Lab 2: Cats vs Dogs

In this lab, you will train a convolutional neural network to classify an image into one of two classes: "cat" or "dog". The code for the neural networks you train will be written for you, and you are not (yet!) expected to understand all provided code. However, by the end of the lab, you should be able to:

1. Understand at a high level the training loop for a machine learning model.
2. Understand the distinction between training, validation, and test data.
3. The concepts of overfitting and underfitting.
4. Investigate how different hyperparameters, such as learning rate and batch size, affect the success of training.
5. Compare an ANN (aka Multi-Layer Perceptron) with a CNN.

What to submit

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.

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.

With Colab, you can export a PDF file using the menu option `File -> Print` and save as PDF file. **Adjust the scaling to ensure that the text is not cutoff at the margins.**

Colab Link

Include a link to your colab file here

Colab Link:
https://colab.research.google.com/github/GreatArcStudios/APS360/blob/master/Lab%202/Lab2%20Cats%20vs%20Dogs.ipynb#scrollTo=Rp7LVcGfqlD3

```
import numpy as np
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

```

Part 0. Helper Functions

We will be making use of the following helper functions. You will be asked to look at and possibly modify some of these, but you are not expected to understand all of them.

You should look at the function names and read the docstrings. If you are curious, come back and explore the code *after* making some progress on the lab.

```
################################################################################
# Data Loading

def get_relevant_indices(dataset, classes, target_classes):
    """ Return the indices for datapoints in the dataset that belongs to the
    desired target classes, a subset of all possible classes.

    Args:
        dataset: Dataset object
        classes: A list of strings denoting the name of each class
        target_classes: A list of strings denoting the name of desired classes
                        Should be a subset of the 'classes'
    Returns:
        indices: list of indices that have labels corresponding to one of the
```

```
                target classes
    """
    indices = []
    for i in range(len(dataset)):
        # Check if the label is in the target classes
        label_index = dataset[i][1] # ex: 3
        label_class = classes[label_index] # ex: 'cat'
        if label_class in target_classes:
            indices.append(i)
    return indices

def get_data_loader(target_classes, batch_size):
    """ Loads images of cats and dogs, splits the data into training, validation
    and testing datasets. Returns data loaders for the three preprocessed datasets.

    Args:
        target_classes: A list of strings denoting the name of the desired
                        classes. Should be a subset of the argument 'classes'
        batch_size: A int representing the number of samples per batch

    Returns:
        train_loader: iterable training dataset organized according to batch size
        val_loader: iterable validation dataset organized according to batch size
        test_loader: iterable testing dataset organized according to batch size
        classes: A list of strings denoting the name of each class
    """

    classes = ('plane', 'car', 'bird', 'cat',
               'deer', 'dog', 'frog', 'horse', 'ship', 'truck')
    ########################################################################
    # The output of torchvision datasets are PILImage images of range [0, 1].
    # We transform them to Tensors of normalized range [-1, 1].
    transform = transforms.Compose(
        [transforms.ToTensor(),
         transforms.Normalize((0.5, 0.5, 0.5), (0.5, 0.5, 0.5))])
    # Load CIFAR10 training data
    trainset = torchvision.datasets.CIFAR10(root='./data', train=True,
                                            download=True, transform=transform)
    # Get the list of indices to sample from
    relevant_indices = get_relevant_indices(trainset, classes, target_classes)

    # Split into train and validation
    np.random.seed(1000) # Fixed numpy random seed for reproducible shuffling
    np.random.shuffle(relevant_indices)
    split = int(len(relevant_indices) * 0.8) #split at 80%

    # split into training and validation indices
    relevant_train_indices, relevant_val_indices = relevant_indices[:split], relevant_indices[split:]
    train_sampler = SubsetRandomSampler(relevant_train_indices)
    train_loader = torch.utils.data.DataLoader(trainset, batch_size=batch_size,
                                               num_workers=1, sampler=train_sampler)
    val_sampler = SubsetRandomSampler(relevant_val_indices)
    val_loader = torch.utils.data.DataLoader(trainset, batch_size=batch_size,
                                             num_workers=1, sampler=val_sampler)
    # Load CIFAR10 testing data
    testset = torchvision.datasets.CIFAR10(root='./data', train=False,
                                           download=True, transform=transform)
    # Get the list of indices to sample from
    relevant_test_indices = get_relevant_indices(testset, classes, target_classes)
    test_sampler = SubsetRandomSampler(relevant_test_indices)
    test_loader = torch.utils.data.DataLoader(testset, batch_size=batch_size,
                                              num_workers=1, sampler=test_sampler)
    return train_loader, val_loader, test_loader, classes

################################################################################
# Training
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
```

```
94
95 def normalize_label(labels):
96     """
97     Given a tensor containing 2 possible values, normalize this to 0/1
98
99     Args:
100         labels: a 1D tensor containing two possible scalar values
101     Returns:
102         A tensor normalize to 0/1 value
103     """
104     max_val = torch.max(labels)
105     min_val = torch.min(labels)
106     norm_labels = (labels - min_val)/(max_val - min_val)
107     return norm_labels
108
109 def evaluate(net, loader, criterion):
110     """ Evaluate the network on the validation set.
111
112      Args:
113          net: PyTorch neural network object
114          loader: PyTorch data loader for the validation set
115          criterion: The loss function
116      Returns:
117          err: A scalar for the avg classification error over the validation set
118          loss: A scalar for the average loss function over the validation set
119      """
120     total_loss = 0.0
121     total_err = 0.0
122     total_epoch = 0
123     for i, data in enumerate(loader, 0):
124         inputs, labels = data
125         labels = normalize_label(labels)  # Convert labels to 0/1
126         outputs = net(inputs)
127         loss = criterion(outputs, labels.float())
128         corr = (outputs > 0.0).squeeze().long() != labels
129         total_err += int(corr.sum())
130         total_loss += loss.item()
131         total_epoch += len(labels)
132     err = float(total_err) / total_epoch
133     loss = float(total_loss) / (i + 1)
134     return err, loss
135
136 ##############################################################################
137 # Training Curve
138 def plot_training_curve(path):
139     """ Plots the training curve for a model run, given the csv files
140     containing the train/validation error/loss.
141
142     Args:
143         path: The base path of the csv files produced during training
144     """
145     import matplotlib.pyplot as plt
146     train_err = np.loadtxt("{}_train_err.csv".format(path))
147     val_err = np.loadtxt("{}_val_err.csv".format(path))
148     train_loss = np.loadtxt("{}_train_loss.csv".format(path))
149     val_loss = np.loadtxt("{}_val_loss.csv".format(path))
150     plt.title("Train vs Validation Error")
151     n = len(train_err) # number of epochs
152     plt.plot(range(1,n+1), train_err, label="Train")
153     plt.plot(range(1,n+1), val_err, label="Validation")
154     plt.xlabel("Epoch")
155     plt.ylabel("Error")
156     plt.legend(loc='best')
157     plt.show()
158     plt.title("Train vs Validation Loss")
159     plt.plot(range(1,n+1), train_loss, label="Train")
160     plt.plot(range(1,n+1), val_loss, label="Validation")
161     plt.xlabel("Epoch")
162     plt.ylabel("Loss")
163     plt.legend(loc='best')
164     plt.show()
```

Part 1. Visualizing the Data [7 pt]

We will make use of some of the CIFAR-10 data set, which consists of colour images of size 32x32 pixels belonging to 10 categories. You can find out more about the dataset at https://www.cs.toronto.edu/~kriz/cifar.html

For this assignment, we will only be using the cat and dog categories. We have included code that automatically downloads the dataset the first time that the main script is run.

```
# This will download the CIFAR-10 dataset to a folder called "data"
# the first time you run this code.
train_loader, val_loader, test_loader, classes = get_data_loader(
    target_classes=["cat", "dog"],
    batch_size=1) # One image per batch
```

```
Downloading https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz to ./data/cifar-10-python.t
100%                                          170498071/170498071 [00:02<00:00, 60502398.32it/s]
Extracting ./data/cifar-10-python.tar.gz to ./data
Files already downloaded and verified
```

Part (a) -- 1 pt

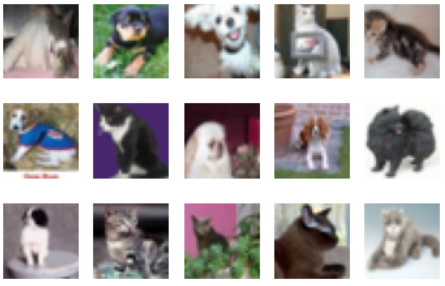
Visualize some of the data by running the code below. Include the visualization in your writeup.

(You don't need to submit anything else.)

```
import matplotlib.pyplot as plt

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:
        break
```



Part (b) -- 3 pt

How many training examples do we have for the combined `cat` and `dog` classes? What about validation examples? What about test examples?

```
len(train_loader.dataset), len(val_loader.dataset), len(test_loader.dataset)
```

Show hidden output

There is 50000+50000+10000 samples, which is a total of 110000 samples

Part (c) -- 3pt

Why do we need a validation set when training our model? What happens if we judge the performance of our models using the training set loss/error instead of the validation set loss/error?

THe validation set is used for tuning hyperparameters, e.g., learning rate, number of hidden units, layers, etc.... This is done to prevent biasing model training to optimize over the test set, which should be "out of sample" data, i.e., the test set is used to mirror new data you'd get when

deploying a model. If you tune your hyperparameters on the test set rather than the validation, then you cannot trust your test set loss to be

Part 2. Training [15 pt]

We define two neural networks, a `LargeNet` and `SmallNet`. We'll be training the networks in this section.

You won't understand fully what these networks are doing until the next few classes, and that's okay. For this assignment, please focus on learning how to train networks, and how hyperparameters affect training.

```
class LargeNet(nn.Module):
    def __init__(self):
        super(LargeNet, self).__init__()
        self.name = "large"
        self.conv1 = nn.Conv2d(3, 5, 5)
        self.pool = nn.MaxPool2d(2, 2)
        self.conv2 = nn.Conv2d(5, 10, 5)
        self.fc1 = nn.Linear(10 * 5 * 5, 32)
        self.fc2 = nn.Linear(32, 1)

    def forward(self, x):
        x = self.pool(F.relu(self.conv1(x)))
        x = self.pool(F.relu(self.conv2(x)))
        x = x.view(-1, 10 * 5 * 5)
        x = F.relu(self.fc1(x))
        x = self.fc2(x)
        x = x.squeeze(1) # Flatten to [batch_size]
        return x
```

```
class SmallNet(nn.Module):
    def __init__(self):
        super(SmallNet, self).__init__()
        self.name = "small"
        self.conv = nn.Conv2d(3, 5, 3)
        self.pool = nn.MaxPool2d(2, 2)
        self.fc = nn.Linear(5 * 7 * 7, 1)

    def forward(self, x):
        x = self.pool(F.relu(self.conv(x)))
        x = self.pool(x)
        x = x.view(-1, 5 * 7 * 7)
        x = self.fc(x)
        x = x.squeeze(1) # Flatten to [batch_size]
        return x
```

```
small_net = SmallNet()
large_net = LargeNet()
```

Part (a) -- 2pt

The methods `small_net.parameters()` and `large_net.parameters()` produces an iterator of all the trainable parameters of the network. These parameters are torch tensors containing many scalar values.

We haven't learned how how the parameters in these high-dimensional tensors will be used, but we should be able to count the number of parameters. Measuring the number of parameters in a network is one way of measuring the "size" of a network.

What is the total number of parameters in `small_net` and in `large_net`? (Hint: how many numbers are in each tensor?)

```
for param in small_net.parameters():
    print(param.shape)
```

Show hidden output

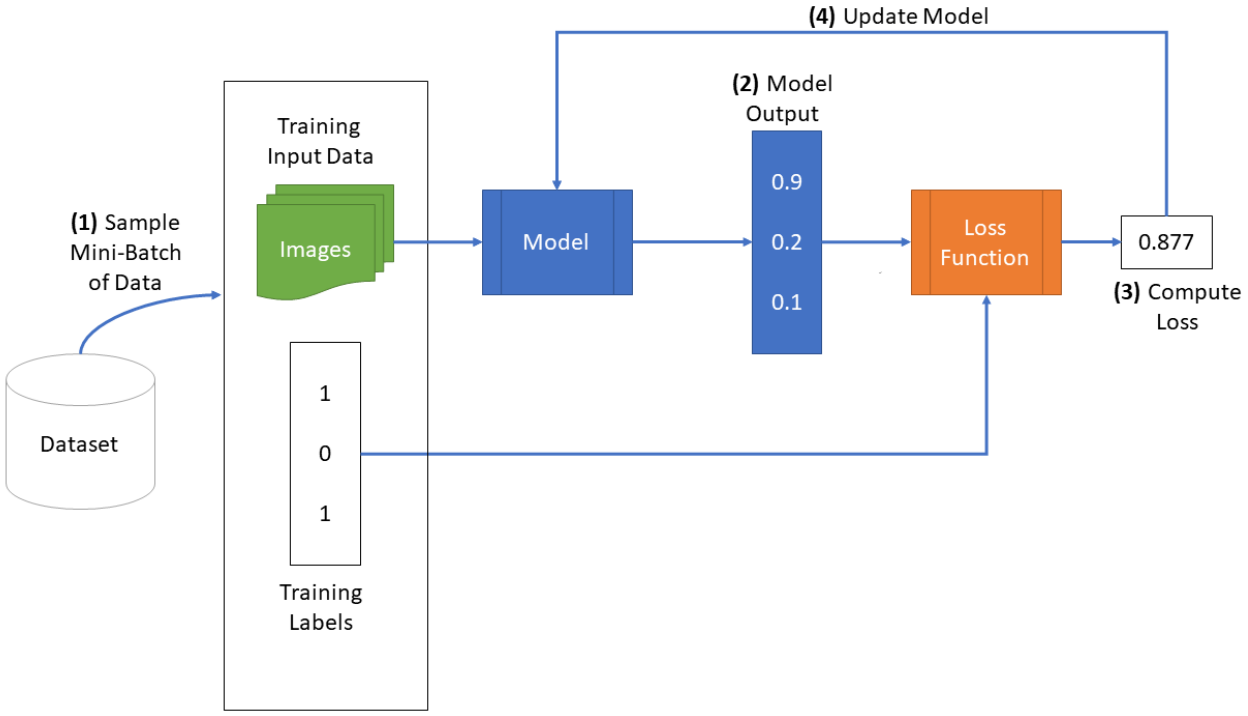
```
for param in large_net.parameters():
    print(param.shape)
```

```
torch.Size([5, 3, 5, 5])
torch.Size([5])
torch.Size([10, 5, 5, 5])
torch.Size([10])
torch.Size([32, 250])
torch.Size([32])
torch.Size([1, 32])
torch.Size([1])
```

From above, we see that small net has a total of $5 \times 3 \times 3 \times 3 + 5 + 245 + 1 = 386$ parameters, while large net has a total of $5 \times 3 \times 5 \times 5 + 5 + 10 \times 5^3 + 10 + 32 \times 250 + 32 + 32 + 1 = 9705$ parameters.

The function train_net

The function `train_net` below takes an untrained neural network (like `small_net` and `large_net`) and several other parameters. You should be able to understand how this function works. The figure below shows the high level training loop for a machine learning model:




```
def train_net(net, batch_size=64, learning_rate=0.01, num_epochs=30):
    ########################################################################
    # Train a classifier on cats vs dogs
    target_classes = ["cat", "dog"]
    ########################################################################
    # Fixed PyTorch random seed for reproducible result
    torch.manual_seed(1000)
    ########################################################################
    # Obtain the PyTorch data loader objects to load batches of the datasets
    train_loader, val_loader, test_loader, classes = get_data_loader(
            target_classes, batch_size)
    ########################################################################
    # Define the Loss function and optimizer
    # The loss function will be Binary Cross Entropy (BCE). In this case we
    # will use the BCEWithLogitsLoss which takes unnormalized output from
    # the neural network and scalar label.
    # Optimizer will be SGD with Momentum.
    criterion = nn.BCEWithLogitsLoss()
    optimizer = optim.SGD(net.parameters(), lr=learning_rate, momentum=0.9)
    ########################################################################
    # 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
            labels = normalize_label(labels) # Convert labels to 0/1
            # Zero the parameter gradients
            optimizer.zero_grad()
            # Forward pass, backward pass, and optimize
            outputs = net(inputs)
            loss = criterion(outputs, labels.float())
            loss.backward()
            optimizer.step()
            # Calculate the statistics
            corr = (outputs > 0.0).squeeze().long() != 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
        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)
    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 (b) -- 1pt

The parameters to the function `train_net` are hyperparameters of our neural network. We made these hyperparameters easy to modify so that we can tune them later on.

What are the default values of the parameters `batch_size`, `learning_rate`, and `num_epochs`?

The default parameters for `batch_size`, `learning_rate`, and `num_epochs` respectively are: $64, 0.01, 30$.

Part (c) -- 3 pt

What files are written to disk when we call `train_net` with `small_net`, and train for 5 epochs? Provide a list of all the files written to disk, and what information the files contain.

We have the following files:

1. The model state dictionary that can be used to reinitalize the model: `model_small_bs64_lr0.01_epoch4`
2. Training error vector over epochs: `model_small_bs64_lr0.01_epoch4_train_err.csv`
3. Training loss vector over epochs `model_small_bs64_lr0.01_epoch4_train_loss.csv`
4. Validation err vector over epochs `model_small_bs64_lr0.01_epoch4_val_err.csv`
5. Validation loss vector over epochs `model_small_bs64_lr0.01_epoch4_val_loss.csv`

Note: we use the following formatting: model_small_bs64_lr0.01_epoch4

Part (d) -- 2pt

Train both `small_net` and `large_net` using the function `train_net` and its default parameters. The function will write many files to disk, including a model checkpoint (saved values of model weights) at the end of each epoch.

If you are using Google Colab, you will need to mount Google Drive so that the files generated by `train_net` gets saved. We will be using these files in part (d). (See the Google Colab tutorial for more information about this.)

Report the total time elapsed when training each network. Which network took longer to train? Why?

```
# Since the function writes files to disk, you will need to mount
# your Google Drive. If you are working on the lab locally, you
# can comment out this code.

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

```
small_net_trained = train_net(small_net)
large_net_trained = train_net(large_net)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.42075, Train loss: 0.6723377504348755 |Validation err: 0.3945, Validation loss: 0.6595788542181253
Epoch 2: Train err: 0.372125, Train loss: 0.6458917841911316 |Validation err: 0.383, Validation loss: 0.6515465062111616
Epoch 3: Train err: 0.343125, Train loss: 0.6254546680450439 |Validation err: 0.3425, Validation loss: 0.6258589867502451
Epoch 4: Train err: 0.337125, Train loss: 0.609498464345932 |Validation err: 0.369, Validation loss: 0.6355494987219572
Epoch 5: Train err: 0.322375, Train loss: 0.5989378657341003 |Validation err: 0.3405, Validation loss: 0.6206743214279413
Epoch 6: Train err: 0.310875, Train loss: 0.5884755213260651 |Validation err: 0.326, Validation loss: 0.6120300143957138
Epoch 7: Train err: 0.310625, Train loss: 0.5866070160865784 |Validation err: 0.321, Validation loss: 0.6046791933476925
Epoch 8: Train err: 0.307125, Train loss: 0.5793938844203949 |Validation err: 0.324, Validation loss: 0.6076856087893248
Epoch 9: Train err: 0.304375, Train loss: 0.5793318803310394 |Validation err: 0.32, Validation loss: 0.6107112914323807
Epoch 10: Train err: 0.298375, Train loss: 0.5729791498184205 |Validation err: 0.324, Validation loss: 0.5990636218339205
Epoch 11: Train err: 0.30175, Train loss: 0.5721399612426757 |Validation err: 0.315, Validation loss: 0.6016753632575274
Epoch 12: Train err: 0.29725, Train loss: 0.5668565320968628 |Validation err: 0.324, Validation loss: 0.6089460058137774
Epoch 13: Train err: 0.296375, Train loss: 0.5697250504493714 |Validation err: 0.3175, Validation loss: 0.6021875496953726
Epoch 14: Train err: 0.291625, Train loss: 0.5643618679046631 |Validation err: 0.3315, Validation loss: 0.6197572741657495
Epoch 15: Train err: 0.295875, Train loss: 0.5622392120361328 |Validation err: 0.323, Validation loss: 0.6083460543304682
Epoch 16: Train err: 0.297375, Train loss: 0.5666043102741242 |Validation err: 0.3185, Validation loss: 0.6069362768903375
Epoch 17: Train err: 0.2915, Train loss: 0.5629100692272186 |Validation err: 0.3105, Validation loss: 0.5950558912009001
Epoch 18: Train err: 0.2915, Train loss: 0.5594740123748779 |Validation err: 0.314, Validation loss: 0.5971398083493114
Epoch 19: Train err: 0.286625, Train loss: 0.5555289885997772 |Validation err: 0.3195, Validation loss: 0.6096482370048761
Epoch 20: Train err: 0.288625, Train loss: 0.5552017977237701 |Validation err: 0.3085, Validation loss: 0.597175769507885
Epoch 21: Train err: 0.290625, Train loss: 0.5562412028312683 |Validation err: 0.3075, Validation loss: 0.5909940749406815
Epoch 22: Train err: 0.288375, Train loss: 0.5543886396884918 |Validation err: 0.316, Validation loss: 0.6057861195877194
Epoch 23: Train err: 0.283125, Train loss: 0.5535137028694153 |Validation err: 0.3095, Validation loss: 0.5987622132524848
Epoch 24: Train err: 0.283875, Train loss: 0.5503103513717651 |Validation err: 0.3045, Validation loss: 0.5935934986919165
Epoch 25: Train err: 0.28025, Train loss: 0.5479731974601746 |Validation err: 0.3045, Validation loss: 0.5936530018225312
Epoch 26: Train err: 0.27925, Train loss: 0.5494892387390137 |Validation err: 0.301, Validation loss: 0.5884830839931965
Epoch 27: Train err: 0.2785, Train loss: 0.5470522263050079 |Validation err: 0.311, Validation loss: 0.6042452156543732
Epoch 28: Train err: 0.2815, Train loss: 0.5472548701763154 |Validation err: 0.301, Validation loss: 0.5863441815599799
Epoch 29: Train err: 0.2795, Train loss: 0.5473523101806641 |Validation err: 0.309, Validation loss: 0.6027381829917431
Epoch 30: Train err: 0.2745, Train loss: 0.5447670686244964 |Validation err: 0.302, Validation loss: 0.5936911879107356
Finished Training
Total time elapsed: 120.52 seconds
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.46125, Train loss: 0.6916171078681945 |Validation err: 0.443, Validation loss: 0.6835415046662092
Epoch 2: Train err: 0.430625, Train loss: 0.6798879141807557 |Validation err: 0.415, Validation loss: 0.6774508208036423
Epoch 3: Train err: 0.401375, Train loss: 0.6661484107971192 |Validation err: 0.3685, Validation loss: 0.6517221424728632
Epoch 4: Train err: 0.375875, Train loss: 0.6487688703536987 |Validation err: 0.3665, Validation loss: 0.6480504535138607
Epoch 5: Train err: 0.353625, Train loss: 0.6338096480369568 |Validation err: 0.3505, Validation loss: 0.6348792873322964
Epoch 6: Train err: 0.344375, Train loss: 0.6208558247089386 |Validation err: 0.343, Validation loss: 0.6203478295356035
Epoch 7: Train err: 0.333125, Train loss: 0.6081179265975952 |Validation err: 0.342, Validation loss: 0.6148544475436211
Epoch 8: Train err: 0.32, Train loss: 0.5924234871864319 |Validation err: 0.356, Validation loss: 0.6236894335597754
Epoch 9: Train err: 0.313, Train loss: 0.5872985486984252 |Validation err: 0.3445, Validation loss: 0.610544616356492
Epoch 10: Train err: 0.300625, Train loss: 0.568794233083725 |Validation err: 0.329, Validation loss: 0.6003457447513938
Epoch 11: Train err: 0.29025, Train loss: 0.5581837718486786 |Validation err: 0.3205, Validation loss: 0.6016701087355614
Epoch 12: Train err: 0.28125, Train loss: 0.547592334985733 |Validation err: 0.319, Validation loss: 0.5911015504971147
Epoch 13: Train err: 0.278375, Train loss: 0.5375853321552276 |Validation err: 0.306, Validation loss: 0.5952251544222236
Epoch 14: Train err: 0.268125, Train loss: 0.5255287497043609 |Validation err: 0.304, Validation loss: 0.5920366067439318
Epoch 15: Train err: 0.256125, Train loss: 0.5139626488685608 |Validation err: 0.2945, Validation loss: 0.6061807116493583
Epoch 16: Train err: 0.25775, Train loss: 0.5116786625385285 |Validation err: 0.3015, Validation loss: 0.6064690677449107
Epoch 17: Train err: 0.244, Train loss: 0.49486677432060244 |Validation err: 0.301, Validation loss: 0.5971814813092351
Epoch 18: Train err: 0.2345, Train loss: 0.4801792130470276 |Validation err: 0.2965, Validation loss: 0.5946418670937419
Epoch 19: Train err: 0.234125, Train loss: 0.4754448218345642 |Validation err: 0.3165, Validation loss: 0.6154889222234488
Epoch 20: Train err: 0.223625, Train loss: 0.4621390643119812 |Validation err: 0.3165, Validation loss: 0.6338241305202246
Epoch 21: Train err: 0.220875, Train loss: 0.464368599653244 |Validation err: 0.3125, Validation loss: 0.6164801139384508
Epoch 22: Train err: 0.209625, Train loss: 0.4436914005279541 |Validation err: 0.3, Validation loss: 0.6328806057572365
```

Small net took 120 seconds to train, while large net took 130 seconds. Large net should take longer since it has more parameters, meaning it is requires more operations for the processor to perform gradient descent updates and gradient calculations.

Part (e) - 2pt

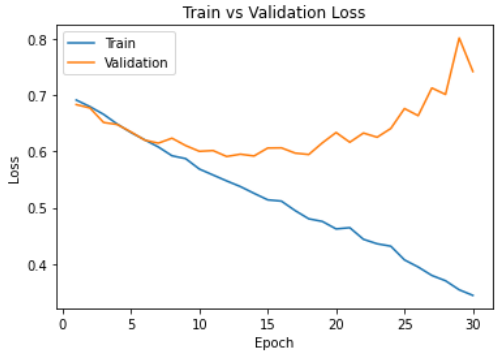
Use the function `plot_training_curve` to display the trajectory of the training/validation error and the training/validation loss. You will need to use the function `get_model_name` to generate the argument to the `plot_training_curve` function.

Do this for both the small network and the large network. Include both plots in your writeup.

```
model_path = get_model_name("small", batch_size=64, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```

Show hidden output

```
model_path = get_model_name("large", batch_size=64, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```



Part (f) - 5pt

Describe what you notice about the training curve. How do the curves differ for `small_net` and `large_net`? Identify any occurences of underfitting and overfitting.

We see that for the small net, the training/validation loss curves look fairly well behaved. In that, the loss still appears to be going for both the validation and training curves, while the error very much is still going down. This means we may still have a somewhat underfit model on the small net, and could require further training. However, on the large net, we see that while the training loss rapidly decreases, the validation loss is going up rapidly too, and the validation error is starting to increase, despite a decreasing training error. This is textbook overfitting as we are memorizing the data noise on the training set for the large net.

Part 3. Optimization Parameters [12 pt]

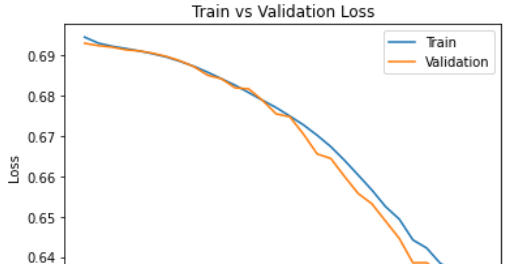
For this section, we will work with `large_net` only.

Part (a) - 3pt

Train `large_net` with all default parameters, except set `learning_rate=0.001`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *lowering* the learning rate.

```
# Note: When we re-construct the model, we start the training
# with *random weights*. If we omit this code, the values of
# the weights will still be the previously trained values.
large_net = LargeNet()
large_net_small_lr = train_net(large_net, learning_rate=0.001)
model_path = get_model_name("large", batch_size=64, learning_rate=0.001, epoch=29)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.50225, Train loss: 0.6945205240249633 |Validation err: 0.491, Validation
Epoch 2: Train err: 0.50225, Train loss: 0.6930275931358337 |Validation err: 0.491, Validation
Epoch 3: Train err: 0.487375, Train loss: 0.6922533187866211 |Validation err: 0.4765, Validatio
Epoch 4: Train err: 0.448625, Train loss: 0.6916869764328003 |Validation err: 0.4515, Validatio
Epoch 5: Train err: 0.44225, Train loss: 0.6910718812942505 |Validation err: 0.4415, Validation
Epoch 6: Train err: 0.44025, Train loss: 0.6903757758140564 |Validation err: 0.437, Validation
Epoch 7: Train err: 0.43825, Train loss: 0.6895534009933472 |Validation err: 0.434, Validation
Epoch 8: Train err: 0.439, Train loss: 0.6884737334251404 |Validation err: 0.434, Validation lo
Epoch 9: Train err: 0.44175, Train loss: 0.6872530660629272 |Validation err: 0.4295, Validation
Epoch 10: Train err: 0.437875, Train loss: 0.6858069658279419 |Validation err: 0.434, Validatio
Epoch 11: Train err: 0.4345, Train loss: 0.6841950092315674 |Validation err: 0.4205, Validation
Epoch 12: Train err: 0.4345, Train loss: 0.6825841746330261 |Validation err: 0.419, Validation
Epoch 13: Train err: 0.43225, Train loss: 0.6807464566230774 |Validation err: 0.4175, Validatio
Epoch 14: Train err: 0.42825, Train loss: 0.6788556156158447 |Validation err: 0.4175, Validatio
Epoch 15: Train err: 0.424, Train loss: 0.6770424566268921 |Validation err: 0.413, Validation l
Epoch 16: Train err: 0.418125, Train loss: 0.6749243412017822 |Validation err: 0.4065, Validati
Epoch 17: Train err: 0.417125, Train loss: 0.6727307920455933 |Validation err: 0.4115, Validati
Epoch 18: Train err: 0.40875, Train loss: 0.6701569061279297 |Validation err: 0.4005, Validatio
Epoch 19: Train err: 0.39925, Train loss: 0.6673338022232056 |Validation err: 0.3945, Validatio
Epoch 20: Train err: 0.391, Train loss: 0.663942033290863 |Validation err: 0.391, Validation lo
Epoch 21: Train err: 0.39, Train loss: 0.6602936053276062 |Validation err: 0.382, Validation lo
Epoch 22: Train err: 0.38175, Train loss: 0.6565788884162903 |Validation err: 0.376, Validation
Epoch 23: Train err: 0.373375, Train loss: 0.6524632716178894 |Validation err: 0.37, Validation
Epoch 24: Train err: 0.371625, Train loss: 0.6493743572235108 |Validation err: 0.3585, Validati
Epoch 25: Train err: 0.365625, Train loss: 0.6442021884918213 |Validation err: 0.363, Validatio
Epoch 26: Train err: 0.36525, Train loss: 0.6422023077011109 |Validation err: 0.3655, Validatio
Epoch 27: Train err: 0.362, Train loss: 0.6383951888084411 |Validation err: 0.359, Validation l
Epoch 28: Train err: 0.358125, Train loss: 0.6363182072639465 |Validation err: 0.354, Validatio
Epoch 29: Train err: 0.35375, Train loss: 0.634887017250061 |Validation err: 0.35, Validation l
Epoch 30: Train err: 0.3545, Train loss: 0.6319920964241028 |Validation err: 0.357, Validation
Finished Training
Total time elapsed: 133.02 seconds
```



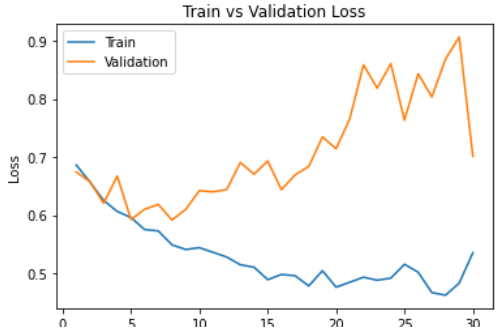
Training took roughly the same amount of time, i.e., 130 seconds vs 133 seconds.This makes sense as we are just multiplying the gradient computation by a smaller amount, so the operations are the same. However, we do see that the loss curves are much better behaved, i.e., we haven't started to overfit yet, and it appears that we can keep training the model (currently underfit). The training error is higher while the validation error is about the same as the default parameters. The loss curves are also a lot smoother as we don't "bounce" around the loss landscape nearly as much with a smaller learning rate.

Part (b) - 3pt

Train `large_net` with all default parameters, except set `learning_rate=0.1`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *increasing* the learning rate.

```
large_net = LargeNet()
large_net_large_lr = train_net(large_net, learning_rate=0.1)
model_path = get_model_name("large", batch_size=64, learning_rate=0.1, epoch=29)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.467625, Train loss: 0.6861868515014649 |Validation err: 0.4215, Validatio
Epoch 2: Train err: 0.39, Train loss: 0.6569749841690063 |Validation err: 0.391, Validation los
Epoch 3: Train err: 0.355125, Train loss: 0.6253251066207886 |Validation err: 0.3505, Validatio
Epoch 4: Train err: 0.329125, Train loss: 0.606244039773941 |Validation err: 0.3575, Validation
Epoch 5: Train err: 0.326, Train loss: 0.5957692120075225 |Validation err: 0.334, Validation lo
Epoch 6: Train err: 0.303375, Train loss: 0.575137921333313 |Validation err: 0.3205, Validation
Epoch 7: Train err: 0.304, Train loss: 0.5726823313236237 |Validation err: 0.317, Validation lo
Epoch 8: Train err: 0.288625, Train loss: 0.5487984850406646 |Validation err: 0.323, Validation
Epoch 9: Train err: 0.284375, Train loss: 0.540764660358429 |Validation err: 0.332, Validation
Epoch 10: Train err: 0.28525, Train loss: 0.543907998085022 |Validation err: 0.344, Validation
Epoch 11: Train err: 0.276, Train loss: 0.5359194176197052 |Validation err: 0.3245, Validation
Epoch 12: Train err: 0.266875, Train loss: 0.527840470790863 |Validation err: 0.3135, Validatio
Epoch 13: Train err: 0.263625, Train loss: 0.5145214052200318 |Validation err: 0.316, Validatio
Epoch 14: Train err: 0.257, Train loss: 0.5103720374107361 |Validation err: 0.3115, Validation
Epoch 15: Train err: 0.24025, Train loss: 0.4889113302230835 |Validation err: 0.3165, Validatio
Epoch 16: Train err: 0.250375, Train loss: 0.49782308340072634 |Validation err: 0.337, Validati
Epoch 17: Train err: 0.245125, Train loss: 0.4957301735877991 |Validation err: 0.3245, Validati
Epoch 18: Train err: 0.237375, Train loss: 0.4781391134262085 |Validation err: 0.3275, Validati
Epoch 19: Train err: 0.2505, Train loss: 0.5043014485836029 |Validation err: 0.349, Validation
Epoch 20: Train err: 0.233625, Train loss: 0.47596864688396456 |Validation err: 0.3285, Validat
Epoch 21: Train err: 0.241375, Train loss: 0.48449467778205874 |Validation err: 0.342, Validati
Epoch 22: Train err: 0.24725, Train loss: 0.4931287405490875 |Validation err: 0.332, Validation
Epoch 23: Train err: 0.241625, Train loss: 0.48796604776382446 |Validation err: 0.3305, Validat
Epoch 24: Train err: 0.24925, Train loss: 0.4914700272083282 |Validation err: 0.3425, Validatio
Epoch 25: Train err: 0.266125, Train loss: 0.5153710978031159 |Validation err: 0.331, Validatio
Epoch 26: Train err: 0.25825, Train loss: 0.5016732423305511 |Validation err: 0.3445, Validatio
Epoch 27: Train err: 0.236875, Train loss: 0.4666298909187317 |Validation err: 0.346, Validatio
Epoch 28: Train err: 0.237375, Train loss: 0.4621445622444153 |Validation err: 0.345, Validatio
Epoch 29: Train err: 0.2405, Train loss: 0.4829731698036194 |Validation err: 0.3515, Validation
Epoch 30: Train err: 0.2805, Train loss: 0.5351826040744782 |Validation err: 0.389, Validation
Finished Training
Total time elapsed: 128.78 seconds
```



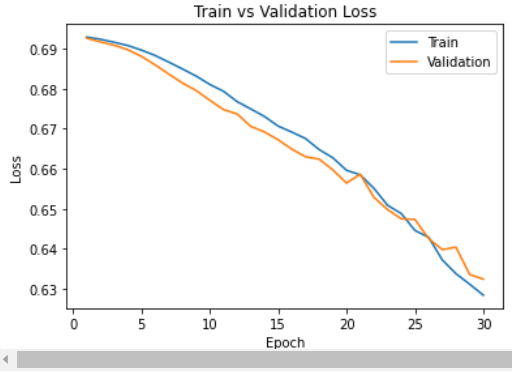
Training took roughly the same amount of time, i.e., 130 seconds vs 128 seconds.This makes sense as we are just multiplying the gradient computation by a smaller amount, so the operations are the same. However, we do see that the loss curves are poorly behaved in that the validation loss is going up quite a bit, and even the training loss is too. This is also a very unstable curve since the loss curves are not smoother, which is due to the optimizer "bouncing" around the loss landscape when the learning rate is too high (steps towards the global minima are too large). Also the model is overfit as training error is much lower than the validation error and both are going up.

Part (c) - 3pt

Train `large_net` with all default parameters, including with `learning_rate=0.01`. Now, set `batch_size=512`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *increasing* the batch size.

```
large_net = LargeNet()
large_net_large_batch = train_net(large_net, batch_size=512)
model_path = get_model_name("large", batch_size=512, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.48175, Train loss: 0.6929379552602768 |Validation err: 0.478, Validation
Epoch 2: Train err: 0.457625, Train loss: 0.6924104019999504 |Validation err: 0.434, Validation
Epoch 3: Train err: 0.437, Train loss: 0.6916500590741634 |Validation err: 0.4265, Validation l
Epoch 4: Train err: 0.433625, Train loss: 0.6908449940383434 |Validation err: 0.424, Validation
Epoch 5: Train err: 0.434, Train loss: 0.6896935552358627 |Validation err: 0.424, Validation lo
Epoch 6: Train err: 0.438, Train loss: 0.688353206962347 |Validation err: 0.4285, Validation lo
Epoch 7: Train err: 0.439375, Train loss: 0.6866871677339077 |Validation err: 0.426, Validation
Epoch 8: Train err: 0.43525, Train loss: 0.6849770769476891 |Validation err: 0.4115, Validation
Epoch 9: Train err: 0.42375, Train loss: 0.6832009293138981 |Validation err: 0.414, Validation
Epoch 10: Train err: 0.421, Train loss: 0.6811089366674423 |Validation err: 0.416, Validation l
Epoch 11: Train err: 0.420875, Train loss: 0.6794026419520378 |Validation err: 0.4095, Validati
Epoch 12: Train err: 0.41475, Train loss: 0.6768048219382763 |Validation err: 0.412, Validation
Epoch 13: Train err: 0.4105, Train loss: 0.6749702803790569 |Validation err: 0.412, Validation
Epoch 14: Train err: 0.407125, Train loss: 0.6730880849063396 |Validation err: 0.4125, Validati
Epoch 15: Train err: 0.4005, Train loss: 0.6706806942820549 |Validation err: 0.4105, Validation
Epoch 16: Train err: 0.397625, Train loss: 0.6691771410405636 |Validation err: 0.405, Validatio
Epoch 17: Train err: 0.393875, Train loss: 0.6675694733858109 |Validation err: 0.401, Validatio
Epoch 18: Train err: 0.393, Train loss: 0.6648042872548103 |Validation err: 0.3945, Validation
Epoch 19: Train err: 0.38625, Train loss: 0.662746611982584 |Validation err: 0.388, Validation
Epoch 20: Train err: 0.38175, Train loss: 0.6596181839704514 |Validation err: 0.4005, Validatio
Epoch 21: Train err: 0.38575, Train loss: 0.6584899798035622 |Validation err: 0.3885, Validatio
Epoch 22: Train err: 0.378125, Train loss: 0.655123382806778 |Validation err: 0.3855, Validatio
Epoch 23: Train err: 0.372125, Train loss: 0.6508794128894806 |Validation err: 0.3835, Validati
Epoch 24: Train err: 0.37675, Train loss: 0.6488028429448605 |Validation err: 0.385, Validation
Epoch 25: Train err: 0.368625, Train loss: 0.6445869170129299 |Validation err: 0.382, Validatio
Epoch 26: Train err: 0.372625, Train loss: 0.6428566053509712 |Validation err: 0.3745, Validati
Epoch 27: Train err: 0.359375, Train loss: 0.6372117549180984 |Validation err: 0.379, Validatio
Epoch 28: Train err: 0.35425, Train loss: 0.6337667480111122 |Validation err: 0.3695, Validatio
Epoch 29: Train err: 0.3535, Train loss: 0.6311353109776974 |Validation err: 0.366, Validation
Epoch 30: Train err: 0.353, Train loss: 0.6283832415938377 |Validation err: 0.3675, Validation
Finished Training
Total time elapsed: 117.97 seconds
```



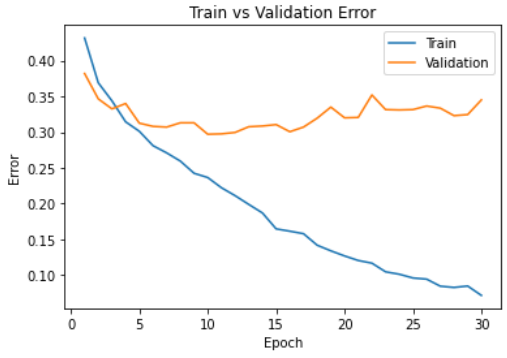
Training with a larger batch led to shorter training times, i.e., 118 seconds vs 130 seconds. Additionally, the loss curves are better behaved, i.e., they are not overfit and the validation curves closely follows that of the training curve. Also, the model doesn't overfit as fast and has more stable curves, i.e., they are smoother.

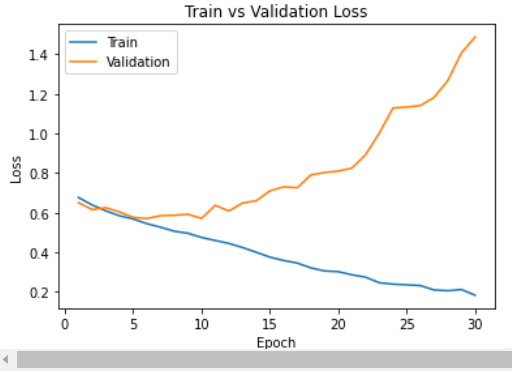
Part (d) - 3pt

Train `large_net` with all default parameters, including with `learning_rate=0.01`. Now, set `batch_size=16`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *decreasing* the batch size.

```
large_net = LargeNet()
large_net_small_batch = train_net(large_net, batch_size=16)
model_path = get_model_name("large", batch_size=16, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.43175, Train loss: 0.6774994022846222 |Validation err: 0.382, Validation
Epoch 2: Train err: 0.369, Train loss: 0.639639899969101 |Validation err: 0.3465, Validation lo
Epoch 3: Train err: 0.34375, Train loss: 0.6098222947120666 |Validation err: 0.3325, Validation
Epoch 4: Train err: 0.314375, Train loss: 0.5849691489338875 |Validation err: 0.34, Validation
Epoch 5: Train err: 0.301125, Train loss: 0.5689119303822517 |Validation err: 0.3125, Validatio
Epoch 6: Train err: 0.281, Train loss: 0.5452213581204415 |Validation err: 0.308, Validation lo
Epoch 7: Train err: 0.270875, Train loss: 0.5272981298565864 |Validation err: 0.307, Validation
Epoch 8: Train err: 0.259375, Train loss: 0.5070905526578426 |Validation err: 0.313, Validation
Epoch 9: Train err: 0.242375, Train loss: 0.4968344421982765 |Validation err: 0.313, Validation
Epoch 10: Train err: 0.236375, Train loss: 0.4756101597249508 |Validation err: 0.297, Validatio
Epoch 11: Train err: 0.222125, Train loss: 0.4599769461452961 |Validation err: 0.2975, Validati
Epoch 12: Train err: 0.211, Train loss: 0.4454492371380329 |Validation err: 0.2995, Validation
Epoch 13: Train err: 0.19875, Train loss: 0.4245421719551086 |Validation err: 0.3075, Validatio
Epoch 14: Train err: 0.18675, Train loss: 0.4007472907453775 |Validation err: 0.3085, Validatio
Epoch 15: Train err: 0.1645, Train loss: 0.3759974058121443 |Validation err: 0.3105, Validation
Epoch 16: Train err: 0.16125, Train loss: 0.3591455406397581 |Validation err: 0.3005, Validatio
Epoch 17: Train err: 0.15775, Train loss: 0.3463234790861607 |Validation err: 0.307, Validation
Epoch 18: Train err: 0.141625, Train loss: 0.32175366275012496 |Validation err: 0.3195, Validat
Epoch 19: Train err: 0.13375, Train loss: 0.30618105667084455 |Validation err: 0.335, Validatio
Epoch 20: Train err: 0.126625, Train loss: 0.3029071792438626 |Validation err: 0.32, Validation
Epoch 21: Train err: 0.12025, Train loss: 0.28682796490937473 |Validation err: 0.3205, Validati
Epoch 22: Train err: 0.1165, Train loss: 0.27489088076353074 |Validation err: 0.352, Validation
Epoch 23: Train err: 0.104375, Train loss: 0.2467898527495563 |Validation err: 0.3315, Validati
Epoch 24: Train err: 0.101, Train loss: 0.23970085787773132 |Validation err: 0.331, Validation
Epoch 25: Train err: 0.09575, Train loss: 0.23643119425699116 |Validation err: 0.3315, Validati
Epoch 26: Train err: 0.094125, Train loss: 0.2325953512713313 |Validation err: 0.3365, Validati
Epoch 27: Train err: 0.08425, Train loss: 0.21040759468451142 |Validation err: 0.3335, Validati
Epoch 28: Train err: 0.0825, Train loss: 0.20643112615589052 |Validation err: 0.323, Validation
Epoch 29: Train err: 0.0845, Train loss: 0.21273409337876364 |Validation err: 0.3245, Validatio
Epoch 30: Train err: 0.071375, Train loss: 0.18387044295761734 |Validation err: 0.345, Validati
Finished Training
Total time elapsed: 188.18 seconds
```





Training with a smaller batch led to longer training times, i.e., 188 seconds vs 130 seconds. Additionally, the loss curves are poorly behaved, i.e., they are clearly overfit (validation loss/error much higher than training loss/error and increasing while training loss/error is still decreasing). Also, while the curves are fairly smooth, the model seems to immedately overfit, meaning the optimizer is going into rather poor regions of the loss landscape that have bad local optima, where associated parameters correlate to fitting data noise.

Part 4. Hyperparameter Search [6 pt]

Part (a) - 2pt

Based on the plots from above, choose another set of values for the hyperparameters (network, batch_size, learning_rate) that you think would help you improve the validation accuracy. Justify your choice.

If we are comfortable with a longer training period, we can choose a smaller learning_rate, especially with a larger network. This helps smooth out the loss curves as we take smaller steps towards the global minima. Further, we can take a larger (but not too large) `batch_size` in order to help improve genearlization on this dataset. We should also use the large network as it has more capacity (more parameters/layers) that would help model genearlization.

So I propose:

- `learning_rate` = 0.006
- `batch_size` = 256
- `num_epochs` = 150

Part (b) - 1pt

Train the model with the hyperparameters you chose in part(a), and include the training curve.

```
large_net = LargeNet()
large_net_custom_1 = train_net(large_net, batch_size=256, learning_rate=0.006, num_epochs=150)
model_path = get_model_name("large", batch_size=256, learning_rate=0.006, epoch=149)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.47525, Train loss: 0.6928301826119423 |Validation err: 0.4635, Validation
Epoch 2: Train err: 0.448625, Train loss: 0.6920892838388681 |Validation err: 0.4395, Validatio
Epoch 3: Train err: 0.431125, Train loss: 0.6911100950092077 |Validation err: 0.416, Validation
Epoch 4: Train err: 0.430625, Train loss: 0.6896353028714657 |Validation err: 0.421, Validation
Epoch 5: Train err: 0.437625, Train loss: 0.6878515146672726 |Validation err: 0.424, Validation
Epoch 6: Train err: 0.43275, Train loss: 0.6858931612223387 |Validation err: 0.4165, Validation
Epoch 7: Train err: 0.43025, Train loss: 0.6835607439279556 |Validation err: 0.4115, Validation
Epoch 8: Train err: 0.42375, Train loss: 0.6814770270138979 |Validation err: 0.4135, Validation
Epoch 9: Train err: 0.4155, Train loss: 0.6791375018656254 |Validation err: 0.409, Validation lo
Epoch 10: Train err: 0.41325, Train loss: 0.6772175505757332 |Validation err: 0.4085, Validatio
Epoch 11: Train err: 0.41175, Train loss: 0.6741531416773796 |Validation err: 0.41, Validation
Epoch 12: Train err: 0.404875, Train loss: 0.6706440430134535 |Validation err: 0.4085, Validati
Epoch 13: Train err: 0.399625, Train loss: 0.6695251110941172 |Validation err: 0.399, Validatio
Epoch 14: Train err: 0.3955, Train loss: 0.6673812586814165 |Validation err: 0.3995, Validation
Epoch 15: Train err: 0.393, Train loss: 0.6641833987087011 |Validation err: 0.3935, Validation
Epoch 16: Train err: 0.3885, Train loss: 0.6604212839156389 |Validation err: 0.3895, Validation
Epoch 17: Train err: 0.38075, Train loss: 0.658942686393857 |Validation err: 0.396, Validation
Epoch 18: Train err: 0.377, Train loss: 0.6567721255123615 |Validation err: 0.388, Validation lo
Epoch 19: Train err: 0.3735, Train loss: 0.6510208249092102 |Validation err: 0.385, Validation
Epoch 20: Train err: 0.368, Train loss: 0.6451032403856516 |Validation err: 0.374, Validation lo
Epoch 21: Train err: 0.365125, Train loss: 0.6429767720401287 |Validation err: 0.3745, Validati
Epoch 22: Train err: 0.359875, Train loss: 0.6384326964616776 |Validation err: 0.367, Validatio
Epoch 23: Train err: 0.351875, Train loss: 0.634610041975975 |Validation err: 0.37, Validation
Epoch 24: Train err: 0.35525, Train loss: 0.6322696879506111 |Validation err: 0.3655, Validatio
Epoch 25: Train err: 0.344875, Train loss: 0.6252214908599854 |Validation err: 0.359, Validatio
Epoch 26: Train err: 0.347375, Train loss: 0.6217316184192896 |Validation err: 0.362, Validatio
Epoch 27: Train err: 0.34775, Train loss: 0.61972482688725 |Validation err: 0.352, Validation lo
Epoch 28: Train err: 0.344375, Train loss: 0.616970457136631 |Validation err: 0.3605, Validatio
Epoch 29: Train err: 0.34725, Train loss: 0.6153552904725075 |Validation err: 0.344, Validation
Epoch 30: Train err: 0.3415, Train loss: 0.6163260713219643 |Validation err: 0.34, Validation lo
Epoch 31: Train err: 0.338, Train loss: 0.6108253505080938 |Validation err: 0.3385, Validation
Epoch 32: Train err: 0.33525, Train loss: 0.6062465161085129 |Validation err: 0.3345, Validatio
Epoch 33: Train err: 0.332125, Train loss: 0.6036703959107399 |Validation err: 0.3425, Validati
Epoch 34: Train err: 0.329125, Train loss: 0.6026168316602707 |Validation err: 0.3295, Validati
Epoch 35: Train err: 0.32525, Train loss: 0.5965587478131056 |Validation err: 0.3315, Validatio
Epoch 36: Train err: 0.323, Train loss: 0.58942985907197 |Validation err: 0.325, Validation los
Epoch 37: Train err: 0.318625, Train loss: 0.5935651641339064 |Validation err: 0.332, Validatio
Epoch 38: Train err: 0.317375, Train loss: 0.5899881776422262 |Validation err: 0.322, Validatio
Epoch 39: Train err: 0.314625, Train loss: 0.5820056162774563 |Validation err: 0.317, Validatio
Epoch 40: Train err: 0.31, Train loss: 0.5779258571565151 |Validation err: 0.3275, Validation lo
Epoch 41: Train err: 0.3075, Train loss: 0.5769532769918442 |Validation err: 0.323, Validation
Epoch 42: Train err: 0.30625, Train loss: 0.5691406931728125 |Validation err: 0.33, Validation
Epoch 43: Train err: 0.300125, Train loss: 0.5677790101617575 |Validation err: 0.3195, Validati
Epoch 44: Train err: 0.296375, Train loss: 0.5652447436004877 |Validation err: 0.3235, Validati
Epoch 45: Train err: 0.297125, Train loss: 0.5571357104927301 |Validation err: 0.325, Validatio
Epoch 46: Train err: 0.297125, Train loss: 0.5639094654470682 |Validation err: 0.314, Validatio
Epoch 47: Train err: 0.294, Train loss: 0.5593381598591805 |Validation err: 0.313, Validation lo
Epoch 48: Train err: 0.289125, Train loss: 0.5498161353170872 |Validation err: 0.315, Validatio
Epoch 49: Train err: 0.286, Train loss: 0.5449566459283233 |Validation err: 0.3115, Validation
Epoch 50: Train err: 0.284125, Train loss: 0.5410005338490009 |Validation err: 0.3105, Validati
Epoch 51: Train err: 0.275375, Train loss: 0.5423429952934384 |Validation err: 0.313, Validatio
Epoch 52: Train err: 0.281, Train loss: 0.5421533472836018 |Validation err: 0.307, Validation lo
Epoch 53: Train err: 0.276625, Train loss: 0.5388263547793031 |Validation err: 0.309, Validatio
Epoch 54: Train err: 0.26775, Train loss: 0.5300652738660574 |Validation err: 0.3065, Validatio
Epoch 55: Train err: 0.268, Train loss: 0.528857572004199 |Validation err: 0.3035, Validation lo
Epoch 56: Train err: 0.26675, Train loss: 0.5262993331998587 |Validation err: 0.308, Validation
Epoch 57: Train err: 0.26575, Train loss: 0.5246628616005182 |Validation err: 0.3075, Validatio
Epoch 58: Train err: 0.261625, Train loss: 0.5234110914170742 |Validation err: 0.3045, Validati
Epoch 59: Train err: 0.26375, Train loss: 0.5187957966700196 |Validation err: 0.3055, Validatio
Epoch 60: Train err: 0.254375, Train loss: 0.5125386584550142 |Validation err: 0.308, Validatio
Epoch 61: Train err: 0.25575, Train loss: 0.5123818358406425 |Validation err: 0.304, Validation
Epoch 62: Train err: 0.251875, Train loss: 0.5100651849061251 |Validation err: 0.3125, Validati
Epoch 63: Train err: 0.251375, Train loss: 0.5070849740877748 |Validation err: 0.305, Validatio
Epoch 64: Train err: 0.25125, Train loss: 0.5057728411629796 |Validation err: 0.313, Validation
Epoch 65: Train err: 0.2495, Train loss: 0.5048461621627212 |Validation err: 0.301, Validation
Epoch 66: Train err: 0.2445, Train loss: 0.4974956065416336 |Validation err: 0.296, Validation
Epoch 67: Train err: 0.24275, Train loss: 0.4910230487585068 |Validation err: 0.308, Validation
Epoch 68: Train err: 0.238625, Train loss: 0.49132071156054735 |Validation err: 0.306, Validati
Epoch 69: Train err: 0.24375, Train loss: 0.49216268211603165 |Validation err: 0.2915, Validati
Epoch 70: Train err: 0.23675, Train loss: 0.4822801472619176 |Validation err: 0.2965, Validatio
Epoch 71: Train err: 0.23725, Train loss: 0.4832655331119895 |Validation err: 0.3105, Validatio
Epoch 72: Train err: 0.22625, Train loss: 0.48279030434787273 |Validation err: 0.297, Validatio
Epoch 73: Train err: 0.233125, Train loss: 0.4816231867298484 |Validation err: 0.286, Validatio
Epoch 74: Train err: 0.2295, Train loss: 0.47824827022850513 |Validation err: 0.306, Validation
Epoch 75: Train err: 0.228375, Train loss: 0.471593564376235 |Validation err: 0.301, Validation
Epoch 76: Train err: 0.2205, Train loss: 0.4656660743057728 |Validation err: 0.2985, Validation
Epoch 77: Train err: 0.220625, Train loss: 0.4651225982233882 |Validation err: 0.298, Validatio
Epoch 78: Train err: 0.224875, Train loss: 0.4658273411914706 |Validation err: 0.3005, Validati
Epoch 79: Train err: 0.225625, Train loss: 0.4661049945279956 |Validation err: 0.297, Validatio
Epoch 80: Train err: 0.220125, Train loss: 0.4618999632075429 |Validation err: 0.2995, Validati
Epoch 81: Train err: 0.210875, Train loss: 0.45358242373913527 |Validation err: 0.2945, Validat
Epoch 82: Train err: 0.212625, Train loss: 0.45234073232859373 |Validation err: 0.2975, Validat
Epoch 83: Train err: 0.212375, Train loss: 0.4504633955657482 |Validation err: 0.2985, Validati
Epoch 84: Train err: 0.213, Train loss: 0.4520760914310813 |Validation err: 0.3095, Validation
Epoch 85: Train err: 0.212125, Train loss: 0.44944946840405464 |Validation err: 0.2975, Validat
```

```
Epoch 85: Train err: 0.213125, Train loss: 0.44944946840405464 |Validation err: 0.2975, Validat
Epoch 86: Train err: 0.206625, Train loss: 0.4448174713179469 |Validation err: 0.3125, Validatio
Epoch 87: Train err: 0.214, Train loss: 0.449812525883317 |Validation err: 0.306, Validation lo
Epoch 88: Train err: 0.217375, Train loss: 0.4553459417074919 |Validation err: 0.3065, Validatio
Epoch 89: Train err: 0.206375, Train loss: 0.43831581622362137 |Validation err: 0.297, Validatio
Epoch 90: Train err: 0.2115, Train loss: 0.44507231935858727 |Validation err: 0.3075, Validatio
Epoch 91: Train err: 0.2035, Train loss: 0.439149240963161 |Validation err: 0.307, Validation lo
Epoch 92: Train err: 0.207125, Train loss: 0.43998841010034084 |Validation err: 0.2995, Validat
Epoch 93: Train err: 0.194, Train loss: 0.424812245182693 |Validation err: 0.295, Validation lo
Epoch 94: Train err: 0.19825, Train loss: 0.4236988201737404 |Validation err: 0.308, Validation
Epoch 95: Train err: 0.2015, Train loss: 0.4287644922733307 |Validation err: 0.3075, Validation
Epoch 96: Train err: 0.194625, Train loss: 0.42641882319003344 |Validation err: 0.302, Validatio
Epoch 97: Train err: 0.194, Train loss: 0.4200139753520489 |Validation err: 0.307, Validation lo
Epoch 98: Train err: 0.197125, Train loss: 0.4190165791660547 |Validation err: 0.3055, Validatio
Epoch 99: Train err: 0.19225, Train loss: 0.4181303260847926 |Validation err: 0.3045, Validatio
Epoch 100: Train err: 0.188625, Train loss: 0.41057868022471666 |Validation err: 0.294, Validat
Epoch 101: Train err: 0.18525, Train loss: 0.4058832749724388 |Validation err: 0.3045, Validatio
Epoch 102: Train err: 0.184125, Train loss: 0.4029556680470705 |Validation err: 0.299, Validatio
Epoch 103: Train err: 0.195375, Train loss: 0.4154032403603196 |Validation err: 0.3135, Validat
Epoch 104: Train err: 0.20125, Train loss: 0.426170002669096 |Validation err: 0.2945, Validatio
Epoch 105: Train err: 0.180125, Train loss: 0.4026267910376191 |Validation err: 0.3035, Validat
Epoch 106: Train err: 0.18525, Train loss: 0.4016262562945485 |Validation err: 0.303, Validatio
Epoch 107: Train err: 0.182875, Train loss: 0.39815902803093195 |Validation err: 0.2995, Valida
Epoch 108: Train err: 0.178875, Train loss: 0.3916069734841585 |Validation err: 0.31, Validatio
Epoch 109: Train err: 0.19125, Train loss: 0.409749967046082 |Validation err: 0.297, Validation
Epoch 110: Train err: 0.17225, Train loss: 0.3877886449918151 |Validation err: 0.3045, Validatio
Epoch 111: Train err: 0.173125, Train loss: 0.3807867141440511 |Validation err: 0.2975, Validat
Epoch 112: Train err: 0.17075, Train loss: 0.38056657556444407 |Validation err: 0.297, Validatio
Epoch 113: Train err: 0.1695, Train loss: 0.37817580811679363 |Validation err: 0.2945, Validatio
Epoch 114: Train err: 0.166125, Train loss: 0.3780082454904914 |Validation err: 0.3065, Validat
Epoch 115: Train err: 0.17575, Train loss: 0.3874451769515872 |Validation err: 0.302, Validatio
Epoch 116: Train err: 0.166875, Train loss: 0.379365854896605 |Validation err: 0.2945, Validatio
Epoch 117: Train err: 0.160375, Train loss: 0.3664812184870243 |Validation err: 0.2965, Validat
Epoch 118: Train err: 0.165, Train loss: 0.3703144369646907 |Validation err: 0.2965, Validation
Epoch 119: Train err: 0.16525, Train loss: 0.3664805442094803 |Validation err: 0.2945, Validatio
Epoch 120: Train err: 0.15825, Train loss: 0.3561297170817852 |Validation err: 0.296, Validatio
Epoch 121: Train err: 0.162625, Train loss: 0.35834966879338026 |Validation err: 0.299, Validat
Epoch 122: Train err: 0.155, Train loss: 0.35238442942500114 |Validation err: 0.2975, Validatio
Epoch 123: Train err: 0.162375, Train loss: 0.35803890973329544 |Validation err: 0.3, Validatio
Epoch 124: Train err: 0.15775, Train loss: 0.3521362356841564 |Validation err: 0.299, Validatio
Epoch 125: Train err: 0.157625, Train loss: 0.34882341884076595 |Validation err: 0.31, Validatio
```

Part (c) - 2pt

Based on your result from Part(a), suggest another set of hyperparameter values to try. Justify your choice.

```
Epoch 131: Train err: 0.140125, Train loss: 0.3234555684030056 |Validation err: 0.293, Validatio
```

The choice of hyperparameters from part a suggest that I have a seriously overfit model, especially looking at the validation loss curve. For the next set of hyperparameters, I will choose a much smaller learning rate. Specifically, I'll choose 0.002, and I'll up the batch size to 384 for faster training. Also I'll up the `num_epochs` to 300 to account for the lower learning rate.

```
Epoch 137: Train err: 0.1315, Train loss: 0.3104266319423914 |Validation err: 0.3025, Validatio
```

Part (d) - 1pt

Train the model with the hyperparameters you chose in part(c), and include the training curve.

```
Epoch 142: Train err: 0.128375, Train loss: 0.3000007342068017 |Validation err: 0.306, Validati
```

```
large_net = LargeNet()
large_net_custom_1 = train_net(large_net, batch_size=384, learning_rate=0.002, num_epochs=300)
model_path = get_model_name("large", batch_size=384, learning_rate=0.002, epoch=299)
plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.501875, Train loss: 0.6935614432607379 |Validation err: 0.4915, Validatio
Epoch 2: Train err: 0.50075, Train loss: 0.6931842735835484 |Validation err: 0.486, Validation
Epoch 3: Train err: 0.4995, Train loss: 0.6927901648339772 |Validation err: 0.466, Validation lo
Epoch 4: Train err: 0.491625, Train loss: 0.6924529529753185 |Validation err: 0.4435, Validatio
Epoch 5: Train err: 0.47975, Train loss: 0.6920922824314663 |Validation err: 0.44, Validation lo
Epoch 6: Train err: 0.47275, Train loss: 0.6917929507437206 |Validation err: 0.438, Validation
Epoch 7: Train err: 0.4645, Train loss: 0.6914707337106977 |Validation err: 0.4305, Validation
Epoch 8: Train err: 0.46475, Train loss: 0.6911416791734242 |Validation err: 0.429, Validation
Epoch 9: Train err: 0.454, Train loss: 0.6908145802361625 |Validation err: 0.425, Validation lo
Epoch 10: Train err: 0.452875, Train loss: 0.6904456785746983 |Validation err: 0.4235, Validati
Epoch 11: Train err: 0.4515, Train loss: 0.6900598435174852 |Validation err: 0.4205, Validation
Epoch 12: Train err: 0.449125, Train loss: 0.6896000081670852 |Validation err: 0.42, Validation
Epoch 13: Train err: 0.448125, Train loss: 0.689206199986594 |Validation err: 0.416, Validation
Epoch 14: Train err: 0.445875, Train loss: 0.6887184863998776 |Validation err: 0.411, Validatio
Epoch 15: Train err: 0.445125, Train loss: 0.6881674925486246 |Validation err: 0.411, Validatio
Epoch 16: Train err: 0.44275, Train loss: 0.6876884869166783 |Validation err: 0.4085, Validatio
Epoch 17: Train err: 0.441, Train loss: 0.6871288078171867 |Validation err: 0.412, Validation lo
Epoch 18: Train err: 0.43875, Train loss: 0.6865484146844774 |Validation err: 0.409, Validation
Epoch 19: Train err: 0.43775, Train loss: 0.6859708513532367 |Validation err: 0.4075, Validatio
Epoch 20: Train err: 0.434875, Train loss: 0.6853001174472627 |Validation err: 0.415, Validatio
Epoch 21: Train err: 0.4315, Train loss: 0.684616622470674 |Validation err: 0.4095, Validation
Epoch 22: Train err: 0.431375, Train loss: 0.684009333451589 |Validation err: 0.4085, Validatio
Epoch 23: Train err: 0.4305, Train loss: 0.6831680536270142 |Validation err: 0.4135, Validation
Epoch 24: Train err: 0.42825, Train loss: 0.6824065021106175 |Validation err: 0.41, Validation
Epoch 25: Train err: 0.42725, Train loss: 0.6816281846591404 |Validation err: 0.411, Validation
Epoch 26: Train err: 0.42525, Train loss: 0.6809041045960926 |Validation err: 0.4105, Validatio
Epoch 27: Train err: 0.4245, Train loss: 0.6800790627797445 |Validation err: 0.4055, Validation
Epoch 28: Train err: 0.42225, Train loss: 0.6793284274282909 |Validation err: 0.4085, Validatio
Epoch 29: Train err: 0.419625, Train loss: 0.6784559914043972 |Validation err: 0.412, Validatio
Epoch 30: Train err: 0.419, Train loss: 0.6775769733247303 |Validation err: 0.411, Validation lo
Epoch 31: Train err: 0.41725, Train loss: 0.6768558848471868 |Validation err: 0.4065, Validatio
Epoch 32: Train err: 0.414, Train loss: 0.6759738070624215 |Validation err: 0.409, Validation lo
Epoch 33: Train err: 0.410125, Train loss: 0.6749294854345775 |Validation err: 0.4055, Validati
Epoch 34: Train err: 0.407875, Train loss: 0.6742542017073858 |Validation err: 0.403, Validatio
Epoch 35: Train err: 0.405, Train loss: 0.6732088185492016 |Validation err: 0.402, Validation lo
Epoch 36: Train err: 0.404125, Train loss: 0.6723936483973548 |Validation err: 0.4015, Validati
Epoch 37: Train err: 0.4005, Train loss: 0.6714257711455935 |Validation err: 0.4, Validation lo
Epoch 38: Train err: 0.39975, Train loss: 0.6707160785084679 |Validation err: 0.399, Validation
Epoch 39: Train err: 0.39925, Train loss: 0.6695523574238732 |Validation err: 0.396, Validation
Epoch 40: Train err: 0.397875, Train loss: 0.6685675808361599 |Validation err: 0.3975, Validati
Epoch 41: Train err: 0.394125, Train loss: 0.6675098197800773 |Validation err: 0.3965, Validati
Epoch 42: Train err: 0.393, Train loss: 0.6664183111417861 |Validation err: 0.3975, Validation
Epoch 43: Train err: 0.391625, Train loss: 0.6652722500619435 |Validation err: 0.392, Validatio
Epoch 44: Train err: 0.38975, Train loss: 0.6640864213307699 |Validation err: 0.3895, Validatio
Epoch 45: Train err: 0.3875, Train loss: 0.662622006166549 |Validation err: 0.387, Validation lo
Epoch 46: Train err: 0.386625, Train loss: 0.6614572320665631 |Validation err: 0.3855, Validati
Epoch 47: Train err: 0.38625, Train loss: 0.6603661406607855 |Validation err: 0.3865, Validatio
Epoch 48: Train err: 0.381875, Train loss: 0.6591115792592367 |Validation err: 0.3805, Validati
Epoch 49: Train err: 0.3815, Train loss: 0.6579348927452451 |Validation err: 0.3815, Validation
Epoch 50: Train err: 0.379, Train loss: 0.6566029559998285 |Validation err: 0.379, Validation lo
Epoch 51: Train err: 0.377, Train loss: 0.6550732027916681 |Validation err: 0.3715, Validation
Epoch 52: Train err: 0.375, Train loss: 0.6534387611207508 |Validation err: 0.3715, Validation
Epoch 53: Train err: 0.371625, Train loss: 0.6522390019325983 |Validation err: 0.3705, Validati
Epoch 54: Train err: 0.371, Train loss: 0.6507618540809268 |Validation err: 0.3735, Validation
Epoch 55: Train err: 0.366, Train loss: 0.649889471985045 |Validation err: 0.3665, Validation lo
Epoch 56: Train err: 0.3675, Train loss: 0.6484618669464475 |Validation err: 0.3605, Validation
Epoch 57: Train err: 0.363875, Train loss: 0.6472205150695074 |Validation err: 0.3615, Validati
Epoch 58: Train err: 0.362, Train loss: 0.6450624409176055 |Validation err: 0.3655, Validation
Epoch 59: Train err: 0.36275, Train loss: 0.6440935049738202 |Validation err: 0.361, Validation
Epoch 60: Train err: 0.36025, Train loss: 0.6429301273255121 |Validation err: 0.361, Validation
Epoch 61: Train err: 0.35975, Train loss: 0.6417114961714971 |Validation err: 0.361, Validation
Epoch 62: Train err: 0.359375, Train loss: 0.6403176954814366 |Validation err: 0.3615, Validati
Epoch 63: Train err: 0.358375, Train loss: 0.6392025152842203 |Validation err: 0.358, Validatio
Epoch 64: Train err: 0.360375, Train loss: 0.6378643399193173 |Validation err: 0.359, Validatio
Epoch 65: Train err: 0.359625, Train loss: 0.6376743997846331 |Validation err: 0.359, Validatio
Epoch 66: Train err: 0.355875, Train loss: 0.6365235107285636 |Validation err: 0.362, Validatio
Epoch 67: Train err: 0.35775, Train loss: 0.6352295648484003 |Validation err: 0.363, Validation
Epoch 68: Train err: 0.35425, Train loss: 0.6353545160520644 |Validation err: 0.3605, Validatio
Epoch 69: Train err: 0.353375, Train loss: 0.6338228725251698 |Validation err: 0.3595, Validati
Epoch 70: Train err: 0.35775, Train loss: 0.6334867505800157 |Validation err: 0.361, Validation
Epoch 71: Train err: 0.35275, Train loss: 0.6319434869857061 |Validation err: 0.363, Validation
Epoch 72: Train err: 0.354, Train loss: 0.6309357824779692 |Validation err: 0.359, Validation lo
Epoch 73: Train err: 0.351875, Train loss: 0.6300177716073536 |Validation err: 0.356, Validatio
Epoch 74: Train err: 0.349125, Train loss: 0.629738137835548 |Validation err: 0.3595, Validatio
Epoch 75: Train err: 0.35275, Train loss: 0.6295832338787261 |Validation err: 0.359, Validation
Epoch 76: Train err: 0.35325, Train loss: 0.6303177873293558 |Validation err: 0.361, Validation
Epoch 77: Train err: 0.351375, Train loss: 0.6278062349274045 |Validation err: 0.357, Validatio
Epoch 78: Train err: 0.347125, Train loss: 0.6264287119820005 |Validation err: 0.358, Validatio
Epoch 79: Train err: 0.348, Train loss: 0.6258815640494937 |Validation err: 0.3585, Validation
Epoch 80: Train err: 0.34825, Train loss: 0.6251703671046666 |Validation err: 0.359, Validation
Epoch 81: Train err: 0.34625, Train loss: 0.6243969883237567 |Validation err: 0.355, Validation
Epoch 82: Train err: 0.3485, Train loss: 0.6238566495123363 |Validation err: 0.3545, Validation
Epoch 83: Train err: 0.34375, Train loss: 0.6237902839978536 |Validation err: 0.3575, Validatio
Epoch 84: Train err: 0.347125, Train loss: 0.6218883168129694 |Validation err: 0.354, Validatio
Epoch 85: Train err: 0.345625, Train loss: 0.6209398039038075 |Validation err: 0.3535, Validatio
```

```
Epoch 85: Train err: 0.345625, Train loss: 0.6209398309389/5 |Validation err: 0.3535, Validatio
Epoch 86: Train err: 0.3475, Train loss: 0.620567588579087 |Validation err: 0.35, Validation lo
Epoch 87: Train err: 0.343, Train loss: 0.6196296498889015 |Validation err: 0.3585, Validation
Epoch 88: Train err: 0.340125, Train loss: 0.6193114916483561 |Validation err: 0.3525, Validatio
Epoch 89: Train err: 0.341625, Train loss: 0.6178454444521949 |Validation err: 0.3505, Validatio
Epoch 90: Train err: 0.340625, Train loss: 0.6179101552282061 |Validation err: 0.3505, Validatio
Epoch 91: Train err: 0.3415, Train loss: 0.6166997949282328 |Validation err: 0.3515, Validation
Epoch 92: Train err: 0.342, Train loss: 0.6164319344929287 |Validation err: 0.352, Validation lo
Epoch 93: Train err: 0.3395, Train loss: 0.6160476122583661 |Validation err: 0.349, Validation
Epoch 94: Train err: 0.339125, Train loss: 0.6145682618731544 |Validation err: 0.349, Validatio
Epoch 95: Train err: 0.34275, Train loss: 0.6139400573003859 |Validation err: 0.3465, Validatio
Epoch 96: Train err: 0.3405, Train loss: 0.6128250474021548 |Validation err: 0.3485, Validation
Epoch 97: Train err: 0.335625, Train loss: 0.6122668754486811 |Validation err: 0.347, Validatio
Epoch 98: Train err: 0.33625, Train loss: 0.611500396614983 |Validation err: 0.3435, Validation
Epoch 99: Train err: 0.338, Train loss: 0.6113415105002267 |Validation err: 0.3425, Validation
Epoch 100: Train err: 0.337375, Train loss: 0.609312579745338 |Validation err: 0.345, Validatio
Epoch 101: Train err: 0.333625, Train loss: 0.6088921172278268 |Validation err: 0.349, Validatio
Epoch 102: Train err: 0.334625, Train loss: 0.6086878095354352 |Validation err: 0.342, Validatio
Epoch 103: Train err: 0.33375, Train loss: 0.607030227070763 |Validation err: 0.344, Validation
Epoch 104: Train err: 0.3335, Train loss: 0.6066757440567017 |Validation err: 0.345, Validation
Epoch 105: Train err: 0.333625, Train loss: 0.6064751488821847 |Validation err: 0.343, Validatio
Epoch 106: Train err: 0.335875, Train loss: 0.6056273210616339 |Validation err: 0.347, Validatio
Epoch 107: Train err: 0.32825, Train loss: 0.6036564509073893 |Validation err: 0.3425, Validatio
Epoch 108: Train err: 0.330875, Train loss: 0.6035362311771938 |Validation err: 0.3445, Validat
Epoch 109: Train err: 0.332, Train loss: 0.6017067517553057 |Validation err: 0.3405, Validation
Epoch 110: Train err: 0.325375, Train loss: 0.6007333170799982 |Validation err: 0.338, Validatio
Epoch 111: Train err: 0.32625, Train loss: 0.5999934446244013 |Validation err: 0.338, Validatio
Epoch 112: Train err: 0.32525, Train loss: 0.5991402041344416 |Validation err: 0.3415, Validatio
Epoch 113: Train err: 0.32625, Train loss: 0.5986226371356419 |Validation err: 0.3415, Validatio
Epoch 114: Train err: 0.326, Train loss: 0.598805064246768 |Validation err: 0.343, Validation lo
Epoch 115: Train err: 0.324375, Train loss: 0.5969435004960923 |Validation err: 0.331, Validatio
Epoch 116: Train err: 0.322625, Train loss: 0.595651041893732 |Validation err: 0.331, Validatio
Epoch 117: Train err: 0.323375, Train loss: 0.5953413304828462 |Validation err: 0.33, Validatio
Epoch 118: Train err: 0.32375, Train loss: 0.5945436159769694 |Validation err: 0.3415, Validatio
Epoch 119: Train err: 0.319125, Train loss: 0.594249807652973 |Validation err: 0.334, Validatio
Epoch 120: Train err: 0.320625, Train loss: 0.5917192811057681 |Validation err: 0.329, Validatio
Epoch 121: Train err: 0.32025, Train loss: 0.5928340781302679 |Validation err: 0.335, Validatio
Epoch 122: Train err: 0.320125, Train loss: 0.5908742859250024 |Validation err: 0.333, Validatio
Epoch 123: Train err: 0.318, Train loss: 0.5901268124580383 |Validation err: 0.327, Validation
Epoch 124: Train err: 0.317625, Train loss: 0.590784265881493 |Validation err: 0.33, Validation
Epoch 125: Train err: 0.31625, Train loss: 0.58881185735975 |Validation err: 0.326, Validation
Epoch 126: Train err: 0.3155, Train loss: 0.5861207133247739 |Validation err: 0.3295, Validatio
Epoch 127: Train err: 0.316875, Train loss: 0.5859912860961187 |Validation err: 0.327, Validatio
Epoch 128: Train err: 0.315, Train loss: 0.584439354283469 |Validation err: 0.3335, Validation
Epoch 129: Train err: 0.310125, Train loss: 0.5826627952711922 |Validation err: 0.3265, Validat
Epoch 130: Train err: 0.309875, Train loss: 0.5823912677310762 |Validation err: 0.3245, Validat
Epoch 131: Train err: 0.311375, Train loss: 0.5818183705920265 |Validation err: 0.325, Validatio
Epoch 132: Train err: 0.31, Train loss: 0.5819726756640843 |Validation err: 0.3225, Validation
Epoch 133: Train err: 0.309, Train loss: 0.5788822571436564 |Validation err: 0.3215, Validation
Epoch 134: Train err: 0.306625, Train loss: 0.5777809506370908 |Validation err: 0.3235, Validat
Epoch 135: Train err: 0.307375, Train loss: 0.5788352603004092 |Validation err: 0.323, Validatio
Epoch 136: Train err: 0.30975, Train loss: 0.5793073546318781 |Validation err: 0.32, Validation
Epoch 137: Train err: 0.303125, Train loss: 0.5752747853597006 |Validation err: 0.3215, Validat
Epoch 138: Train err: 0.301375, Train loss: 0.5749560310727074 |Validation err: 0.3225, Validat
Epoch 139: Train err: 0.3035, Train loss: 0.5761806624276298 |Validation err: 0.319, Validation
Epoch 140: Train err: 0.3025, Train loss: 0.5728824081875029 |Validation err: 0.318, Validation
Epoch 141: Train err: 0.298125, Train loss: 0.5709542603719802 |Validation err: 0.3205, Validat
Epoch 142: Train err: 0.299, Train loss: 0.5707725882530212 |Validation err: 0.322, Validation
Epoch 143: Train err: 0.296375, Train loss: 0.5711694047564552 |Validation err: 0.3145, Validat
Epoch 144: Train err: 0.297875, Train loss: 0.5687289436658224 |Validation err: 0.3195, Validat
Epoch 145: Train err: 0.295375, Train loss: 0.5675144280706134 |Validation err: 0.321, Validatio
Epoch 146: Train err: 0.297375, Train loss: 0.568290630976359 |Validation err: 0.317, Validatio
Epoch 147: Train err: 0.296125, Train loss: 0.5672819018363953 |Validation err: 0.3165, Validat
Epoch 148: Train err: 0.29275, Train loss: 0.564356994061243 |Validation err: 0.3215, Validatio
Epoch 149: Train err: 0.2935, Train loss: 0.5646615170297169 |Validation err: 0.3175, Validatio
Epoch 150: Train err: 0.293, Train loss: 0.5631969088599795 |Validation err: 0.315, Validation
Epoch 151: Train err: 0.29175, Train loss: 0.5612457820347377 |Validation err: 0.3145, Validatio
Epoch 152: Train err: 0.291625, Train loss: 0.5609272179149446 |Validation err: 0.317, Validatio
Epoch 153: Train err: 0.289625, Train loss: 0.5605705806187221 |Validation err: 0.3125, Validat
Epoch 154: Train err: 0.289, Train loss: 0.5598814004943484 |Validation err: 0.3095, Validation
Epoch 155: Train err: 0.28725, Train loss: 0.5592579983529591 |Validation err: 0.3155, Validatio
Epoch 156: Train err: 0.29425, Train loss: 0.5605765098617l9 |Validation err: 0.306, Validation
Epoch 157: Train err: 0.285375, Train loss: 0.5568833152453104 |Validation err: 0.31, Validatio
Epoch 158: Train err: 0.287875, Train loss: 0.5566764261041369 |Validation err: 0.316, Validatio
Epoch 159: Train err: 0.28625, Train loss: 0.555456226780301 |Validation err: 0.3185, Validatio
Epoch 160: Train err: 0.28275, Train loss: 0.5539139083453587 |Validation err: 0.305, Validatio
Epoch 161: Train err: 0.283125, Train loss: 0.5523700401896522 |Validation err: 0.3115, Validat
Epoch 162: Train err: 0.282625, Train loss: 0.5516773774510338 |Validation err: 0.3075, Validat
Epoch 163: Train err: 0.28675, Train loss: 0.5536199808120728 |Validation err: 0.3075, Validatio
Epoch 164: Train err: 0.28225, Train loss: 0.5501406249545869 |Validation err: 0.3205, Validatio
Epoch 165: Train err: 0.287875, Train loss: 0.553909767241705 |Validation err: 0.3195, Validatio
Epoch 166: Train err: 0.282125, Train loss: 0.5522103678612482 |Validation err: 0.309, Validatio
Epoch 167: Train err: 0.28575, Train loss: 0.5504923746699378 |Validation err: 0.307, Validatio
Epoch 168: Train err: 0.27575, Train loss: 0.5470665693283081 |Validation err: 0.314, Validatio
Epoch 169: Train err: 0.282125, Train loss: 0.5484188539641244 |Validation err: 0.3075, Validat
Epoch 170: Train err: 0.279125, Train loss: 0.5475781645093646 |Validation err: 0.3025, Validat
Epoch 171: Train err: 0.28475, Train loss: 0.5495592071896508 |Validation err: 0.3145, Validatio
```

```
Epoch 172: Train err: 0.277625, Train loss: 0.545041873341515 |Validation err: 0.3075, Validatio
Epoch 173: Train err: 0.2735, Train loss: 0.5434519052505493 |Validation err: 0.312, Validation
Epoch 174: Train err: 0.27525, Train loss: 0.5426444411277771 |Validation err: 0.307, Validatio
Epoch 175: Train err: 0.274625, Train loss: 0.541669644060589 |Validation err: 0.3065, Validatio
Epoch 176: Train err: 0.274875, Train loss: 0.5425510647751036 |Validation err: 0.306, Validatio
Epoch 177: Train err: 0.278, Train loss: 0.5423692748660133 |Validation err: 0.3085, Validation
Epoch 178: Train err: 0.27575, Train loss: 0.540714864219938 |Validation err: 0.3165, Validatio
Epoch 179: Train err: 0.273125, Train loss: 0.5399954248042333 |Validation err: 0.304, Validatio
Epoch 180: Train err: 0.27825, Train loss: 0.5392189891565413 |Validation err: 0.308, Validatio
Epoch 181: Train err: 0.27325, Train loss: 0.5417267850467137 |Validation err: 0.3025, Validatio
Epoch 182: Train err: 0.268875, Train loss: 0.535632312297821 |Validation err: 0.3085, Validatio
Epoch 183: Train err: 0.269125, Train loss: 0.536546223220371 |Validation err: 0.312, Validatio
Epoch 184: Train err: 0.271375, Train loss: 0.5366627602350145 |Validation err: 0.3045, Validat
Epoch 185: Train err: 0.269, Train loss: 0.5332411357334682 |Validation err: 0.3045, Validation
Epoch 186: Train err: 0.267625, Train loss: 0.5340347701594943 |Validation err: 0.3055, Validat
Epoch 187: Train err: 0.2685, Train loss: 0.5324997163954235 |Validation err: 0.3065, Validatio
Epoch 188: Train err: 0.26725, Train loss: 0.531715696766263 |Validation err: 0.3025, Validatio
Epoch 189: Train err: 0.268875, Train loss: 0.53335987670081 |Validation err: 0.3025, Validatio
Epoch 190: Train err: 0.2685, Train loss: 0.5298999136402494 |Validation err: 0.3105, Validatio
Epoch 191: Train err: 0.270125, Train loss: 0.5312172671159109 |Validation err: 0.316, Validatio
Epoch 192: Train err: 0.26575, Train loss: 0.5312522252400717 |Validation err: 0.31, Validation
Epoch 193: Train err: 0.267125, Train loss: 0.5311695379870278 |Validation err: 0.3045, Validat
Epoch 194: Train err: 0.264375, Train loss: 0.5268106616678692 |Validation err: 0.301, Validatio
Epoch 195: Train err: 0.27025, Train loss: 0.5279586882818312 |Validation err: 0.3115, Validatio
Epoch 196: Train err: 0.266125, Train loss: 0.5279154181480408 |Validation err: 0.3055, Validat
Epoch 197: Train err: 0.26325, Train loss: 0.5268668276923043 |Validation err: 0.3055, Validatio
Epoch 198: Train err: 0.26475, Train loss: 0.5233580980982099 |Validation err: 0.3045, Validatio
Epoch 199: Train err: 0.262875, Train loss: 0.5244026184082031 |Validation err: 0.3065, Validat
Epoch 200: Train err: 0.265125, Train loss: 0.5283136992227464 |Validation err: 0.3035, Validat
Epoch 201: Train err: 0.26275, Train loss: 0.5228659567378816 |Validation err: 0.302, Validatio
Epoch 202: Train err: 0.261375, Train loss: 0.5202691810471671 |Validation err: 0.3065, Validat
Epoch 203: Train err: 0.26325, Train loss: 0.519646555185318 |Validation err: 0.3035, Validatio
Epoch 204: Train err: 0.263625, Train loss: 0.5200250560329074 |Validation err: 0.307, Validatio
Epoch 205: Train err: 0.26125, Train loss: 0.5211065383184523 |Validation err: 0.3045, Validatio
Epoch 206: Train err: 0.264125, Train loss: 0.5206111414091927 |Validation err: 0.305, Validatio
Epoch 207: Train err: 0.262125, Train loss: 0.5229181789216542 |Validation err: 0.317, Validatio
Epoch 208: Train err: 0.258, Train loss: 0.5174059016363961 |Validation err: 0.3055, Validation
Epoch 209: Train err: 0.256625, Train loss: 0.5161289544332595 |Validation err: 0.305, Validatio
Epoch 210: Train err: 0.256375, Train loss: 0.5158517303920928 |Validation err: 0.3005, Validat
Epoch 211: Train err: 0.2585, Train loss: 0.5165318903468904 |Validation err: 0.3075, Validatio
Epoch 212: Train err: 0.261625, Train loss: 0.5186613854907808 |Validation err: 0.301, Validatio
Epoch 213: Train err: 0.2575, Train loss: 0.5141348356292361 |Validation err: 0.299, Validation
Epoch 214: Train err: 0.258875, Train loss: 0.513372859784535 |Validation err: 0.3025, Validatio
Epoch 215: Train err: 0.256, Train loss: 0.5124503743080866 |Validation err: 0.3025, Validation
Epoch 216: Train err: 0.256375, Train loss: 0.5120635756424495 |Validation err: 0.307, Validatio
Epoch 217: Train err: 0.256, Train loss: 0.5124697912307012 |Validation err: 0.3, Validation lo
Epoch 218: Train err: 0.25075, Train loss: 0.5087103304408845 |Validation err: 0.298, Validatio
Epoch 219: Train err: 0.255, Train loss: 0.509272928748812 |Validation err: 0.307, Validation lo
Epoch 220: Train err: 0.25475, Train loss: 0.5120846387885866 |Validation err: 0.3045, Validatio
Epoch 221: Train err: 0.2525, Train loss: 0.5067759738081977 |Validation err: 0.3045, Validatio
Epoch 222: Train err: 0.252875, Train loss: 0.5095175419534955 |Validation err: 0.301, Validatio
Epoch 223: Train err: 0.2535, Train loss: 0.5078650102728889 |Validation err: 0.309, Validation
Epoch 224: Train err: 0.249625, Train loss: 0.5062720960094815 |Validation err: 0.2945, Validat
Epoch 225: Train err: 0.24975, Train loss: 0.5038043970153445 |Validation err: 0.3, Validation
Epoch 226: Train err: 0.25025, Train loss: 0.5074268437567211 |Validation err: 0.299, Validatio
Epoch 227: Train err: 0.248, Train loss: 0.5009516264711108 |Validation err: 0.2965, Validation
Epoch 228: Train err: 0.244375, Train loss: 0.5005771063622975 |Validation err: 0.308, Validatio
Epoch 229: Train err: 0.246125, Train loss: 0.5022220058100564 |Validation err: 0.2985, Validat
Epoch 230: Train err: 0.248375, Train loss: 0.5013305175872076 |Validation err: 0.3005, Validat
Epoch 231: Train err: 0.249125, Train loss: 0.5015043190547398 |Validation err: 0.307, Validatio
Epoch 232: Train err: 0.2485, Train loss: 0.4991803211825235 |Validation err: 0.3045, Validatio
Epoch 233: Train err: 0.250875, Train loss: 0.5031386613845825 |Validation err: 0.296, Validatio
Epoch 234: Train err: 0.24775, Train loss: 0.5012602096512204 |Validation err: 0.3, Validation
Epoch 235: Train err: 0.24425, Train loss: 0.4959279412315005 |Validation err: 0.2985, Validatio
Epoch 236: Train err: 0.247, Train loss: 0.49711660402161734 |Validation err: 0.3035, Validatio
Epoch 237: Train err: 0.245125, Train loss: 0.4952708411784399 |Validation err: 0.2995, Validat
Epoch 238: Train err: 0.248125, Train loss: 0.49858701938674566 |Validation err: 0.3, Validatio
Epoch 239: Train err: 0.240625, Train loss: 0.4922239297912234 |Validation err: 0.2985, Validat
Epoch 240: Train err: 0.241125, Train loss: 0.49187814763614107 |Validation err: 0.2935, Validat
Epoch 241: Train err: 0.24175, Train loss: 0.4913441439469655 |Validation err: 0.2995, Validatio
Epoch 242: Train err: 0.24075, Train loss: 0.4899051473254249 |Validation err: 0.304, Validatio
Epoch 243: Train err: 0.245, Train loss: 0.4939776843502408 |Validation err: 0.3135, Validation
Epoch 244: Train err: 0.2415, Train loss: 0.4906413484187353 |Validation err: 0.2975, Validatio
Epoch 245: Train err: 0.240875, Train loss: 0.4917007940156119 |Validation err: 0.294, Validatio
Epoch 246: Train err: 0.24575, Train loss: 0.49142694615182425 |Validation err: 0.2975, Validat
Epoch 247: Train err: 0.23725, Train loss: 0.4877427277110872 |Validation err: 0.2985, Validatio
Epoch 248: Train err: 0.23775, Train loss: 0.48898849317005705 |Validation err: 0.2965, Validat
Epoch 249: Train err: 0.23775, Train loss: 0.4866296819278172 |Validation err: 0.2985, Validatio
Epoch 250: Train err: 0.238375, Train loss: 0.4837887656121027 |Validation err: 0.3025, Validat
Epoch 251: Train err: 0.23675, Train loss: 0.48316557918276104 |Validation err: 0.2965, Validat
Epoch 252: Train err: 0.238, Train loss: 0.48351813497997465 |Validation err: 0.3005, Validatio
Epoch 253: Train err: 0.238, Train loss: 0.4814928755873725 |Validation err: 0.3005, Validation
Epoch 254: Train err: 0.237625, Train loss: 0.48512183484577 |Validation err: 0.301, Validation
Epoch 255: Train err: 0.239125, Train loss: 0.4814445348013015 |Validation err: 0.301, Validatio
Epoch 256: Train err: 0.235, Train loss: 0.4809731330190386 |Validation err: 0.3025, Validation
Epoch 257: Train err: 0.235, Train loss: 0.4818913354760125 |Validation err: 0.3015, Validation
Epoch 258: Train err: 0.23425, Train loss: 0.4780005798453376 |Validation err: 0.2945, Validatio
```

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Epoch 259: Train err: 0.235875, Train loss: 0.479814738035202 |Validation err: 0.2985, Validati
Epoch 260: Train err: 0.231375, Train loss: 0.4761910339196523 |Validation err: 0.294, Validati
Epoch 261: Train err: 0.232125, Train loss: 0.47766249378522235 |Validation err: 0.309, Validat
Epoch 262: Train err: 0.230625, Train loss: 0.47875541306677316 |Validation err: 0.298, Validat
Epoch 263: Train err: 0.244625, Train loss: 0.4893791476885478 |Validation err: 0.2945, Validat
Epoch 264: Train err: 0.234375, Train loss: 0.47575843192282175 |Validation err: 0.2945, Valida
Epoch 265: Train err: 0.231, Train loss: 0.4731812846092951 |Validation err: 0.3, Validation lo
Epoch 266: Train err: 0.23575, Train loss: 0.4798568770999 |Validation err: 0.2945, Validation
Epoch 267: Train err: 0.232125, Train loss: 0.47548696114903405 |Validation err: 0.299, Validat
Epoch 268: Train err: 0.2295, Train loss: 0.4721653163433075 |Validation err: 0.2955, Validatio
Epoch 269: Train err: 0.23175, Train loss: 0.47422135018167044 |Validation err: 0.3025, Validat
Epoch 270: Train err: 0.236875, Train loss: 0.4800112247467041 |Validation err: 0.293, Validati
Epoch 271: Train err: 0.225875, Train loss: 0.4690083222729819 |Validation err: 0.2975, Validat
Epoch 272: Train err: 0.228375, Train loss: 0.46841006051926387 |Validation err: 0.298, Validat
Epoch 273: Train err: 0.22575, Train loss: 0.46946370885485694 |Validation err: 0.293, Validati
Epoch 274: Train err: 0.224625, Train loss: 0.46685949251765296 |Validation err: 0.2965, Valida
Epoch 275: Train err: 0.2255, Train loss: 0.465996177423568 |Validation err: 0.295, Validation
Epoch 276: Train err: 0.224375, Train loss: 0.47090515068599154 |Validation err: 0.298, Validat
Epoch 277: Train err: 0.228, Train loss: 0.4725813567638397 |Validation err: 0.2975, Validation
Epoch 278: Train err: 0.2275, Train loss: 0.46658978291920256 |Validation err: 0.2955, Validati
Epoch 279: Train err: 0.236875, Train loss: 0.48608684681710745 |Validation err: 0.2945, Valida
Epoch 280: Train err: 0.228625, Train loss: 0.4675252806572687 |Validation err: 0.2955, Validat
Epoch 281: Train err: 0.2285, Train loss: 0.47144570520945955 |Validation err: 0.306, Validatio
Epoch 282: Train err: 0.221, Train loss: 0.4645608989965348 |Validation err: 0.2965, Validation
Epoch 283: Train err: 0.222, Train loss: 0.4649955474195026 |Validation err: 0.306, Validation
Epoch 284: Train err: 0.231125, Train loss: 0.47040509893780663 |Validation err: 0.311, Validat
Epoch 285: Train err: 0.2255, Train loss: 0.4665735463301341 |Validation err: 0.293, Validation
Epoch 286: Train err: 0.223125, Train loss: 0.4602849809896378 |Validation err: 0.294, Validati
Epoch 287: Train err: 0.22325, Train loss: 0.45975106670742943 |Validation err: 0.295, Validati
Epoch 288: Train err: 0.220875, Train loss: 0.45628882731710163 |Validation err: 0.296, Validat
Epoch 289: Train err: 0.222875, Train loss: 0.46096536659059073 |Validation err: 0.2945, Valida
Epoch 290: Train err: 0.223, Train loss: 0.46354954015640987 |Validation err: 0.2945, Validatio
Epoch 291: Train err: 0.22025, Train loss: 0.46309466163317364 |Validation err: 0.3005, Validat
Epoch 292: Train err: 0.217875, Train loss: 0.45364269898051307 |Validation err: 0.292, Validat
Epoch 293: Train err: 0.220375, Train loss: 0.4559927469208127 |Validation err: 0.2965, Validat
Epoch 294: Train err: 0.22, Train loss: 0.4580588809081486 |Validation err: 0.293, Validation l
Epoch 295: Train err: 0.217875, Train loss: 0.4514763199147724 |Validation err: 0.289, Validati
Epoch 296: Train err: 0.215125, Train loss: 0.44903996728715445 |Validation err: 0.298, Validat
Epoch 297: Train err: 0.21675, Train loss: 0.45137703276815866 |Validation err: 0.2925, Validat
Epoch 298: Train err: 0.21525, Train loss: 0.45430561616307213 |Validation err: 0.3035, Validat
Epoch 299: Train err: 0.218625, Train loss: 0.4571545592376164 |Validation err: 0.289, Validati
Epoch 300: Train err: 0.218, Train loss: 0.4540261314028785 |Validation err: 0.293, Validation
Finished Training
Total time elapsed: 1156.62 seconds
```

Part 4. Evaluating the Best Model [15 pt]

Part (a) - 1pt

Choose the **best** model that you have so far. This means choosing the best model checkpoint, including the choice of `small_net` vs `large_net`, the `batch_size`, `learning_rate`, **and the epoch number**.

Modify the code below to load your chosen set of weights to the model object `net`.

```
net = LargeNet()
model_path = get_model_name(net.name, batch_size=384, learning_rate=0.002, epoch=299)
state = torch.load(model_path)
net.load_state_dict(state)
```

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

Part (b) - 2pt

Justify your choice of model from part (a).

I chose this specific model because it has the most consistently lowest validation loss, meaning that the optima that the optimizer reached is likely to be actually good for genearlization performance. Specifically, this model scored around 0.29 for the validation loss consistently over nearly 100 (1/3 of total) epochs, which is something the other models were unable to achieve. I chose the final epoch since it had the loweset

validation error that I saw training this model, and in the ~50 epochs before it, the model also achieved roughly the same validaiton loss, so at epoch 300, the optimizer reached a satisfactory region of the loss landscape.

Part (c) - 2pt

Using the code in Part 0, any code from lecture notes, or any code that you write, compute and report the **test classification error** for your chosen model.

```
# If you use the `evaluate` function provided in part 0, you will need to
# set batch_size > 1
train_loader, val_loader, test_loader, classes = get_data_loader(
    target_classes=["cat", "dog"],
    batch_size=384)

evaluate(net, test_loader, nn.BCEWithLogitsLoss())
```

```
Files already downloaded and verified
Files already downloaded and verified
(0.2945, 0.5806906521320343)
```

The test classification error is only 0.2945 using the model from part a.

Part (d) - 3pt

How does the test classification error compare with the **validation error**? Explain why you would expect the test error to be *higher* than the validation error.

The test classification error is slightly higher than that of the validation error (0.2945 vs 0.293 respectively), which is expected since we biased our model to perform well on the validation set. This means we likely biased the hyperparameters to optimize over the data noise of the validation set, which is probably not present in the test set.

Part (e) - 2pt

Why did we only use the test data set at the very end? Why is it important that we use the test data as little as possible?

Because it is our "hold out" set, meaning that it should simulate us testing the model on different data in the real world, e.g., if we encounter some picture of a cat or dog on the internet and wanted to classify it. In the same way a student may save practice exams for a simulated testing environment, we should only use the test set as little as possible so that we can learn the over all data (or class material) rather than the test set specific features (or practice exam specific questions).

Part (f) - 5pt

How does the your best CNN model compare with an 2-layer ANN model (no convolutional layers) on classifying cat and dog images. You can use a 2-layer ANN architecture similar to what you used in Lab 1. You should explore different hyperparameter settings to determine how well you can do on the validation dataset. Once satisified with the performance, you may test it out on the test data.

Hint: The ANN in lab 1 was applied on greyscale images. The cat and dog images are colour (RGB) and so you will need to flatted and concatinate all three colour layers before feeding them into an ANN.

```
class SmallestNet(nn.Module):
    def __init__(self, hid_dim = 16, activation=nn.Mish()):
        super(SmallestNet, self).__init__()
        self.name = "smallest"
        self.hidden_1 = nn.Linear(3*32*32, hid_dim*hid_dim)
        self.activation_1 = activation
        self.hidden_2 = nn.Linear(hid_dim*hid_dim, 1)

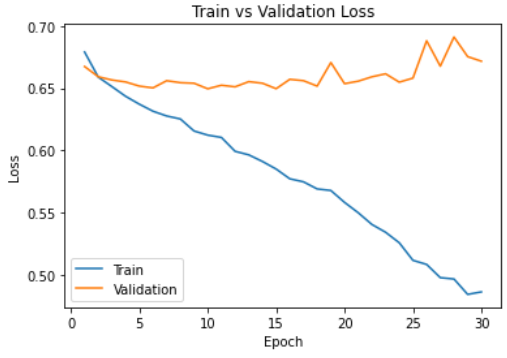
    def forward(self, x):
        x = x.reshape(-1, 3*32*32)
        h = self.hidden_1(x)
        h = self.activation_1(h)
        out = self.hidden_2(h)
        return out.squeeze(1)
```

```
train_loader.dataset[0][0].shape
```

```
torch.Size([1, 3, 32, 32])
```

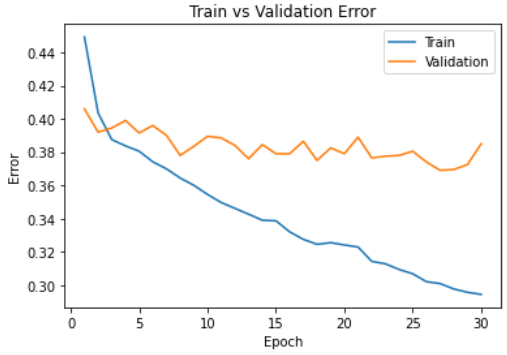
```
smallest_net = SmallestNet()
smallest_net_1 = train_net(smallest_net, batch_size=512, learning_rate=0.02, num_epochs=30)
model_path = get_model_name("smallest", batch_size=512, learning_rate=0.02, epoch=29)
plot_training_curve(model_path)
```

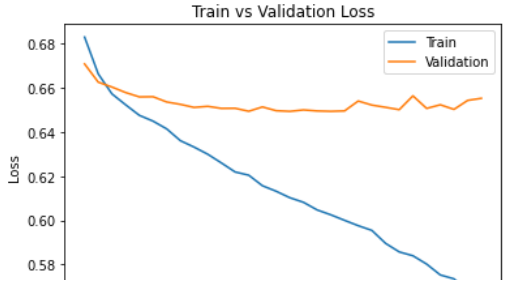
```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.43975, Train loss: 0.6790264807641506 |Validation err: 0.397, Validation loss: 0.6673664301633835
Epoch 2: Train err: 0.3955, Train loss: 0.6588614992797375 |Validation err: 0.3905, Validation loss: 0.6591461896896362
Epoch 3: Train err: 0.380625, Train loss: 0.6512074321508408 |Validation err: 0.3955, Validation loss: 0.6565362364053726
Epoch 4: Train err: 0.371625, Train loss: 0.6434310004115105 |Validation err: 0.395, Validation loss: 0.6549622416496277
Epoch 5: Train err: 0.36625, Train loss: 0.6371243260800838 |Validation err: 0.39, Validation loss: 0.6516404896974564
Epoch 6: Train err: 0.359375, Train loss: 0.6314536742866039 |Validation err: 0.3805, Validation loss: 0.6502120941877365
Epoch 7: Train err: 0.3515, Train loss: 0.6276301816105843 |Validation err: 0.3835, Validation loss: 0.655967190861702
Epoch 8: Train err: 0.354125, Train loss: 0.6252319328486919 |Validation err: 0.3855, Validation loss: 0.6543913036584854
Epoch 9: Train err: 0.335375, Train loss: 0.6155754402279854 |Validation err: 0.382, Validation loss: 0.6539304405450821
Epoch 10: Train err: 0.33225, Train loss: 0.6122569404542446 |Validation err: 0.3795, Validation loss: 0.6494787633419037
Epoch 11: Train err: 0.336, Train loss: 0.6103845201432705 |Validation err: 0.387, Validation loss: 0.6523326486349106
Epoch 12: Train err: 0.325875, Train loss: 0.5992307886481285 |Validation err: 0.381, Validation loss: 0.6510645151138306
Epoch 13: Train err: 0.318125, Train loss: 0.5964005403220654 |Validation err: 0.3785, Validation loss: 0.6552204489707947
Epoch 14: Train err: 0.31975, Train loss: 0.5910800211131573 |Validation err: 0.3715, Validation loss: 0.6539465934038162
Epoch 15: Train err: 0.308375, Train loss: 0.5849945582449436 |Validation err: 0.373, Validation loss: 0.6495428383350372
Epoch 16: Train err: 0.3, Train loss: 0.5771567933261395 |Validation err: 0.3715, Validation loss: 0.6570776402950287
Epoch 17: Train err: 0.29975, Train loss: 0.5747112147510052 |Validation err: 0.3725, Validation loss: 0.6559705287218094
Epoch 18: Train err: 0.298875, Train loss: 0.5690141804516315 |Validation err: 0.368, Validation loss: 0.651624321937561
Epoch 19: Train err: 0.29725, Train loss: 0.5677707009017467 |Validation err: 0.376, Validation loss: 0.6705812811851501
Epoch 20: Train err: 0.288375, Train loss: 0.558214008808136 |Validation err: 0.366, Validation loss: 0.6535870581865311
Epoch 21: Train err: 0.28375, Train loss: 0.5498827435076237 |Validation err: 0.367, Validation loss: 0.6555796414613724
Epoch 22: Train err: 0.270125, Train loss: 0.5404693484306335 |Validation err: 0.368, Validation loss: 0.6591028124094009
Epoch 23: Train err: 0.2675, Train loss: 0.5342064406722784 |Validation err: 0.367, Validation loss: 0.6615106165409088
Epoch 24: Train err: 0.2665, Train loss: 0.5257573779672384 |Validation err: 0.358, Validation loss: 0.6548063606023788
Epoch 25: Train err: 0.25575, Train loss: 0.51164386048913 |Validation err: 0.364, Validation loss: 0.6580648571252823
Epoch 26: Train err: 0.244, Train loss: 0.5083519816398621 |Validation err: 0.387, Validation loss: 0.6880656778812408
Epoch 27: Train err: 0.24075, Train loss: 0.4977183435112238 |Validation err: 0.358, Validation loss: 0.667652040719986
Epoch 28: Train err: 0.239875, Train loss: 0.49664958752691746 |Validation err: 0.386, Validation loss: 0.6911025941371918
Epoch 29: Train err: 0.23125, Train loss: 0.48428635485470295 |Validation err: 0.3675, Validation loss: 0.6753147691488266
Epoch 30: Train err: 0.235, Train loss: 0.4862862303853035 |Validation err: 0.3585, Validation loss: 0.6716384440660477
Finished Training
Total time elapsed: 105.52 seconds
```




```
smallest_net = SmallestNet()
smallest_net_1 = train_net(smallest_net, batch_size=512, learning_rate=0.01, num_epochs=30)
model_path = get_model_name("smallest", batch_size=512, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```

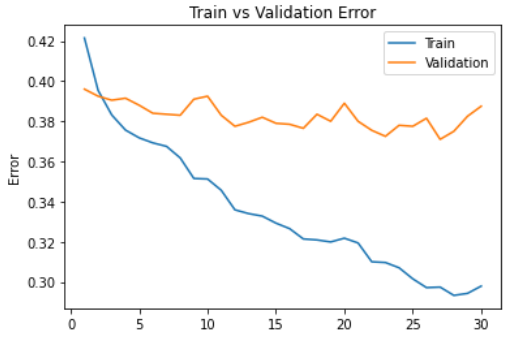
```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.44925, Train loss: 0.6830242313444614 |Validation err: 0.406, Validation loss: 0.6708525121212006
Epoch 2: Train err: 0.4035, Train loss: 0.666317768394947 |Validation err: 0.392, Validation loss: 0.6625947654247284
Epoch 3: Train err: 0.3875, Train loss: 0.6572890840470791 |Validation err: 0.3945, Validation loss: 0.6603899747133255
Epoch 4: Train err: 0.38375, Train loss: 0.6523421891033649 |Validation err: 0.399, Validation loss: 0.6578977108001709
Epoch 5: Train err: 0.3805, Train loss: 0.6475777365267277 |Validation err: 0.3915, Validation loss: 0.6559290736913681
Epoch 6: Train err: 0.374125, Train loss: 0.6449547596275806 |Validation err: 0.396, Validation loss: 0.6560088843107224
Epoch 7: Train err: 0.369875, Train loss: 0.6414322219789028 |Validation err: 0.39, Validation loss: 0.6536260694265366
Epoch 8: Train err: 0.364375, Train loss: 0.6360941492021084 |Validation err: 0.378, Validation loss: 0.6525458246469498
Epoch 9: Train err: 0.36, Train loss: 0.6331859976053238 |Validation err: 0.3835, Validation loss: 0.651161327958107
Epoch 10: Train err: 0.3545, Train loss: 0.6299511790275574 |Validation err: 0.3895, Validation loss: 0.6516521275043488
Epoch 11: Train err: 0.349625, Train loss: 0.6259919218719006 |Validation err: 0.3885, Validation loss: 0.6507135778665543
Epoch 12: Train err: 0.346125, Train loss: 0.6219097711145878 |Validation err: 0.384, Validation loss: 0.6507596671581268
Epoch 13: Train err: 0.342625, Train loss: 0.6204396337270737 |Validation err: 0.376, Validation loss: 0.6494178026914597
Epoch 14: Train err: 0.339, Train loss: 0.6156640388071537 |Validation err: 0.3845, Validation loss: 0.6513747572898865
Epoch 15: Train err: 0.338625, Train loss: 0.6131694689393044 |Validation err: 0.379, Validation loss: 0.6496705710887909
Epoch 16: Train err: 0.332, Train loss: 0.6102428361773491 |Validation err: 0.379, Validation loss: 0.6493712365627289
Epoch 17: Train err: 0.3275, Train loss: 0.608150340616703 |Validation err: 0.3865, Validation loss: 0.6500195562839508
Epoch 18: Train err: 0.3245, Train loss: 0.6046978905797005 |Validation err: 0.375, Validation loss: 0.6495500952005386
Epoch 19: Train err: 0.3255, Train loss: 0.6024853251874447 |Validation err: 0.3825, Validation loss: 0.6493861824274063
Epoch 20: Train err: 0.324125, Train loss: 0.5999844409525394 |Validation err: 0.379, Validation loss: 0.6495722681283951
Epoch 21: Train err: 0.322875, Train loss: 0.5975661277770996 |Validation err: 0.389, Validation loss: 0.6540508270263672
Epoch 22: Train err: 0.31425, Train loss: 0.5954191796481609 |Validation err: 0.3765, Validation loss: 0.6522150188684464
Epoch 23: Train err: 0.31275, Train loss: 0.589551355689764 |Validation err: 0.3775, Validation loss: 0.6512043476104736
Epoch 24: Train err: 0.309375, Train loss: 0.5856704264879227 |Validation err: 0.378, Validation loss: 0.6501335203647614
Epoch 25: Train err: 0.30675, Train loss: 0.5839314348995686 |Validation err: 0.3805, Validation loss: 0.6564003974199295
Epoch 26: Train err: 0.302, Train loss: 0.5801641158759594 |Validation err: 0.374, Validation loss: 0.6507061123847961
Epoch 27: Train err: 0.300875, Train loss: 0.5752346813678741 |Validation err: 0.369, Validation loss: 0.652355968952179
Epoch 28: Train err: 0.297625, Train loss: 0.5734679810702801 |Validation err: 0.3695, Validation loss: 0.650266021490097
Epoch 29: Train err: 0.295625, Train loss: 0.5675358921289444 |Validation err: 0.3725, Validation loss: 0.6543329358100891
Epoch 30: Train err: 0.294375, Train loss: 0.5660532787442207 |Validation err: 0.385, Validation loss: 0.6552906185388565
Finished Training
Total time elapsed: 105.87 seconds
```






```
1 smallest_net = SmallestNet(hid_dim=64)
2 smallest_net_1 = train_net(smallest_net, batch_size=512, learning_rate=0.01, num_epochs=30)
3 model_path = get_model_name("smallest", batch_size=512, learning_rate=0.01, epoch=29)
4 plot_training_curve(model_path)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.4215, Train loss: 0.675833947956562 |Validation err: 0.396, Validation loss: 0.6674904227256775
Epoch 2: Train err: 0.395375, Train loss: 0.6590367667376995 |Validation err: 0.3925, Validation loss: 0.6609920561313629
Epoch 3: Train err: 0.383125, Train loss: 0.6531109102070332 |Validation err: 0.3905, Validation loss: 0.6596569418907166
Epoch 4: Train err: 0.375625, Train loss: 0.6467069685459137 |Validation err: 0.3915, Validation loss: 0.6578879207372665
Epoch 5: Train err: 0.37175, Train loss: 0.6420910581946373 |Validation err: 0.388, Validation loss: 0.6557555645704269
Epoch 6: Train err: 0.36925, Train loss: 0.6386721320450306 |Validation err: 0.384, Validation loss: 0.6538977771997452
Epoch 7: Train err: 0.3675, Train loss: 0.6363576911389828 |Validation err: 0.3835, Validation loss: 0.6574136763811111
Epoch 8: Train err: 0.36175, Train loss: 0.6331921070814133 |Validation err: 0.383, Validation loss: 0.6542101949453354
Epoch 9: Train err: 0.3515, Train loss: 0.6280081011354923 |Validation err: 0.391, Validation loss: 0.6553234755992889
Epoch 10: Train err: 0.35125, Train loss: 0.6260962076485157 |Validation err: 0.3925, Validation loss: 0.6556889861822128
Epoch 11: Train err: 0.345625, Train loss: 0.6216715350747108 |Validation err: 0.383, Validation loss: 0.6560652405023575
Epoch 12: Train err: 0.335875, Train loss: 0.6158887296915054 |Validation err: 0.3775, Validation loss: 0.6528019160032272
Epoch 13: Train err: 0.334, Train loss: 0.612818356603384 |Validation err: 0.3795, Validation loss: 0.6513208448886871
Epoch 14: Train err: 0.33275, Train loss: 0.6095159314572811 |Validation err: 0.382, Validation loss: 0.6539035886526108
Epoch 15: Train err: 0.32925, Train loss: 0.6058181077241898 |Validation err: 0.379, Validation loss: 0.6521380394697189
Epoch 16: Train err: 0.3265, Train loss: 0.6027623265981674 |Validation err: 0.3785, Validation loss: 0.651960015296936
Epoch 17: Train err: 0.321375, Train loss: 0.6011494547128677 |Validation err: 0.3765, Validation loss: 0.6517934501171112
Epoch 18: Train err: 0.320875, Train loss: 0.5986842252314091 |Validation err: 0.3835, Validation loss: 0.65504390001297
Epoch 19: Train err: 0.319875, Train loss: 0.5949810408055782 |Validation err: 0.38, Validation loss: 0.6531081944704056
Epoch 20: Train err: 0.32175, Train loss: 0.5962626598775387 |Validation err: 0.389, Validation loss: 0.6601943075656891
Epoch 21: Train err: 0.319375, Train loss: 0.5918899811804295 |Validation err: 0.38, Validation loss: 0.6525110602378845
Epoch 22: Train err: 0.31, Train loss: 0.5858764015138149 |Validation err: 0.3755, Validation loss: 0.6525903940200806
Epoch 23: Train err: 0.309625, Train loss: 0.5845477469265461 |Validation err: 0.3725, Validation loss: 0.653717041015625
Epoch 24: Train err: 0.307, Train loss: 0.5806862562894821 |Validation err: 0.378, Validation loss: 0.6521870642900467
Epoch 25: Train err: 0.3015, Train loss: 0.5779494494199753 |Validation err: 0.3775, Validation loss: 0.654401883482933
Epoch 26: Train err: 0.297125, Train loss: 0.5752724371850491 |Validation err: 0.3815, Validation loss: 0.6559710502624512
Epoch 27: Train err: 0.297375, Train loss: 0.5703090615570545 |Validation err: 0.371, Validation loss: 0.6552238464355469
Epoch 28: Train err: 0.29325, Train loss: 0.5693467073142529 |Validation err: 0.375, Validation loss: 0.6543445587158203
Epoch 29: Train err: 0.29425, Train loss: 0.5643680915236473 |Validation err: 0.3825, Validation loss: 0.6655240058898926
Epoch 30: Train err: 0.297875, Train loss: 0.5658449791371822 |Validation err: 0.3875, Validation loss: 0.6673222184181213
Finished Training
Total time elapsed: 373.01 seconds
```

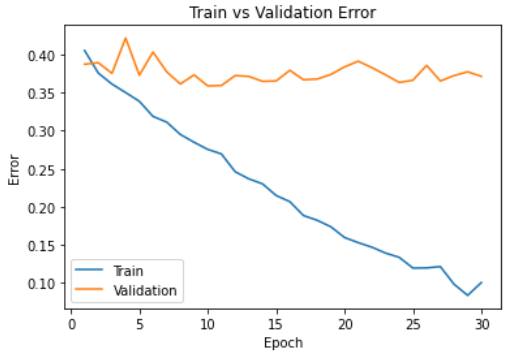


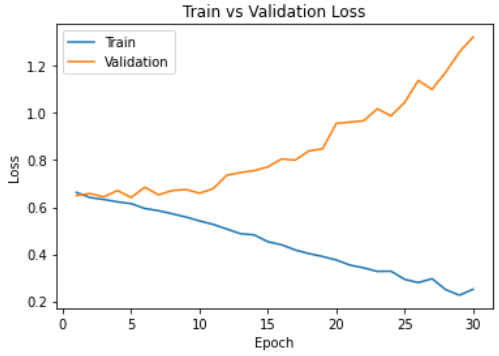

```
1 smallest_net = SmallestNet(hid_dim=64)
2 smallest_net_1 = train_net(smallest_net, batch_size=32, learning_rate=0.01, num_epochs=30)
```

```
1 model_path = get_model_name("smallest", batch_size=32, learning_rate=0.01, epoch=29)
2 plot_training_curve(model_path)
```


```
smallest_net = SmallestNet(hid_dim=8)
smallest_net_1 = train_net(smallest_net, batch_size=32, learning_rate=0.01, num_epochs=30)
```

```
model_path = get_model_name("smallest", batch_size=32, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```






```
smallest_net = SmallestNet(hid_dim=32, activation = nn.SiLU())
smallest_net_1 = train_net(smallest_net, batch_size=128, learning_rate=0.01, num_epochs=30)
model_path = get_model_name("smallest", batch_size=128, learning_rate=0.01, epoch=29)
plot_training_curve(model_path)
```

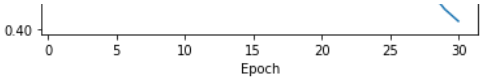
```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.416875, Train loss: 0.671116706870851 |Validation err: 0.396, Validation loss: 0.6617197506129742
Epoch 2: Train err: 0.382875, Train loss: 0.6513930634846763 |Validation err: 0.3905, Validation loss: 0.6564663499593735
Epoch 3: Train err: 0.370625, Train loss: 0.6431955307249039 |Validation err: 0.3805, Validation loss: 0.653038714081049
Epoch 4: Train err: 0.363375, Train loss: 0.6331286108683026 |Validation err: 0.4015, Validation loss: 0.6636248305439949
Epoch 5: Train err: 0.354, Train loss: 0.6275534024314274 |Validation err: 0.394, Validation loss: 0.6549753695726395
Epoch 6: Train err: 0.34725, Train loss: 0.6213555468453301 |Validation err: 0.3875, Validation loss: 0.6568939536809921
Epoch 7: Train err: 0.345375, Train loss: 0.6162608180727277 |Validation err: 0.384, Validation loss: 0.6574971005320549
Epoch 8: Train err: 0.32875, Train loss: 0.6051348788397652 |Validation err: 0.3735, Validation loss: 0.6529454551637173
Epoch 9: Train err: 0.3285, Train loss: 0.6010453521259247 |Validation err: 0.3755, Validation loss: 0.6500012539327145
Epoch 10: Train err: 0.320875, Train loss: 0.5943096630156987 |Validation err: 0.3785, Validation loss: 0.6534797586500645
Epoch 11: Train err: 0.316875, Train loss: 0.5868177617353106 |Validation err: 0.3795, Validation loss: 0.6674174144864082
Epoch 12: Train err: 0.313375, Train loss: 0.5810386784492977 |Validation err: 0.37, Validation loss: 0.6527827940881252
Epoch 13: Train err: 0.303625, Train loss: 0.575602012021201 |Validation err: 0.3895, Validation loss: 0.6734377965331078
Epoch 14: Train err: 0.30325, Train loss: 0.5732624048278445 |Validation err: 0.3815, Validation loss: 0.6669971942901611
Epoch 15: Train err: 0.294125, Train loss: 0.5582416724591028 |Validation err: 0.374, Validation loss: 0.6618062928318977
Epoch 16: Train err: 0.289375, Train loss: 0.5554924626199026 |Validation err: 0.368, Validation loss: 0.6617916524410248
Epoch 17: Train err: 0.28175, Train loss: 0.5450693955497136 |Validation err: 0.3625, Validation loss: 0.6588604040443897
Epoch 18: Train err: 0.2845, Train loss: 0.5432148135843731 |Validation err: 0.3885, Validation loss: 0.7068956755101681
Epoch 19: Train err: 0.269875, Train loss: 0.5304915384640769 |Validation err: 0.38, Validation loss: 0.6796479150652885
Epoch 20: Train err: 0.254625, Train loss: 0.5106072137280117 |Validation err: 0.3715, Validation loss: 0.6772464290261269
Epoch 21: Train err: 0.249, Train loss: 0.5092748578578706 |Validation err: 0.379, Validation loss: 0.6849539689719677
Epoch 22: Train err: 0.2465, Train loss: 0.5031883044848366 |Validation err: 0.375, Validation loss: 0.7073789946734905
Epoch 23: Train err: 0.23575, Train loss: 0.4848797789641789 |Validation err: 0.365, Validation loss: 0.687243428081274
Epoch 24: Train err: 0.23325, Train loss: 0.48764423340085955 |Validation err: 0.372, Validation loss: 0.7108095064759254
Epoch 25: Train err: 0.2325, Train loss: 0.4815786864076342 |Validation err: 0.3785, Validation loss: 0.735851664096117
Epoch 26: Train err: 0.208625, Train loss: 0.45420268509123063 |Validation err: 0.358, Validation loss: 0.7049887292087078
Epoch 27: Train err: 0.21525, Train loss: 0.4524210052830832 |Validation err: 0.365, Validation loss: 0.7295746318995953
Epoch 28: Train err: 0.215625, Train loss: 0.4484085767042069 |Validation err: 0.3595, Validation loss: 0.7331699840724468
Epoch 29: Train err: 0.200125, Train loss: 0.4263358593933166 |Validation err: 0.3745, Validation loss: 0.7449955679476261
```

```
net = SmallestNet(hid_dim=32, activation = nn.SiLU())
model_path = get_model_name(net.name, batch_size=128, learning_rate=0.01, epoch=26)
state = torch.load(model_path)
net.load_state_dict(state)
train_loader, val_loader, test_loader, classes = get_data_loader(
    target_classes=["cat", "dog"],
    batch_size=384)

evaluate(net, test_loader, nn.BCEWithLogitsLoss())
```

```
Files already downloaded and verified
Files already downloaded and verified
(0.3565, 0.6999020874500275)
```

We can see that on my chosen two layer ANN, the classification error is around ~6% worse on the test set in terms of test error (recall the best `LargeNet` model had an error rate of 0.2945). Although suprisingly, the two layer ANN performs rather similarly to the `LargeNet` model, even though it doesn't use convolutions, which should be the main advantage of the `LargeNet` as convolutions allow for the capturing of spatial features. Finally, note that while the large net training curves were mostly well behaved (training curves close to validation, and not clearly overfit), the loss curves for this 2 layer model showed overfitting if examining the loss curves. However, the error curves behaved the best and had the most amount of epochs scoring under 0.4 classification error on the validation set. I preferred the classification error given that the loss is really just a negative log-likelihood evaluation on the samples and is not the full story of genearlization performance, especially when this is a classification task. In this case, it seems that the region of the loss landscape the optimizer ended up in produced rather high loss values on the validation set but also produced relatively lower (in comparison to the other two layer ANN models) classification error, which is indicative of potentially better generalization performance on classification.



✓ 19s completed at 1:50 AM