: 0.1581858407079646, Validation loss:
Epoch 15: Train err: 0.025811209439528023, Train loss: 0.08062066391197055 |Validation err: 0.14491150442477876, Validation loss
Epoch 16: Train err: 0.03281710914454277, Train loss: 0.09549620169279881 |Validation err: 0.1515486725663717, Validation loss:
Epoch 17: Train err: 0.025442477876106196, Train loss: 0.06975388600555964 |Validation err: 0.1570796460176991, Validation loss:
Epoch 18: Train err: 0.032079646017699116, Train loss: 0.09321489548960397 |Validation err: 0.16261061946902655, Validation loss
Epoch 19: Train err: 0.029129793510324485, Train loss: 0.08493054660340381 |Validation err: 0.1515486725663717, Validation loss:
Epoch 20: Train err: 0.02064896755162242, Train loss: 0.05753748088555281 |Validation err: 0.13495575221238937, Validation loss:
Epoch 21: Train err: 0.019542772861356934, Train loss: 0.052221625978343705 |Validation err: 0.17256637168141592, Validation los
Epoch 22: Train err: 0.032079646017699116, Train loss: 0.08900113723262451 |Validation err: 0.15265486725663716, Validation loss
Epoch 23: Train err: 0.03797935103244838, Train loss: 0.10971577378899552 |Validation err: 0.1515486725663717, Validation loss:
Epoch 24: Train err: 0.022492625368731565, Train loss: 0.07292116260112719 |Validation err: 0.1592920353982301, Validation loss:
Epoch 25: Train err: 0.024336283185840708, Train loss: 0.07031276224311007 |Validation err: 0.1592920353982301, Validation loss:
Epoch 26: Train err: 0.018067846607669618, Train loss: 0.047654051441959173 |Validation err: 0.1404867256637168, Validation loss
Epoch 27: Train err: 0.018067846607669618, Train loss: 0.05335356895053803 |Validation err: 0.15597345132743362, Validation loss
Epoch 28: Train err: 0.02064896755162242, Train loss: 0.07180354735532472 |Validation err: 0.1515486725663717, Validation loss:
Epoch 29: Train err: 0.015117994100294985, Train loss: 0.050672956076342354 |Validation err: 0.16482300884955753, Validation los
Epoch 30: Train err: 0.023230088495575223, Train loss: 0.0758651181524836 |Validation err: 0.14712389380530974, Validation loss:
Finished Training
Total time elapsed: 501.54 seconds
Training with batch_size = 64 and learning rate = 0.05
Epoch 1: Train err: 0.8108407079646017, Train loss: 3.9076116417729576 |Validation err: 0.6946902654867256, Validation loss: 1.9
Epoch 2: Train err: 0.6349557522123894, Train loss: 1.7623722775037898 |Validation err: 0.6039823008849557, Validation loss: 1.5
Epoch 3: Train err: 0.5460914454277286, Train loss: 1.5249437260073284 |Validation err: 0.5055309734513275, Validation loss: 1.4
Epoch 4: Train err: 0.5217551622418879, Train loss: 1.4608515057452889 |Validation err: 0.5066371681415929, Validation loss: 1.4
Epoch 5: Train err: 0.49041297935103245, Train loss: 1.3848707648210747 |Validation err: 0.4922566371681416, Validation loss: 1.
Epoch 6: Train err: 0.474557522123893 8, Train loss: 1.3280367019564607 |Validation err: 0.4955752212389380 5, Validation loss: 1
```

```
Epoch 6: Train err: 0.4745375221238938, Train loss: 1.3280507619364607 |Validation err: 0.4955752212389805, Validation loss: 1.
Epoch 7: Train err: 0.4387905604719764, Train loss: 1.248298322045526 |Validation err: 0.47013274336283184, Validation loss: 1.3
Epoch 8: Train err: 0.4299410029498525, Train loss: 1.2210536016974338 |Validation err: 0.45685840707964603, Validation loss: 1.
Epoch 9: Train err: 0.42330383480825956, Train loss: 1.2031889405361442 |Validation err: 0.43694690265486724, Validation loss: 1
Epoch 10: Train err: 0.39823008849557523, Train loss: 1.1417717753454697 |Validation err: 0.43694690265486724, Validation loss:
Epoch 11: Train err: 0.39233038348082594, Train loss: 1.1251795388931451 |Validation err: 0.44026548672566373, Validation loss:
Epoch 12: Train err: 0.387905604719764, Train loss: 1.1024777986282526 |Validation err: 0.4081858407079646, Validation loss: 1.2
Epoch 13: Train err: 0.3893805309734513, Train loss: 1.108664292235707 |Validation err: 0.4579646017699115, Validation loss: 1.3
Epoch 14: Train err: 0.38237463126843657, Train loss: 1.0722381056741226 |Validation err: 0.42035398230088494, Validation loss:
Epoch 15: Train err: 0.37094395280235987, Train loss: 1.0701196817464607 |Validation err: 0.3938053097345133, Validation loss: 1
Epoch 16: Train err: 0.3366519174041298, Train loss: 0.9879743775656057 |Validation err: 0.40154867256637167, Validation loss: 1
Epoch 17: Train err: 0.33112094395280234, Train loss: 0.9676339972850888 |Validation err: 0.4004424778761062, Validation loss: 1
Epoch 18: Train err: 0.33222713864306785, Train loss: 0.9553754329681396 |Validation err: 0.3971238938053097, Validation loss: 1
Epoch 19: Train err: 0.32595870206489674, Train loss: 0.9507999364719835 |Validation err: 0.4247787610619469, Validation loss: 1
Epoch 20: Train err: 0.3255899705014749, Train loss: 0.9361355027487112 |Validation err: 0.39601769911504425, Validation loss: 1
Epoch 21: Train err: 0.2975663716814159, Train loss: 0.8715498516725939 |Validation err: 0.35951327433628316, Validation loss: 1
Epoch 22: Train err: 0.3407079646017699, Train loss: 0.9902026556258978 |Validation err: 0.37610619469026546, Validation loss: 1
Epoch 23: Train err: 0.3163716814159292, Train loss: 0.906769777453223 |Validation err: 0.36283185840707965, Validation loss: 1.
Epoch 24: Train err: 0.2946165191740413, Train loss: 0.8465888292290443 |Validation err: 0.40154867256637167, Validation loss: 1
Epoch 25: Train err: 0.2971976401179941, Train loss: 0.8670799732208252 |Validation err: 0.377212389380531, Validation loss: 1.2
Epoch 26: Train err: 0.2853982300884956, Train loss: 0.8316934947357622 |Validation err: 0.38163716814159293, Validation loss: 1
Epoch 27: Train err: 0.28244837758112096, Train loss: 0.8228462698847748 |Validation err: 0.35951327433628316, Validation loss:
Epoch 28: Train err: 0.2853982300884956, Train loss: 0.8275183480839396 |Validation err: 0.3915929203539823, Validation loss: 1.
Epoch 29: Train err: 0.3056784660766962, Train loss: 0.8772831545319668 |Validation err: 0.4225663716814159, Validation loss: 1.
Epoch 30: Train err: 0.2831858407079646, Train loss: 0.8324906548788381 |Validation err: 0.39491150442477874, Validation loss: 1
Finished Training
Total time elapsed: 500.34 seconds
Training with batch_size = 64 and learning rate = 0.03
Epoch 1: Train err: 0.6935840707964602, Train loss: 2.192405415135761 |Validation err: 0.588495575221239, Validation loss: 1.596
Epoch 2: Train err: 0.5003687315634219, Train loss: 1.4242577830026315 |Validation err: 0.42146017699115046, Validation loss: 1.
Epoch 3: Train err: 0.36172566371681414, Train loss: 1.0489972497141637 |Validation err: 0.3672566371681416, Validation loss: 1.
Epoch 4: Train err: 0.3101032448377581, Train loss: 0.9047110690626987 |Validation err: 0.32964601769911506, Validation loss: 1.
Epoch 5: Train err: 0.2614306784660767, Train loss: 0.747273420178613 |Validation err: 0.26548672566371684, Validation loss: 0.9
Epoch 6: Train err: 0.22492625368731564, Train loss: 0.6790920589552369 |Validation err: 0.27101769911504425, Validation loss: 0
Epoch 7: Train err: 0.20501474926253688, Train loss: 0.5997847997865011 |Validation err: 0.23893805309734514, Validation loss: 0
Epoch 8: Train err: 0.1747787610619469, Train loss: 0.5247605124185252 |Validation err: 0.24668141592920353, Validation loss: 0.
Epoch 9: Train err: 0.181047197640118, Train loss: 0.5277027543201003 |Validation err: 0.2665929203539823, Validation loss: 1.03
Epoch 10: Train err: 0.19063421828908556, Train loss: 0.560115446878034 |Validation err: 0.2588495575221239, Validation loss: 1.
Epoch 11: Train err: 0.17293510324483777, Train loss: 0.5003333680851515 |Validation err: 0.2743362831858407, Validation loss: 1
Epoch 12: Train err: 0.168141592920354, Train loss: 0.4892453097326811 |Validation err: 0.25442477876106195, Validation loss: 0.
Epoch 13: Train err: 0.1430678466076696, Train loss: 0.4041160972312439 |Validation err: 0.25110619469026546, Validation loss: 1
Epoch 14: Train err: 0.1607669616519174, Train loss: 0.47084396834983383 |Validation err: 0.27876106194690264, Validation loss:
Epoch 15: Train err: 0.17293510324483777, Train loss: 0.5227832163489142 |Validation err: 0.24778761061946902, Validation loss:
```

```
Epoch 16: Train err: 0.13458702064896755, Train loss: 0.3904774318947348 |Validation err: 0.22676991150442477, Validation loss:
Epoch 17: Train err: 0.1187315634218289, Train loss: 0.3731723275295524 |Validation err: 0.2754424778761062, Validation loss: 1.
Epoch 18: Train err: 0.193952802359882, Train loss: 0.565856083187946 |Validation err: 0.24778761061946902, Validation loss: 0.9
Epoch 19: Train err: 0.1390117994100295, Train loss: 0.4264672443617222 |Validation err: 0.2555309734513274, Validation loss: 1.
Epoch 20: Train err: 0.13421828908554573, Train loss: 0.4052308350801468 |Validation err: 0.2411504424778761, Validation loss: 0
Epoch 21: Train err: 0.13274336283185842, Train loss: 0.3776980219192283 |Validation err: 0.2577433628318584, Validation loss: 1
Epoch 22: Train err: 0.11762536873156341, Train loss: 0.35049895422403204 |Validation err: 0.24336283185840707, Validation loss:
Epoch 23: Train err: 0.13348082595870206, Train loss: 0.404705043102419 67 |Validation err: 0.290929203539823, Validation loss: 1
Epoch 24: Train err: 0.1109882005899705, Train loss: 0.34287903094014455 |Validation err: 0.24336283185840707, Validation loss:
Epoch 25: Train err: 0.11541297935103245, Train loss: 0.3525738042107848 |Validation err: 0.23119469026548672, Validation loss:
Epoch 26: Train err: 0.11946902654867257, Train loss: 0.3479269761158976 |Validation err: 0.24225663716814158, Validation loss:
Epoch 27: Train err: 0.1084070796460177, Train loss: 0.30724628962749656 |Validation err: 0.23561946902654868, Validation loss:
Epoch 28: Train err: 0.11467551622418878, Train loss: 0.33348093788291133 |Validation err: 0.2488938053097345, Validation loss:
Epoch 29: Train err: 0.12057522123893805, Train loss: 0.34574045067609743 |Validation err: 0.23561946902654868, Validation loss:
Epoch 30: Train err: 0.10545722713864307, Train loss: 0.29804246855336564 |Validation err: 0.25442477876106195, Validation loss:
Finished Training
Total time elapsed: 500.98 seconds
Training with batch_size = 128 and learning rate = 0.01
Epoch 1: Train err: 0.6541297935103245, Train loss: 1.7695457989519292 |Validation err: 0.45685840707964603, Validation loss: 1.
Epoch 2: Train err: 0.33185840707964603, Train loss: 1.03764069351283 |Validation err: 0.2665929203539823, Validation loss: 0.87
Epoch 3: Train err: 0.22382005899705015, Train loss: 0.704112250696529 |Validation err: 0.23008849557522124, Validation loss: 0.
Epoch 4: Train err: 0.1721976401179941, Train loss: 0.5317926244302229 |Validation err: 0.18252212389380532, Validation loss: 0.
Epoch 5: Train err: 0.13679941002949852, Train loss: 0.420324137265032 |Validation err: 0.168141592920354, Validation loss: 0.65
Epoch 6: Train err: 0.11283185840707964, Train loss: 0.31622259674424474 |Validation err: 0.16924778761061948, Validation loss:
Epoch 7: Train err: 0.0866519174041298, Train loss: 0.25384154001420195 |Validation err: 0.1415929203539823, Validation loss: 0.
Epoch 8: Train err: 0.08222713864306784, Train loss: 0.2554846168919043 |Validation err: 0.16592920353982302, Validation loss: 0
Epoch 9: Train err: 0.08591445427728614, Train loss: 0.25324728610840713 |Validation err: 0.15486725663716813, Validation loss:
Epoch 10: Train err: 0.06010324483775811, Train loss: 0.170790953730995 |Validation err: 0.17699115044247787, Validation loss: 0
Epoch 11: Train err: 0.05936578171091445, Train loss: 0.16641584208065813 |Validation err: 0.15376106194690264, Validation loss:
Epoch 12: Train err: 0.042404129793510326, Train loss: 0.12464771690693768 |Validation err: 0.15486725663716813, Validation loss
Epoch 13: Train err: 0.045722713864306784, Train loss: 0.12514789368618617 |Validation err: 0.14933628318584072, Validation loss
Epoch 14: Train err: 0.028392330383480827, Train loss: 0.07786607434338128 |Validation err: 0.15265486725663716, Validation loss
Epoch 15: Train err: 0.04056047197640118, Train loss: 0.11599123647267168 |Validation err: 0.13274336283185842, Validation loss:
Epoch 16: Train err: 0.03650442477876106, Train loss: 0.09560177678411658 |Validation err: 0.13938053097345132, Validation loss:
Epoch 17: Train err: 0.025442477876106196, Train loss: 0.0825022469190034 |Validation err: 0.14712389380530974, Validation loss:
Epoch 18: Train err: 0.04314159292035398, Train loss: 0.12682262689552523 |Validation err: 0.13827433628318583, Validation loss:
Epoch 19: Train err: 0.025811209439528023, Train loss: 0.07075321064753966 |Validation err: 0.1404867256637168, Validation loss:
Epoch 20: Train err: 0.06415929203539823, Train loss: 0.1980377356098457 |Validation err: 0.1581858407079646, Validation loss: 0
Epoch 21: Train err: 0.03797935103244838, Train loss: 0.12386914054778489 |Validation err: 0.15265486725663716, Validation loss:
Epoch 22: Train err: 0.0306047197640118, Train loss: 0.08220932869748636 |Validation err: 0.14712389380530974, Validation loss:
Epoch 23: Train err: 0.02101769911504425, Train loss: 0.06813330152495341 |Validation err: 0.13716814159292035, Validation loss:
Epoch 24: Train err: 0.01327433628318584, Train loss: 0.03481278187510642 |Validation err: 0.1515486725663717, Validation loss:
```

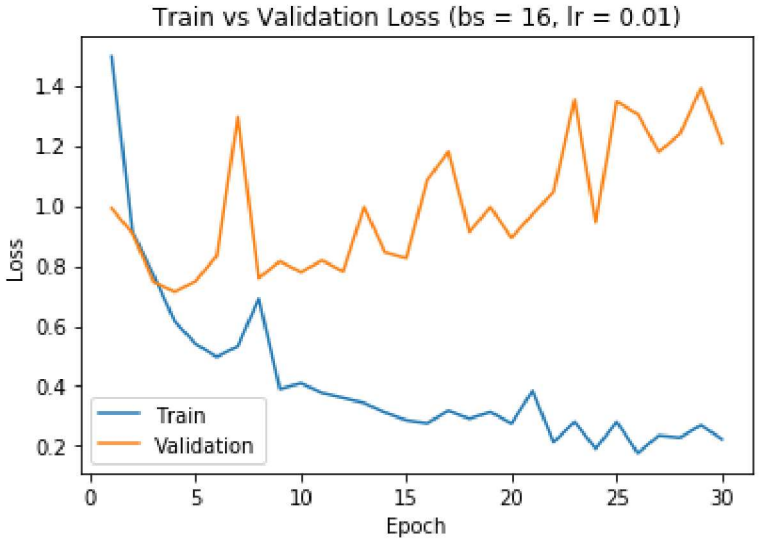
```
Epoch 25: Train err: 0.011430678466076696, Train loss: 0.0281763115410947 |Validation err: 0.13716814159292035, Validation loss:
Epoch 26: Train err: 0.012905604719764012, Train loss: 0.03957259934395552 |Validation err: 0.13053097345132744, Validation loss
Epoch 27: Train err: 0.01696165191740413, Train loss: 0.05277374776249582 |Validation err: 0.1426991150442478, Validation loss:
Epoch 28: Train err: 0.02396755162241888, Train loss: 0.08118767689236185 |Validation err: 0.14823008849557523, Validation loss:
Epoch 29: Train err: 0.014380530973451327, Train loss: 0.037758600446646924 |Validation err: 0.13495575221238937, Validation los
Epoch 30: Train err: 0.009587020648967551, Train loss: 0.026407974475825376 |Validation err: 0.13938053097345132, Validation los
Finished Training
Total time elapsed: 493.35 seconds
Training with batch_size = 128 and learning rate = 0.005
Epoch 1: Train err: 0.6522861356932154, Train loss: 1.7781018668955022 |Validation err: 0.4225663716814159, Validation loss: 1.3
Epoch 2: Train err: 0.33702064896755163, Train loss: 1.080802245573564 |Validation err: 0.3196902654867257, Validation loss: 0.8
Epoch 3: Train err: 0.25700589970501475, Train loss: 0.7922026352448897 |Validation err: 0.2013274336283186, Validation loss: 0.
Epoch 4: Train err: 0.19358407079646017, Train loss: 0.6032967296513644 |Validation err: 0.19911504424778761, Validation loss: 0
Epoch 5: Train err: 0.1364306784660767, Train loss: 0.42347373881123285 |Validation err: 0.18915929203539822, Validation loss: 0
Epoch 6: Train err: 0.11983775811209439, Train loss: 0.36734706383537163 |Validation err: 0.20353982300884957, Validation loss:
Epoch 7: Train err: 0.09992625368731563, Train loss: 0.2774628255177628 |Validation err: 0.15597345132743362, Validation loss: 0
Epoch 8: Train err: 0.06747787610619468, Train loss: 0.19151031429117377 |Validation err: 0.14823008849557523, Validation loss:
Epoch 9: Train err: 0.049410029498525077, Train loss: 0.1423169621689753 |Validation err: 0.13716814159292035, Validation loss:
Epoch 10: Train err: 0.03687315634218289, Train loss: 0.11324352500113574 |Validation err: 0.1504424778761062, Validation loss:
Epoch 11: Train err: 0.05235988200589971, Train loss: 0.14179337871345607 |Validation err: 0.15597345132743362, Validation loss:
Epoch 12: Train err: 0.05346607669616519, Train loss: 0.1523198290643367 |Validation err: 0.1426991150442478, Validation loss: 0
Epoch 13: Train err: 0.04793510324483776, Train loss: 0.1240245947106318 |Validation err: 0.14380530973451328, Validation loss:
Epoch 14: Train err: 0.033185840707964605, Train loss: 0.09739035015015608 |Validation err: 0.13274336283185842, Validation loss
Epoch 15: Train err: 0.019542772861356934, Train loss: 0.055542590668086304 |Validation err: 0.12057522123893805, Validation los
Epoch 16: Train err: 0.00995575221238938, Train loss: 0.03166941339044239 |Validation err: 0.11946902654867257, Validation loss:
Epoch 17: Train err: 0.007374631268436578, Train loss: 0.022915977413173427 |Validation err: 0.11283185840707964, Validation los
Epoch 18: Train err: 0.007374631268436578, Train loss: 0.01910886268491264 |Validation err: 0.12168141592920353, Validation loss
Epoch 19: Train err: 0.006268436578171091, Train loss: 0.017889351753348656 |Validation err: 0.1172566371681416, Validation loss
Epoch 20: Train err: 0.00663716814159292, Train loss: 0.01729288815774701 |Validation err: 0.12168141592920353, Validation loss:
Epoch 21: Train err: 0.006268436578171091, Train loss: 0.01674783331426707 |Validation err: 0.11946902654867257, Validation loss
Epoch 22: Train err: 0.006268436578171091, Train loss: 0.017382912676442753 |Validation err: 0.12057522123893805, Validation los
Epoch 23: Train err: 0.005899705014749262, Train loss: 0.016360337083989925 |Validation err: 0.13163716814159293, Validation lo
Epoch 24: Train err: 0.00663716814159292, Train loss: 0.0156539302657951 |Validation err: 0.12389380530973451, Validation loss:
Epoch 25: Train err: 0.01032448377581121, Train loss: 0.025310298629020424 |Validation err: 0.12831858407079647, Validation loss
Epoch 26: Train err: 0.019542772861356934, Train loss: 0.05620823904940731 |Validation err: 0.15597345132743362, Validation loss
Epoch 27: Train err: 0.03797935103244838, Train loss: 0.13975494795224883 |Validation err: 0.14712389380530974, Validation loss:
Epoch 28: Train err: 0.03834808259587020 6, Train loss: 0.106964351948012 |Validation err: 0.14601769911504425, Validation loss:
Epoch 29: Train err: 0.025811209439528023, Train loss: 0.08040758896888954 |Validation err: 0.14712389380530974, Validation loss
Epoch 30: Train err: 0.022123893805309734, Train loss: 0.06130693924867294 |Validation err: 0.14933628318584072, Validation loss
Finished Training
Total time elapsed: 490.17 seconds
Training with batch_size = 128 and learning rate = 0.05
```

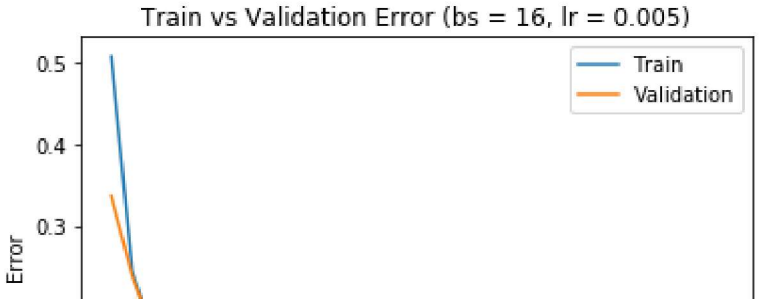
```
Epoch 1: Train err: 0.8853244837758112, Train loss: 3.438805352557789 |Validation err: 0.8893805309734514, Validation loss: 2.20
Epoch 2: Train err: 0.8890117994100295, Train loss: 2.201035358689048 |Validation err: 0.8993362831858407, Validation loss: 2.20
Epoch 3: Train err: 0.8952802359882006, Train loss: 2.198579105463895 |Validation err: 0.8993362831858407, Validation loss: 2.20
Epoch 4: Train err: 0.8823746312684366, Train loss: 2.199087153781544 |Validation err: 0.8993362831858407, Validation loss: 2.19
Epoch 5: Train err: 0.8893805309734514, Train loss: 2.200037956237793 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 6: Train err: 0.8912241887905604, Train loss: 2.198644453828985 |Validation err: 0.8993362831858407, Validation loss: 2.19
Epoch 7: Train err: 0.8915929203539823, Train loss: 2.1992867318066684 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 8: Train err: 0.8952802359882006, Train loss: 2.198845245621421 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 9: Train err: 0.9004424778761062, Train loss: 2.2008767019618642 |Validation err: 0.8926991150442478, Validation loss: 2.1
Epoch 10: Train err: 0.894542772861357, Train loss: 2.199544657360424 |Validation err: 0.8993362831858407, Validation loss: 2.19
Epoch 11: Train err: 0.8823746312684366, Train loss: 2.200770215554671 |Validation err: 0.8893805309734514, Validation loss: 2.1
Epoch 12: Train err: 0.8971238938053098, Train loss: 2.1989001577550713 |Validation err: 0.8926991150442478, Validation loss: 2.
Epoch 13: Train err: 0.8882743362831859, Train loss: 2.198965137655085 |Validation err: 0.8904867256637168, Validation loss: 2.1
Epoch 14: Train err: 0.890117994100295, Train loss: 2.1983729817650537 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 15: Train err: 0.8842182890855457, Train loss: 2.2003092657436025 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 16: Train err: 0.8860619469026548, Train loss: 2.19852171160958 |Validation err: 0.8993362831858407, Validation loss: 2.19
Epoch 17: Train err: 0.8967551622418879, Train loss: 2.1997418728741733 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 18: Train err: 0.8882743362831859, Train loss: 2.199339411475442 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 19: Train err: 0.8989675516224189, Train loss: 2.198785911906849 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 20: Train err: 0.8823746312684366, Train loss: 2.199709502133456 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 21: Train err: 0.8982300884955752, Train loss: 2.19914005019448 |Validation err: 0.8926991150442478, Validation loss: 2.20
Epoch 22: Train err: 0.8849557522123894, Train loss: 2.200798923319036 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 23: Train err: 0.8886430678466076, Train loss: 2.200860771265897 |Validation err: 0.8960176991150443, Validation loss: 2.1
Epoch 24: Train err: 0.8890117994100295, Train loss: 2.1991296031258325 |Validation err: 0.8893805309734514, Validation loss: 2.
Epoch 25: Train err: 0.8926991150442478, Train loss: 2.199031190438704 |Validation err: 0.8993362831858407, Validation loss: 2.2
Epoch 26: Train err: 0.8853244837758112, Train loss: 2.1992029493505303 |Validation err: 0.8993362831858407, Validation loss: 2.
Epoch 27: Train err: 0.8938053097345132, Train loss: 2.1996621760455044 |Validation err: 0.8904867256637168, Validation loss: 2.
Epoch 28: Train err: 0.8967551622418879, Train loss: 2.200305765325373 |Validation err: 0.8993362831858407, Validation loss: 2.1
Epoch 29: Train err: 0.8816371681415929, Train loss: 2.1994688402522695 |Validation err: 0.8926991150442478, Validation loss: 2.
Epoch 30: Train err: 0.8886430678466076, Train loss: 2.2007437402551826 |Validation err: 0.8926991150442478, Validation loss: 2.
Finished Training
Total time elapsed: 488.61 seconds
Training with batch_size = 128 and learning rate = 0.03
Epoch 1: Train err: 0.7205014749262537, Train loss: 2.0342105572873894 |Validation err: 0.536504424778761, Validation loss: 1.52
Epoch 2: Train err: 0.4424778761061947, Train loss: 1.2933736877007918 |Validation err: 0.3396017699115044, Validation loss: 1.1
Epoch 3: Train err: 0.3278023598820059, Train loss: 1.0422970273277976 |Validation err: 0.3141592920353982, Validation loss: 1.0
Epoch 4: Train err: 0.29646017699115046, Train loss: 0.9298202530904249 |Validation err: 0.28761061946902655, Validation loss: 0
Epoch 5: Train err: 0.288716814159292, Train loss: 0.8563627153635025 |Validation err: 0.29314159292035397, Validation loss: 1.0
Epoch 6: Train err: 0.26069321533923306, Train loss: 0.8090645914727991 |Validation err: 0.25331858407079644, Validation loss: 1
Epoch 7: Train err: 0.2617994100294985, Train loss: 0.7962656684897162 |Validation err: 0.28982300884955753, Validation loss: 0.
Epoch 8: Train err: 0.24299410029498525, Train loss: 0.7376709499142386 |Validation err: 0.35398230088495575, Validation loss: 1
Epoch 9: Train err: 0.25, Train loss: 0.7676891386508942 |Validation err: 0.2721238938053097, Validation loss: 1.193323194980621
```

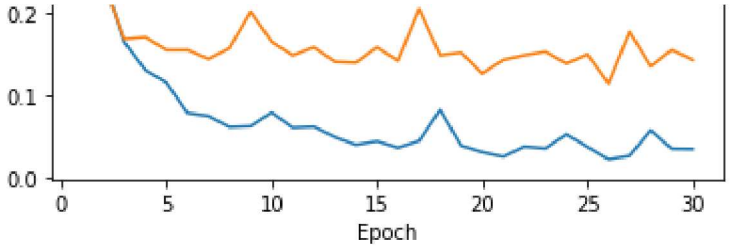
```
Epoch 10: Train err: 0.23561946902654868, Train loss: 0.7466980842026797 |Validation err: 0.2610619469026549, Validation loss: 0
Epoch 11: Train err: 0.2334070796460177, Train loss: 0.69394182481549 |Validation err: 0.2676991150442478, Validation loss: 1.07
Epoch 12: Train err: 0.2079646017699115, Train loss: 0.6389071663672273 |Validation err: 0.23672566371681417, Validation loss: 0
Epoch 13: Train err: 0.19579646017699115, Train loss: 0.5928193642334505 |Validation err: 0.23783185840707965, Validation loss:
Epoch 14: Train err: 0.18547197640117993, Train loss: 0.5726135596632957 |Validation err: 0.22566371681415928, Validation loss:
Epoch 15: Train err: 0.19063421828908556, Train loss: 0.5679817308079113 |Validation err: 0.2157079646017699, Validation loss: 0
Epoch 16: Train err: 0.16592920353982302, Train loss: 0.5131425803357904 |Validation err: 0.24004424778761063, Validation loss:
Epoch 17: Train err: 0.17662241887905605, Train loss: 0.5168976079333912 |Validation err: 0.2411504424778761, Validation loss: 0
Epoch 18: Train err: 0.17588495575221239, Train loss: 0.505373091860251 |Validation err: 0.23893805309734514, Validation loss: 0
Epoch 19: Train err: 0.17404129793510326, Train loss: 0.5077637068249963 |Validation err: 0.2234513274336283, Validation loss: 0
Epoch 20: Train err: 0.1467551622418879, Train loss: 0.4708144095810977 |Validation err: 0.20907079646017698, Validation loss: 0
Epoch 21: Train err: 0.16224188790560473, Train loss: 0.46636317060752347 |Validation err: 0.2079646017699115, Validation loss:
Epoch 22: Train err: 0.137905604719764, Train loss: 0.4212477660991929 |Validation err: 0.19247787610619468, Validation loss: 0.
Epoch 23: Train err: 0.13827433628318583, Train loss: 0.42101779309186066 |Validation err: 0.19911504424778761, Validation loss:
Epoch 24: Train err: 0.13089970501474926, Train loss: 0.38807538084008475 |Validation err: 0.2345132743362832, Validation loss:
Epoch 25: Train err: 0.15228613569321534, Train loss: 0.4351325658234683 |Validation err: 0.20353982300884957, Validation loss:
Epoch 26: Train err: 0.13200589970501475, Train loss: 0.3728548288345337 |Validation err: 0.2411504424778761, Validation loss: 1
Epoch 27: Train err: 0.14343657817109146, Train loss: 0.43466146696697583 |Validation err: 0.2079646017699115, Validation loss:
Epoch 28: Train err: 0.14343657817109146, Train loss: 0.4490248737010089 |Validation err: 0.24557522123893805, Validation loss:
```

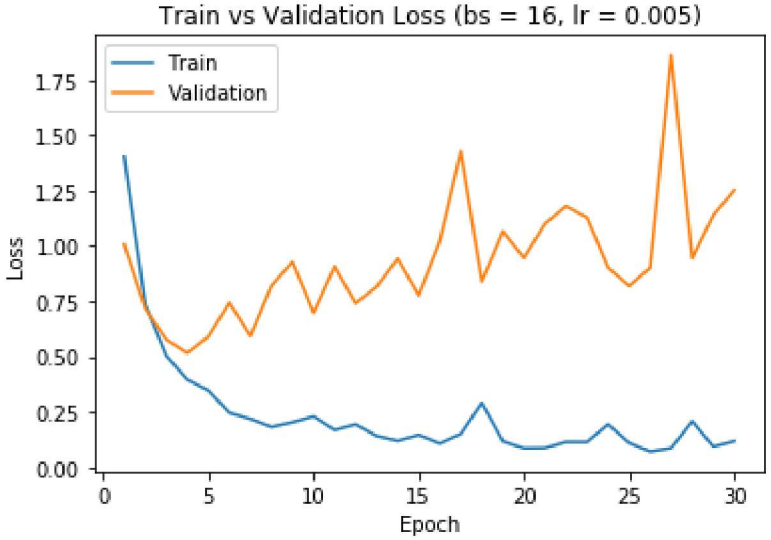
```
# Print Model Performance

for model in models:
  plot_training_curve(model)
```


Train vs Validation Error (bs = 16, lr = 0.01)
Train
Validation
Error
Epoch
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30

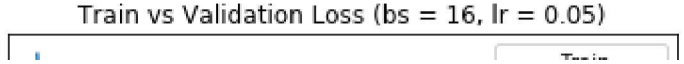

Train vs Validation Loss (bs = 16, lr = 0.01)
Train
Validation
Loss
Epoch
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30

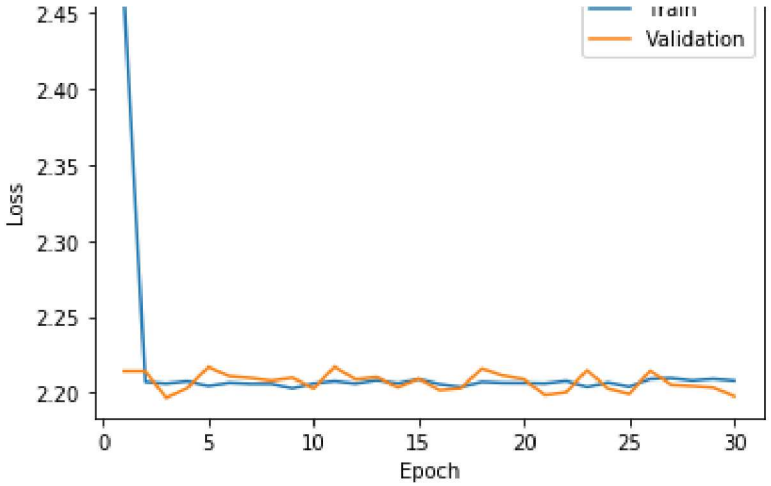

Train vs Validation Error (bs = 16, lr = 0.005)
Train
Validation
Error
0.5
0.4
0.3

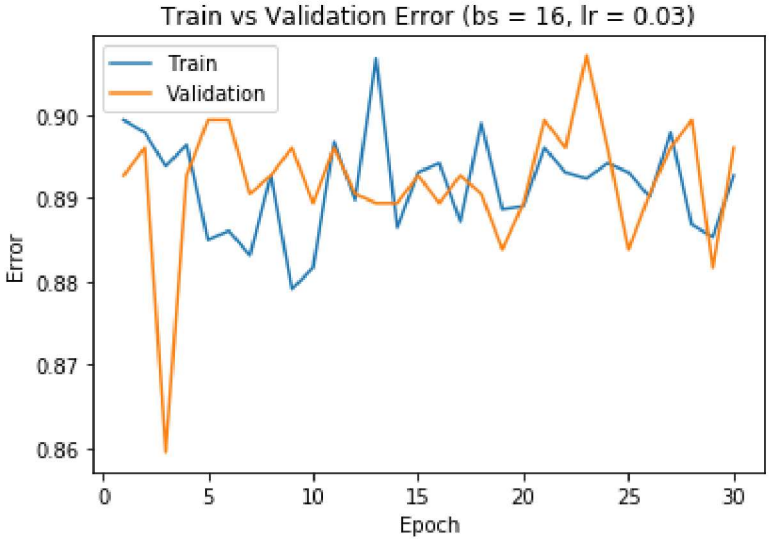

0.2
0.1
0.0
0
5
10
15
20
25
30
Epoch

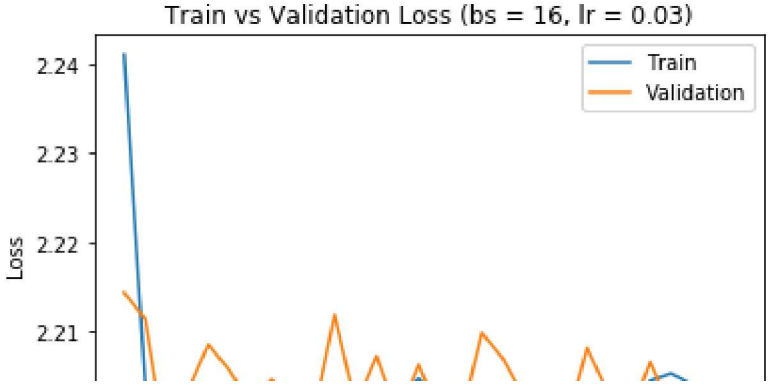

Train vs Validation Loss (bs = 16, lr = 0.005)
Train
Validation
Loss
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
25
30
Epoch

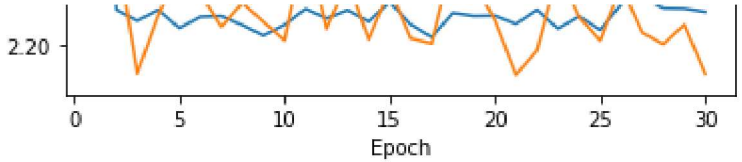

Train vs Validation Error (bs = 16, lr = 0.05)
Error
0.91
0.90
0.89
0.88
0.87
0.86
Train
Validation
0
5
10
15
20
25
30
Epoch

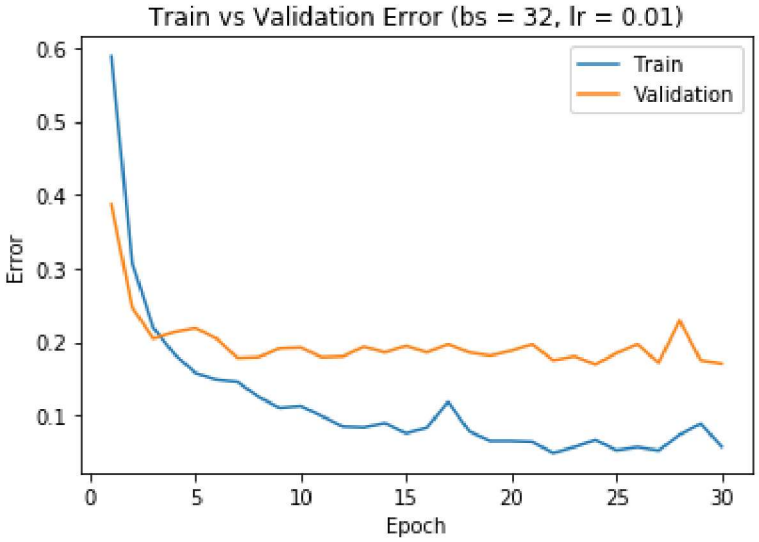

Train vs Validation Loss (bs = 16, lr = 0.05)

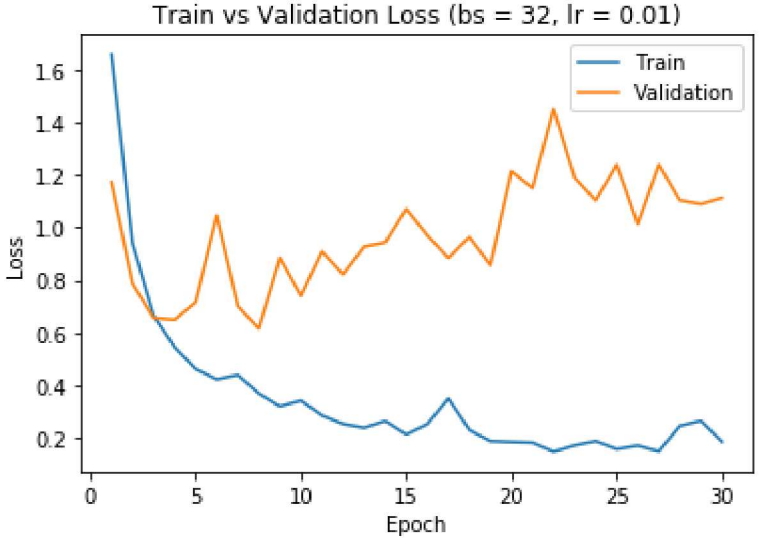

Train
Validation
Loss
Epoch

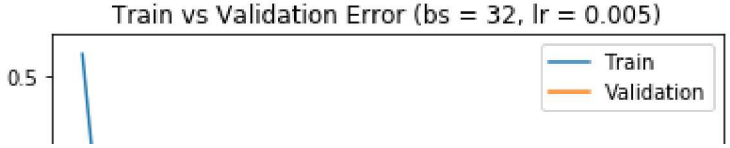

Train vs Validation Error (bs = 16, lr = 0.03)
Train
Validation
Error
Epoch

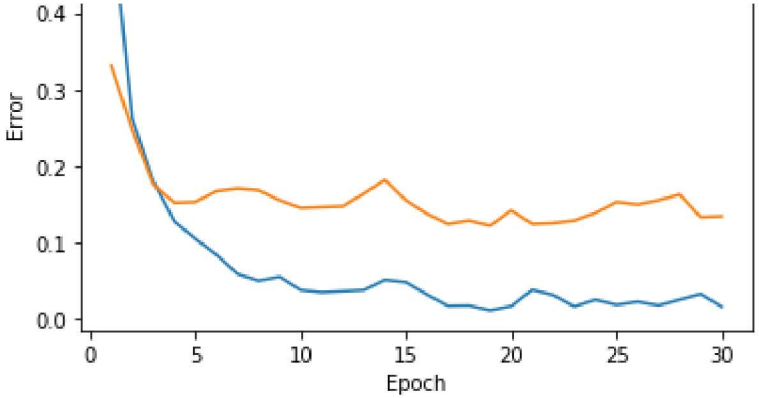

Train vs Validation Loss (bs = 16, lr = 0.03)
Train
Validation
Loss

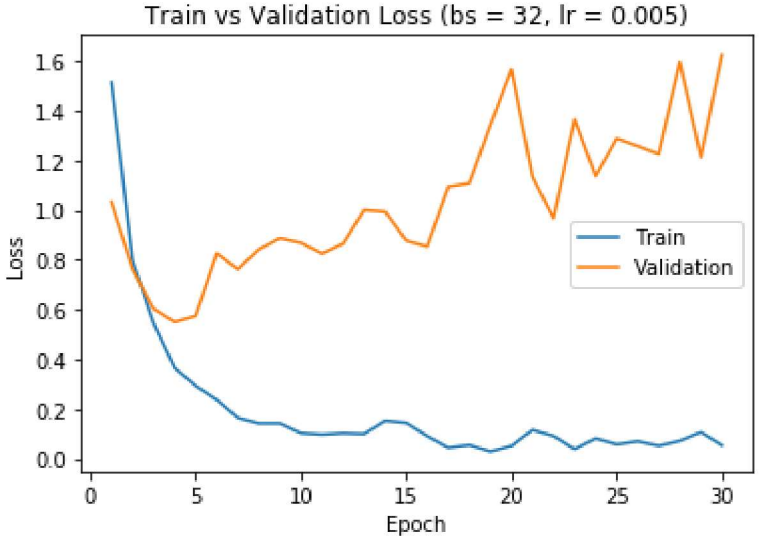

2.20
0
5
10
15
20
25
30
Epoch

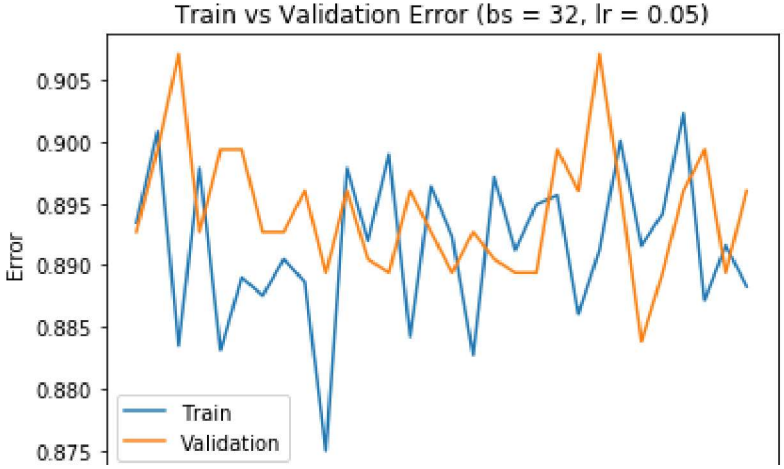

Train vs Validation Error (bs = 32, lr = 0.01)
Train
Validation
Error
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
Epoch

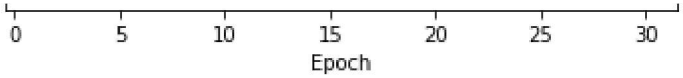

Train vs Validation Loss (bs = 32, lr = 0.01)
Train
Validation
Loss
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
5
10
15
20
25
30
Epoch

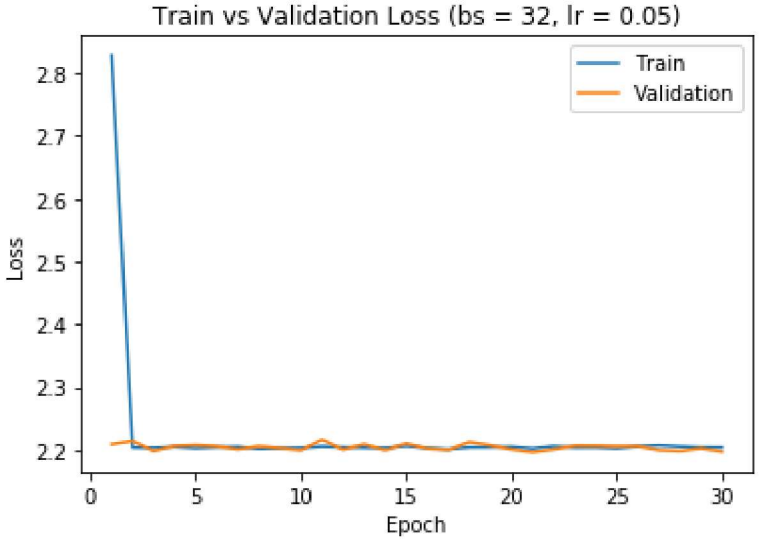

Train vs Validation Error (bs = 32, lr = 0.005)
Train
Validation
0.5


Error
Epoch

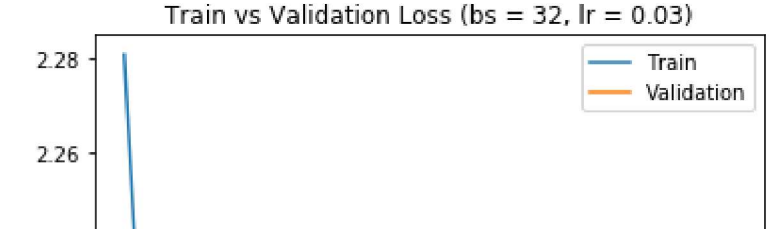

Train vs Validation Loss (bs = 32, lr = 0.005)
Loss
Epoch
Train
Validation

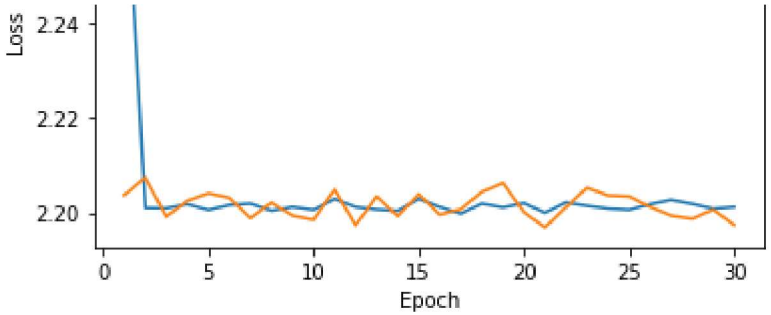

Train vs Validation Error (bs = 32, lr = 0.05)
Error
Train
Validation

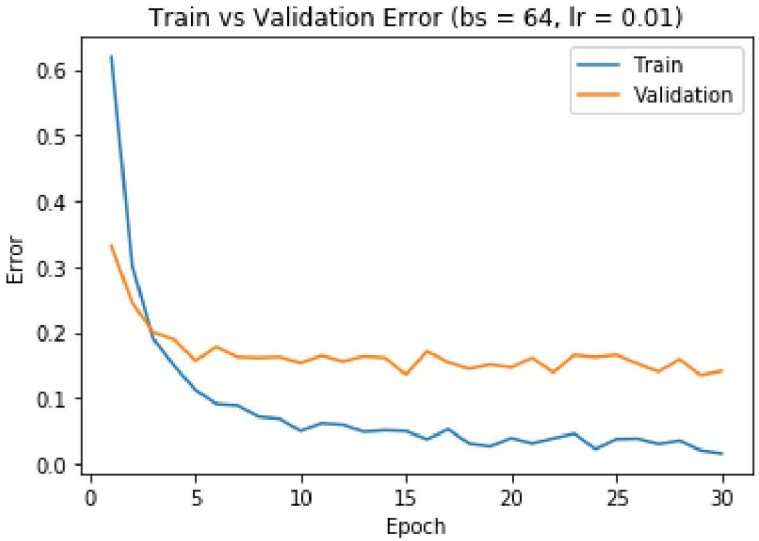

0
5
10
15
20
25
30
Epoch

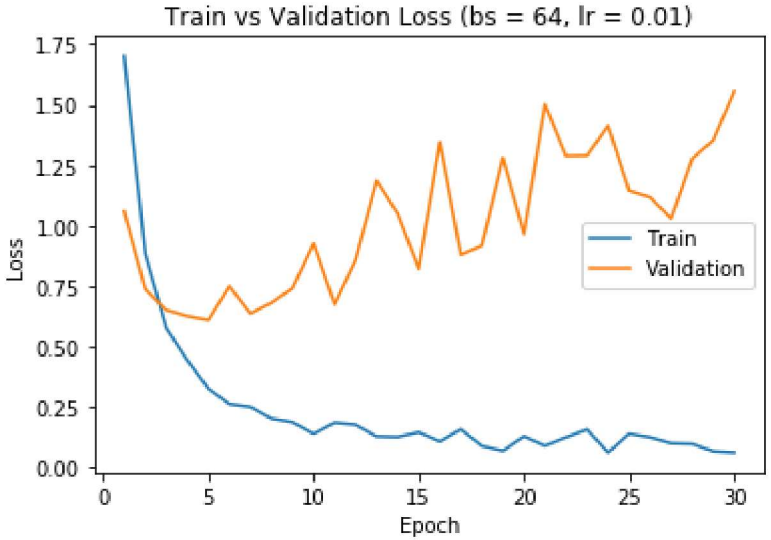

Train vs Validation Loss (bs = 32, lr = 0.05)
Train
Validation
Loss
2.8
2.7
2.6
2.5
2.4
2.3
2.2
0
5
10
15
20
25
30
Epoch

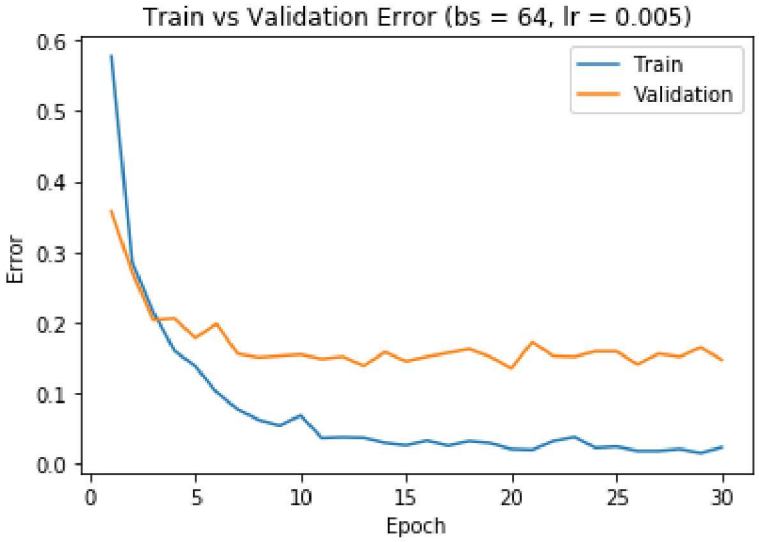

Train vs Validation Error (bs = 32, lr = 0.03)
Error
0.90
0.89
0.88
0.87
0.86
Train
Validation
0
5
10
15
20
25
30
Epoch

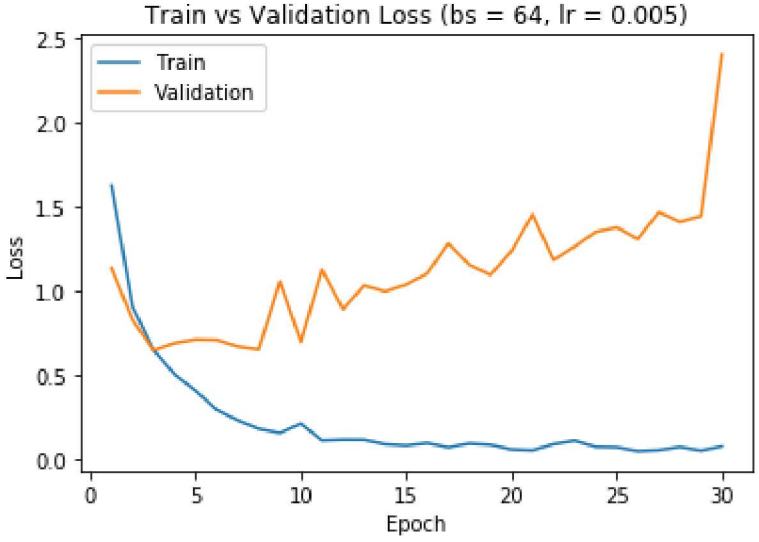

Train vs Validation Loss (bs = 32, lr = 0.03)
Train
Validation
2.28
2.26

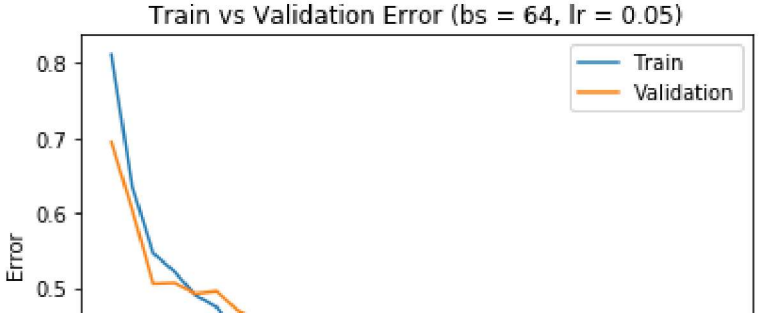

Loss
2.24
2.22
2.20
0
5
10
15
20
25
30
Epoch

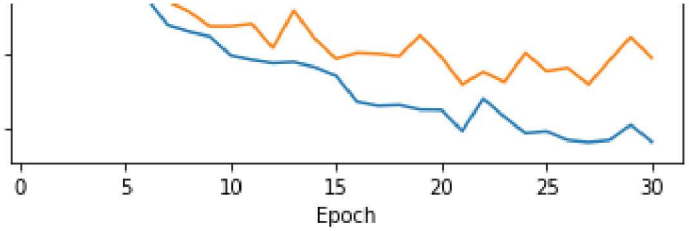

Train vs Validation Error (bs = 64, lr = 0.01)
Train
Validation
Error
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Epoch

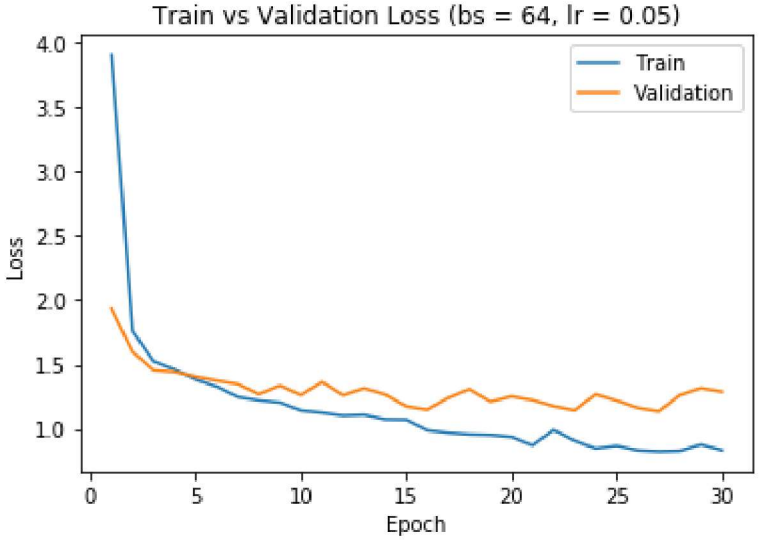

Train vs Validation Loss (bs = 64, lr = 0.01)
Train
Validation
Loss
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
25
30
Epoch

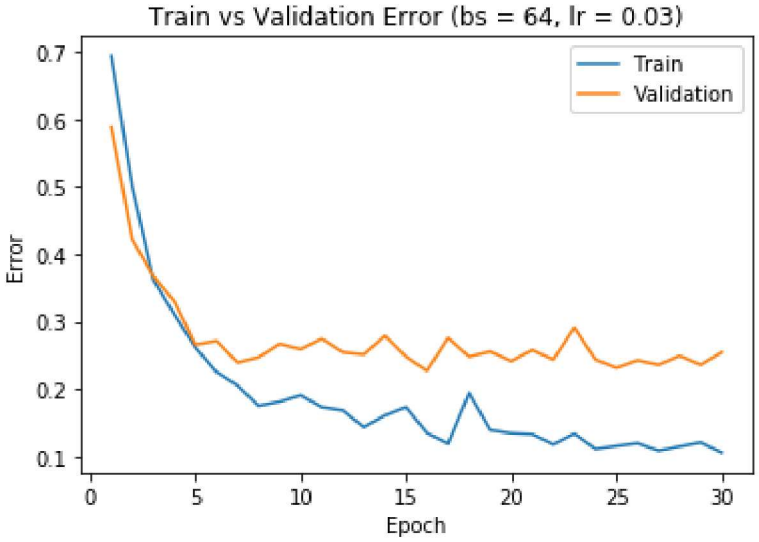

Train vs Validation Error (bs = 64, lr = 0.005)
Train
Validation
Error
Epoch
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
5
10
15
20
25
30

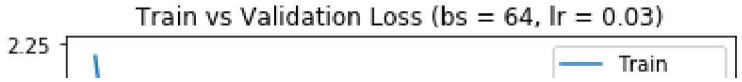

Train vs Validation Loss (bs = 64, lr = 0.005)
Train
Validation
Loss
Epoch
0.0
0.5
1.0
1.5
2.0
2.5
0
5
10
15
20
25
30

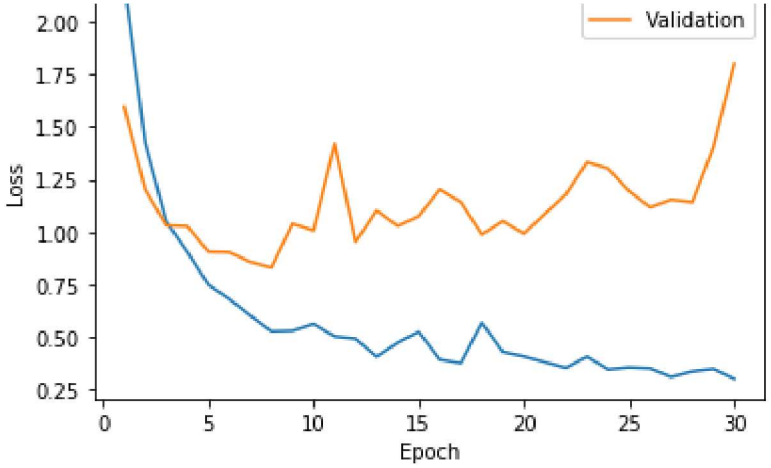

Train vs Validation Error (bs = 64, lr = 0.05)
Train
Validation
Error
0.5
0.6
0.7
0.8

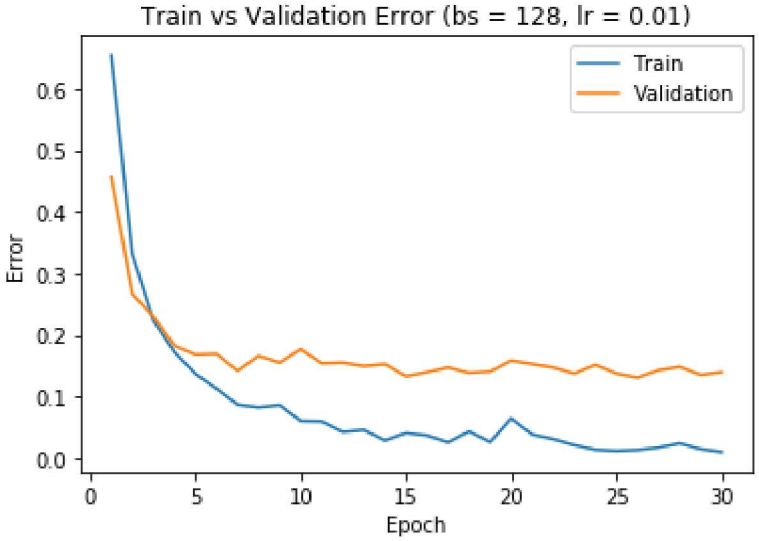

0.4
0.3
0
5
10
15
20
25
30
Epoch

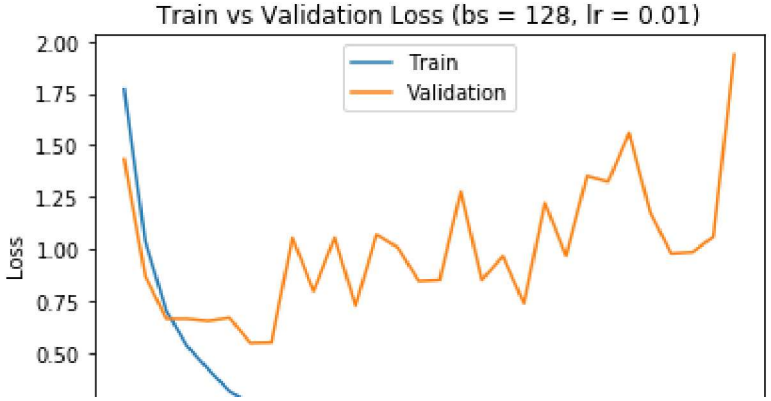

Train vs Validation Loss (bs = 64, lr = 0.05)
Train
Validation
Loss
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0
5
10
15
20
25
30
Epoch

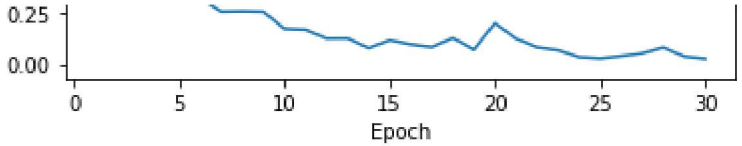

Train vs Validation Error (bs = 64, lr = 0.03)
Train
Validation
Error
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
Epoch

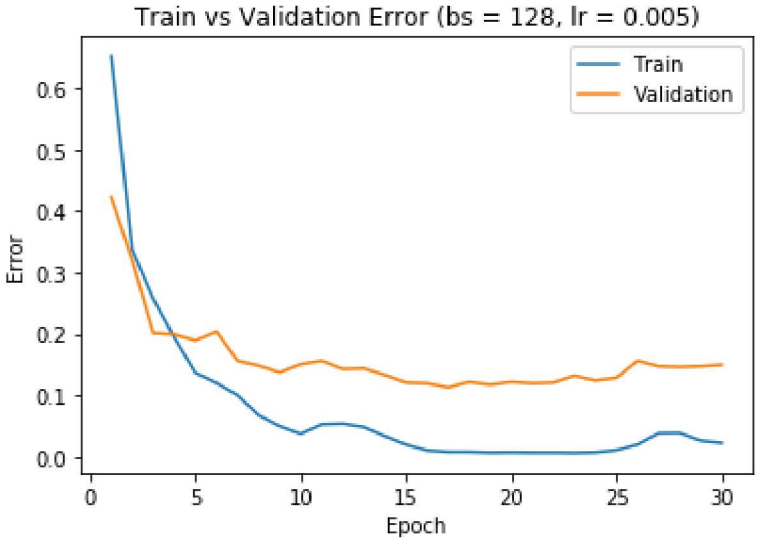

Train vs Validation Loss (bs = 64, lr = 0.03)
2.25
Train

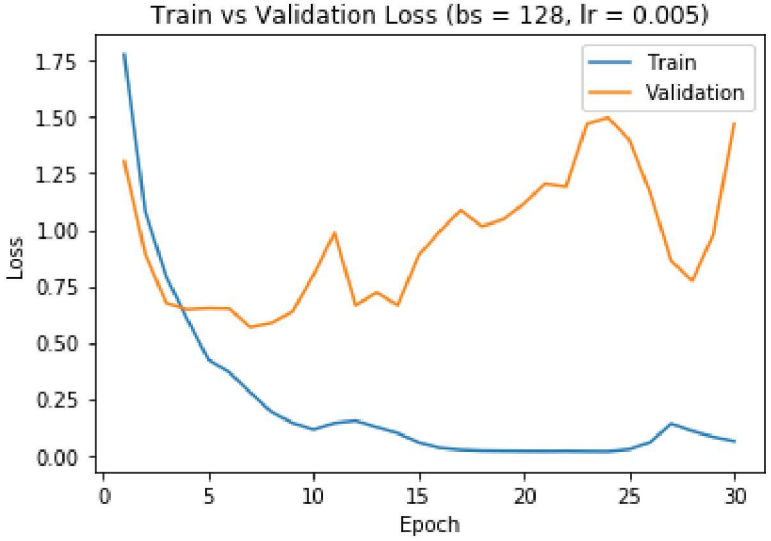

Validation
Loss
Epoch


Train vs Validation Error (bs = 128, lr = 0.01)
Train
Validation
Error
Epoch

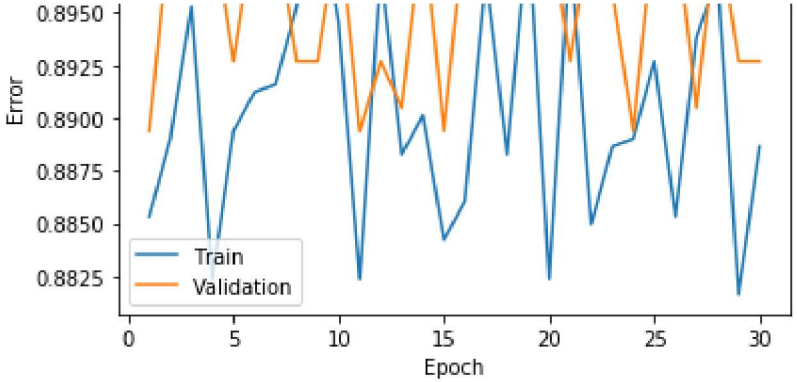

Train vs Validation Loss (bs = 128, lr = 0.01)
Train
Validation
Loss

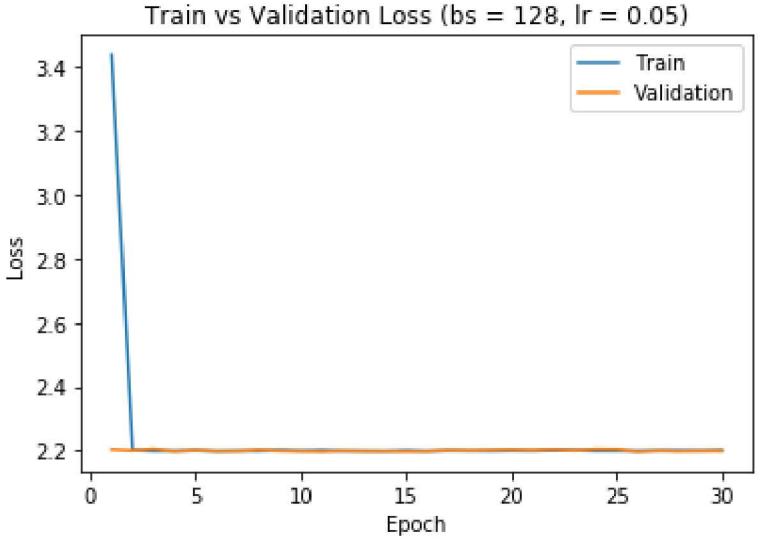

0.25
0.00
0
5
10
15
20
25
30
Epoch

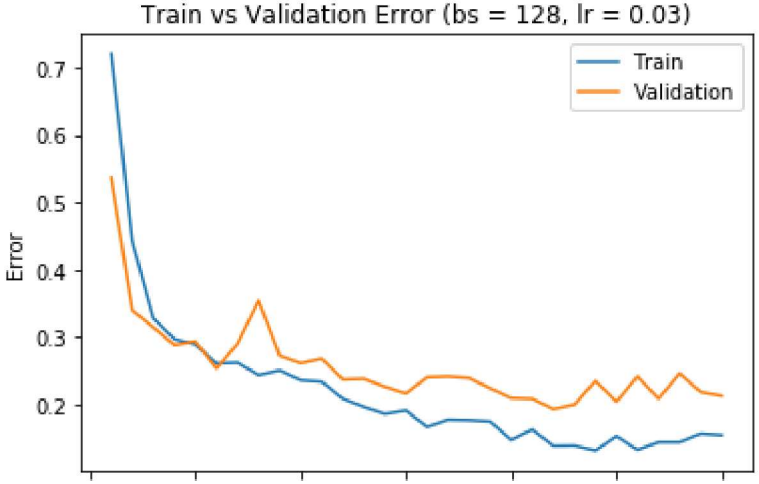

Train vs Validation Error (bs = 128, lr = 0.005)
Train
Validation
Error
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
5
10
15
20
25
30
Epoch

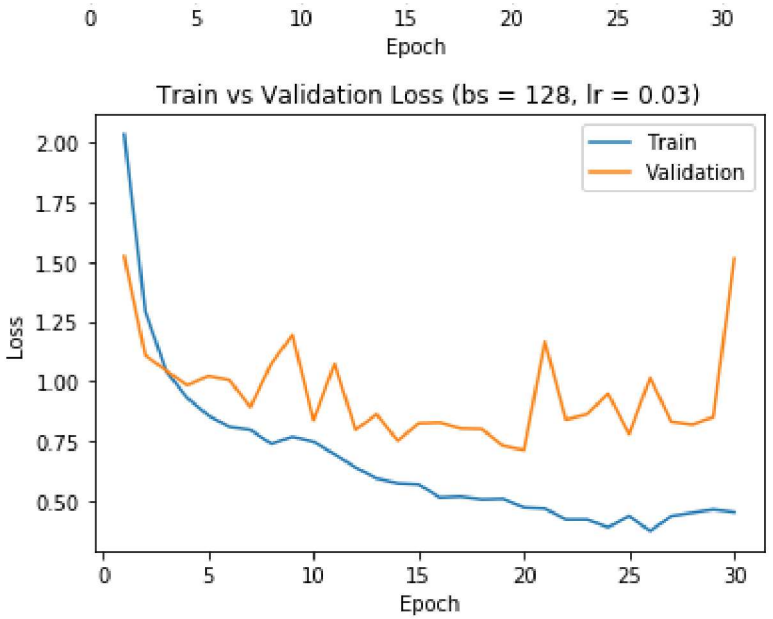

Train vs Validation Loss (bs = 128, lr = 0.005)
Train
Validation
Loss
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
0
5
10
15
20
25
30
Epoch


Train vs Validation Error (bs = 128, lr = 0.05)
0.9000
0.8975


0.8950
0.8925
0.8900
0.8875
0.8850
0.8825
Error
Train
Validation
0
5
10
15
20
25
30
Epoch


Train vs Validation Loss (bs = 128, lr = 0.05)
Train
Validation
3.4
3.2
3.0
2.8
2.6
2.4
2.2
Loss
0
5
10
15
20
25
30
Epoch


Train vs Validation Error (bs = 128, lr = 0.03)
Train
Validation
0.7
0.6
0.5
0.4
0.3
0.2
Error



Part (c) - 1 pt

Choose the best model out of all the ones that you have trained. Justify your choice.

The best model is the model at epoch 28 with `batch_size` = 28 and `learning_rate` = 0.03. This model had the best (and lowest) correlation of training error to validation error, so it is a good model that is not overfitting to the training data. I chose epoch 28 as validation error spikes after this epoch.

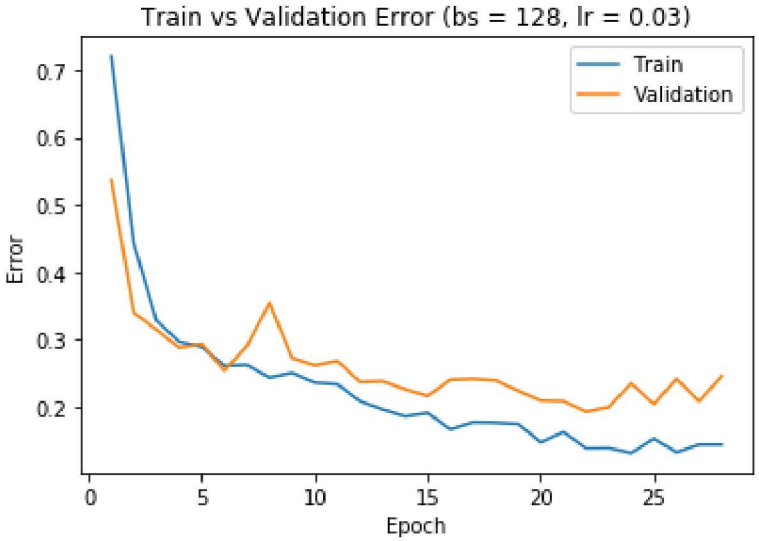
```
best_batch_size = 128
best_learning_rate = 0.03
best_epoch = 28
```

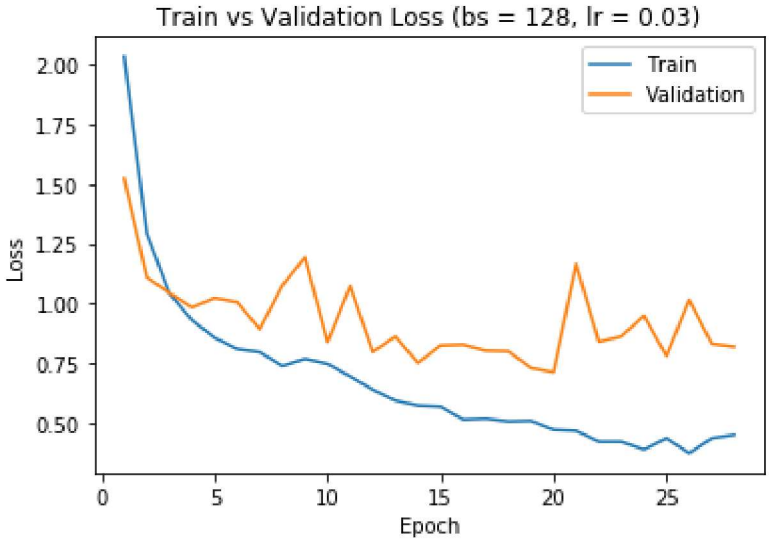
```
# As train function only stored at every 5 epochs, we train again with 28 epochs to obtain the model
best_net = ConvNet("best")
train_loader, val_loader, test_loader = get_data_loader(img_folder, best_batch_size)
```

```
train_net(best_net, train_loader, val_loader, best_batch_size, best_learning_rate, best_epoch)
```

```
Epoch 1: Train err: 0.7205014749262537, Train loss: 2.0342105572873894 |Validation err: 0.536504424778761, Validation loss: 1.52
Epoch 2: Train err: 0.4424778761061947, Train loss: 1.2933736877007918 |Validation err: 0.3396017699115044, Validation loss: 1.1
Epoch 3: Train err: 0.3278023598820059, Train loss: 1.0422970273277976 |Validation err: 0.3141592920353982, Validation loss: 1.0
Epoch 4: Train err: 0.29646017699115046, Train loss: 0.9298202530904249 |Validation err: 0.28761061946902655, Validation loss: 0
Epoch 5: Train err: 0.288716814159292, Train loss: 0.8563627153635025 |Validation err: 0.29314159292035397, Validation loss: 1.0
Epoch 6: Train err: 0.26069321533923306, Train loss: 0.8090645914727991 |Validation err: 0.25331858407079644, Validation loss: 1
Epoch 7: Train err: 0.2617994100294985, Train loss: 0.7962656684897162 |Validation err: 0.28982300884955753, Validation loss: 0.
Epoch 8: Train err: 0.24299410029498525, Train loss: 0.7376709499142386 |Validation err: 0.35398230088495575, Validation loss: 1
Epoch 9: Train err: 0.25, Train loss: 0.7676891386508942 |Validation err: 0.2721238938053097, Validation loss: 1.193323194980621
Epoch 10: Train err: 0.23561946902654868, Train loss: 0.7466980842026797 |Validation err: 0.2610619469026549, Validation loss: 0
Epoch 11: Train err: 0.2334070796460177, Train loss: 0.69394182481549 |Validation err: 0.2676991150442478, Validation loss: 1.07
Epoch 12: Train err: 0.2079646017699115, Train loss: 0.6389071663672273 |Validation err: 0.23672566371681417, Validation loss: 0
Epoch 13: Train err: 0.19579646017699115, Train loss: 0.5928193642334505 |Validation err: 0.23783185840707965, Validation loss:
Epoch 14: Train err: 0.18547197640117993, Train loss: 0.5726135596632957 |Validation err: 0.22566371681415928, Validation loss:
Epoch 15: Train err: 0.19063421828908556, Train loss: 0.5679817308079113 |Validation err: 0.2157079646017699, Validation loss: 0
Epoch 16: Train err: 0.16592920353982302, Train loss: 0.5131425803357904 |Validation err: 0.24004424778761063, Validation loss:
Epoch 17: Train err: 0.17662241887905605, Train loss: 0.5168976079333912 |Validation err: 0.2411504424778761, Validation loss: 0
Epoch 18: Train err: 0.17588495575221239, Train loss: 0.505373091860251 |Validation err: 0.23893805309734514, Validation loss: 0
Epoch 19: Train err: 0.17404129793510326, Train loss: 0.5077637068249963 |Validation err: 0.2234513274336283, Validation loss: 0
Epoch 20: Train err: 0.1467551622418879, Train loss: 0.4708144095810977 |Validation err: 0.20907079646017698, Validation loss: 0
Epoch 21: Train err: 0.16224188790560473, Train loss: 0.46636317060752347 |Validation err: 0.2079646017699115, Validation loss:
Epoch 22: Train err: 0.137905604719764, Train loss: 0.4212477660991929 |Validation err: 0.19247787610619468, Validation loss: 0.
Epoch 23: Train err: 0.13827433628318583, Train loss: 0.42101779309186066 |Validation err: 0.19911504424778761, Validation loss:
Epoch 24: Train err: 0.13089970501474926, Train loss: 0.38807538084008475 |Validation err: 0.2345132743362832, Validation loss:
Epoch 25: Train err: 0.15228613569321534, Train loss: 0.4351325658234683 |Validation err: 0.20353982300884957, Validation loss:
Epoch 26: Train err: 0.13200589970501475, Train loss: 0.3728548288345337 |Validation err: 0.2411504424778761, Validation loss: 1
Epoch 27: Train err: 0.14343657817109146, Train loss: 0.43466146696697583 |Validation err: 0.2079646017699115, Validation loss:
Epoch 28: Train err: 0.14343657817109146, Train loss: 0.4490248737010089 |Validation err: 0.24557522123893805, Validation loss:
Finished Training
Total time elapsed: 519.98 seconds
```

```
# Print graphs for best model

plot_training_curve(get_model_name("best", best_batch_size, best_learning_rate, best_epoch-1))
```





Part (d) - 2 pt

Report the test accuracy of your best model. You should only do this step once and prior to this step you should have only used the training and validation data.

```
# Retrieve the best model
model = get_model_name("best", best_batch_size, best_learning_rate, best_epoch-1)
net = ConvNet()
state = torch.load(model)
net.load_state_dict(state)
```

```
<All keys matched successfully>
```

```
# Evaluate net on testing data

cr = nn.CrossEntropyLoss()

err, loss = evaluate(net, test_loader, cr, enable_cuda=False)

acc = 1 - err

print("Test Accuracy of best model:", 100*acc, "%")
```

```
Test Accuracy of best model: 77.45856353591161 %
```

4. Transfer Learning [15 pt]

For many image classification tasks, it is generally not a good idea to train a very large deep neural network model from scratch due to the enormous compute requirements and lack of sufficient amounts of training data.

One of the better options is to try using an existing model that performs a similar task to the one you need to solve. This method of utilizing a pre-trained network for other similar tasks is broadly termed **Transfer Learning**. In this assignment, we will use Transfer Learning to extract features from the hand gesture images. Then, train a smaller network to use these features as input and classify the hand gestures.

As you have learned from the CNN lecture, convolution layers extract various features from the images which get utilized by the fully connected layers for correct classification. AlexNet architecture played a pivotal role in establishing Deep Neural Nets as a go-to tool for image classification problems and we will use an ImageNet pre-trained AlexNet model to extract features in this assignment.

Part (a) - 5 pt

Here is the code to load the AlexNet network, with pretrained weights. When you first run the code, PyTorch will download the pretrained weights from the internet.

```
import torchvision.models
alexnet = torchvision.models.alexnet(pretrained=True)
```

```
Downloading: "https://download.pytorch.org/models/alexnet-owt-4df8aa71.pth" to /root/.cache/torch/checkpoints/alexnet-owt-4df8aa
100% 233M/233M [00:02<00:00, 114MB/s]
```

The alexnet model is split up into two components: *alexnet.features* and *alexnet.classifier*. The first neural network component, *alexnet.features*, is used to compute convolutional features, which are taken as input in *alexnet.classifier*.

The neural network alexnet.features expects an image tensor of shape Nx3x224x224 as input and it will output a tensor of shape Nx256x6x6 . (N = batch size).

Compute the AlexNet features for each of your training, validation, and test data. Here is an example code snippet showing how you can compute the AlexNet features for some images (your actual code might be different):

```
# Hyperparameters obtained through trial and error
best_batch_size = 128
best_learning_rate = 0.005


dataset = "Lab_3_Gesture_Dataset_W2020"
img_folder = get_img_folder(dataset)

train_loader, val_loader, test_loader = get_data_loader(img_folder, best_batch_size)

imgs, train_labels = iter(train_loader).next()
train_features = alexnet.features(imgs)

imgs, val_labels = iter(val_loader).next()
val_features = alexnet.features(imgs)
```

```
imgs, test_labels = iter(test_loader).next()
test_features = alexnet.features(imgs)
```

Save the computed features. You will be using these features as input to your neural network in Part (b), and you do not want to re-compute the features every time. Instead, run *alexnet.features* once for each image, and save the result.

Part (b) - 3 pt

Build a convolutional neural network model that takes as input these AlexNet features, and makes a prediction. Your model should be a subclass of nn.Module.

Explain your choice of neural network architecture: how many layers did you choose? What types of layers did you use: fully-connected or convolutional? What about other decisions like pooling layers, activation functions, number of channels / hidden units in each layer?

Here is an example of how your model may be called:

```
class Classifier(nn.Module):
    def __init__(self, name="classifier"):
        super(Classifier,self).__init__()
        self.name = name

        # One Convolutional Layer as most
        # features precomputed by AlexNet
        self.pool = nn.MaxPool2d(2,1)
        self.conv = nn.Conv2d(256, 128, 3, padding=1)

        # Two fully connected layers
        self.fc1 = nn.Linear(128 * 5 * 5, 150)
        self.fc2 = nn.Linear(150, 9)

    def forward(self, x):
        x = self.pool(F.relu(self.conv(x)))
        x = x.view(-1, 128 * 5 * 5)
        x = F.relu(self.fc1(x))
```

```
        x = self.fc2(x)
        return x
```

Part (c) - 5 pt

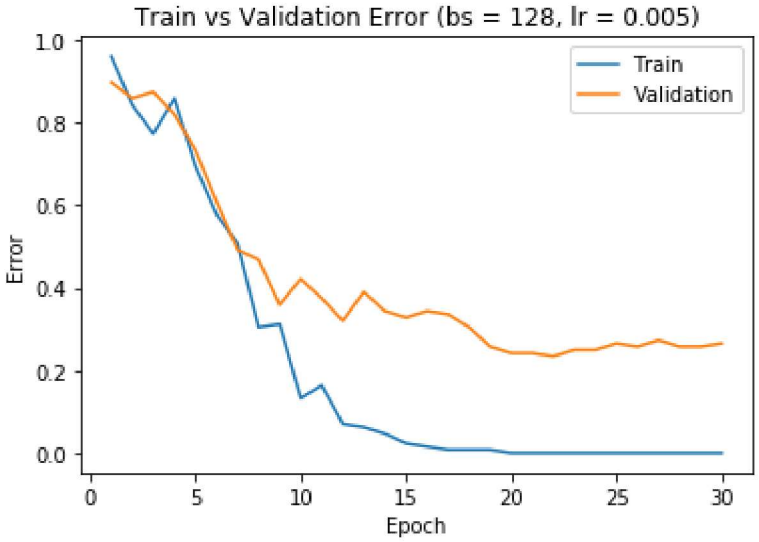
Train your new network, including any hyperparameter tuning. Plot and submit the training curve of your best model only.

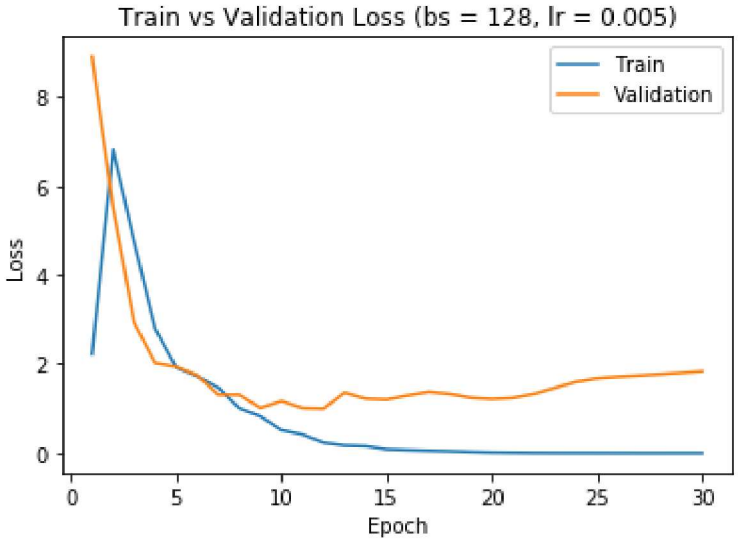
Note: Depending on how you are caching (saving) your AlexNet features, PyTorch might still be tracking updates to the **AlexNet weights**, which we are not tuning. One workaround is to convert your AlexNet feature tensor into a numpy array, and then back into a PyTorch tensor.

```
def get_feature_data_loader(features, labels, batch_size=128):
  features = torch.from_numpy(features.detach().numpy())
  features_dataset = data_utils.TensorDataset(features, labels)
  loader = torch.utils.data.DataLoader(features_dataset, batch_size=batch_size)
  return loader


train_loader_alex = get_feature_data_loader(train_features, train_labels, best_batch_size)
val_loader_alex = get_feature_data_loader(val_features, val_labels, best_batch_size)
test_loader_alex = get_feature_data_loader(test_features, test_labels, best_batch_size)

net = Classifier("alex")
train_net(net, train_loader_alex, val_loader_alex, best_batch_size, best_learning_rate)
```

```
Epoch 1: Train err: 0.9609375, Train loss: 2.2240731716156006 |Validation err: 0.8984375, Validation loss: 8.900553703308105
Epoch 2: Train err: 0.84375, Train loss: 6.813318252563477 |Validation err: 0.859375, Validation loss: 5.511905193328857
Epoch 3: Train err: 0.7734375, Train loss: 4.746793746948242 |Validation err: 0.875, Validation loss: 2.9281468391418457
Epoch 4: Train err: 0.859375, Train loss: 2.790329694747925 |Validation err: 0.8203125, Validation loss: 2.0227200984954834
Epoch 5: Train err: 0.6953125, Train loss: 1.9214521646499634 |Validation err: 0.734375, Validation loss: 1.9394663572311401
Epoch 6: Train err: 0.578125, Train loss: 1.724553108215332 |Validation err: 0.609375, Validation loss: 1.744815468788147
Epoch 7: Train err: 0.5078125, Train loss: 1.4694888591766357 |Validation err: 0.4921875, Validation loss: 1.3102505207061768
Epoch 8: Train err: 0.3046875, Train loss: 1.0045658349990845 |Validation err: 0.46875, Validation loss: 1.3088626861572266
Epoch 9: Train err: 0.3125, Train loss: 0.8266965746879578 |Validation err: 0.359375, Validation loss: 1.0133262872695923
Epoch 10: Train err: 0.1328125, Train loss: 0.516120433807373 |Validation err: 0.421875, Validation loss: 1.1656920909881592
Epoch 11: Train err: 0.1640625, Train loss: 0.4171619117259979 |Validation err: 0.375, Validation loss: 1.0107877254486084
Epoch 12: Train err: 0.0703125, Train loss: 0.23604033887386322 |Validation err: 0.3203125, Validation loss: 0.9971999526023865
Epoch 13: Train err: 0.0625, Train loss: 0.17355696856975555 |Validation err: 0.390625, Validation loss: 1.3577780723571777
Epoch 14: Train err: 0.046875, Train loss: 0.1577819287776947 |Validation err: 0.34375, Validation loss: 1.221875548362732
Epoch 15: Train err: 0.0234375, Train loss: 0.08410035073757172 |Validation err: 0.328125, Validation loss: 1.2025421857833862
Epoch 16: Train err: 0.015625, Train loss: 0.0674547553062439 |Validation err: 0.34375, Validation loss: 1.2951833009719849
Epoch 17: Train err: 0.0078125, Train loss: 0.05325222387909889 |Validation err: 0.3359375, Validation loss: 1.374204158782959
Epoch 18: Train err: 0.0078125, Train loss: 0.041180144995450974 |Validation err: 0.3046875, Validation loss: 1.3284990787506104
Epoch 19: Train err: 0.0078125, Train loss: 0.02502032369375229 |Validation err: 0.2578125, Validation loss: 1.2438549995422363
Epoch 20: Train err: 0.0, Train loss: 0.013128027319908142 |Validation err: 0.2421875, Validation loss: 1.2138876914978027
Epoch 21: Train err: 0.0, Train loss: 0.008941706269979477 |Validation err: 0.2421875, Validation loss: 1.239370584487915
Epoch 22: Train err: 0.0, Train loss: 0.0042636096477508545 |Validation err: 0.234375, Validation loss: 1.328379511833191
Epoch 23: Train err: 0.0, Train loss: 0.002402380108833313 |Validation err: 0.25, Validation loss: 1.4639638662338257
Epoch 24: Train err: 0.0, Train loss: 0.001831747591495514 |Validation err: 0.25, Validation loss: 1.600043773651123
Epoch 25: Train err: 0.0, Train loss: 0.0015571042895317078 |Validation err: 0.265625, Validation loss: 1.6781010627746582
Epoch 26: Train err: 0.0, Train loss: 0.0008884146809577942 |Validation err: 0.2578125, Validation loss: 1.7129650115966797
Epoch 27: Train err: 0.0, Train loss: 0.0003508181803798675537 |Validation err: 0.2734375, Validation loss: 1.7395035028457642
Epoch 28: Train err: 0.0, Train loss: 0.00017002224922180176 |Validation err: 0.2578125, Validation loss: 1.7681411504745483
Epoch 29: Train err: 0.0, Train loss: 0.0001109689474105835 |Validation err: 0.2578125, Validation loss: 1.7997781038284302
Epoch 30: Train err: 0.0, Train loss: 8.850544691085815e-05 |Validation err: 0.265625, Validation loss: 1.8333079814910889
Finished Training
Total time elapsed: 0.39 seconds
```

```
# Plot Training

model = get_model_name(net.name, best_batch_size, best_learning_rate, 29)
plot_training_curve(model)
```





The best hyperparameters were `batch_size` = 128 and `learning_rate` = 0.005. The best model at these values was at epoch #21, as the validation loss and error increased in subsequent epochs, meaning the model was overfitting

Since most features were precomputed by AlexNet, the CNN had one convolution layer and 2 fully connected layers.

Part (d) - 2 pt

Report the test accuracy of your best model. How does the test accuracy compare to part 4(d)?

```
best_batch_size = 128
best_learning_rate = 0.005
best_epoch = 21


# Retrieve the best model
model = get_model_name("alex", best_batch_size, best_learning_rate, best_epoch-1)
net = Classifier("alex")
state = torch.load(model)
net.load_state_dict(state)
```

```
<All keys matched successfully>
```

```
# Evaluate net on testing data

cr = nn.CrossEntropyLoss()

err, loss = evaluate(net, test_loader_alex, cr, enable_cuda=False)

acc = 1 - err

print("Test Accuracy of best model:", 100*acc, "%")
```

```
Test Accuracy of best model: 81.25 %
```

This testing accuracy is higher than the testing accuracy of the ConvNet (which was 77.4%), which makes sense as this new net has the precomputed features from AlexNet.