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/drive/10ZeNA14w4lhVM40Yv3sXqwFcV_7oLS_1?usp=sharing

```python
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

def normalize_label(labels):
    """
    Given a tensor containing 2 possible values, normalize this to 0/1

    Args:
        labels: a 1D tensor containing two possible scalar values
    Returns:
        A tensor normalize to 0/1 value
    """
    max_val = torch.max(labels)
    min_val = torch.min(labels)
    norm_labels = (labels - min_val)/(max_val - min_val)
    return norm_labels

def evaluate(net, loader, criterion):
    """ Evaluate the network on the validation set.

     Args:
         net: PyTorch neural network object
        loader: PyTorch data loader for the validation set
        criterion: The loss function
    Returns:
        err: A scalar for the avg classification error over the
validation set
        loss: A scalar for the average loss function over the
validation set
    """
    total_loss = 0.0
    total_err = 0.0
    total_epoch = 0
    for i, data in enumerate(loader, 0):
        inputs, labels = data
        labels = normalize_label(labels)  # Convert labels to 0/1
        outputs = net(inputs)
        loss = criterion(outputs, labels.float())
        corr = (outputs > 0.0).squeeze().long() != labels
        total_err += int(corr.sum())
        total_loss += loss.item()
        total_epoch += len(labels)
    err = float(total_err) / total_epoch
    loss = float(total_loss) / (i + 1)
    return err, loss

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

    Args:
        path: The base path of the csv files produced during training
    """
    import matplotlib.pyplot as plt
    train_err = np.loadtxt("{}_train_err.csv".format(path))
    val_err = np.loadtxt("{}_val_err.csv".format(path))
    train_loss = np.loadtxt("{}_train_loss.csv".format(path))
    val_loss = np.loadtxt("{}_val_loss.csv".format(path))
    plt.title("Train vs Validation Error")
    n = len(train_err) # number of epochs
    plt.plot(range(1,n+1), train_err, label="Train")
    plt.plot(range(1,n+1), val_err, label="Validation")
    plt.xlabel("Epoch")
    plt.ylabel("Error")
    plt.legend(loc='best')
    plt.show()
    plt.title("Train vs Validation Loss")
    plt.plot(range(1,n+1), train_loss, label="Train")
    plt.plot(range(1,n+1), val_loss, label="Validation")
    plt.xlabel("Epoch")
    plt.ylabel("Loss")
    plt.legend(loc='best')
    plt.show()
```

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
```

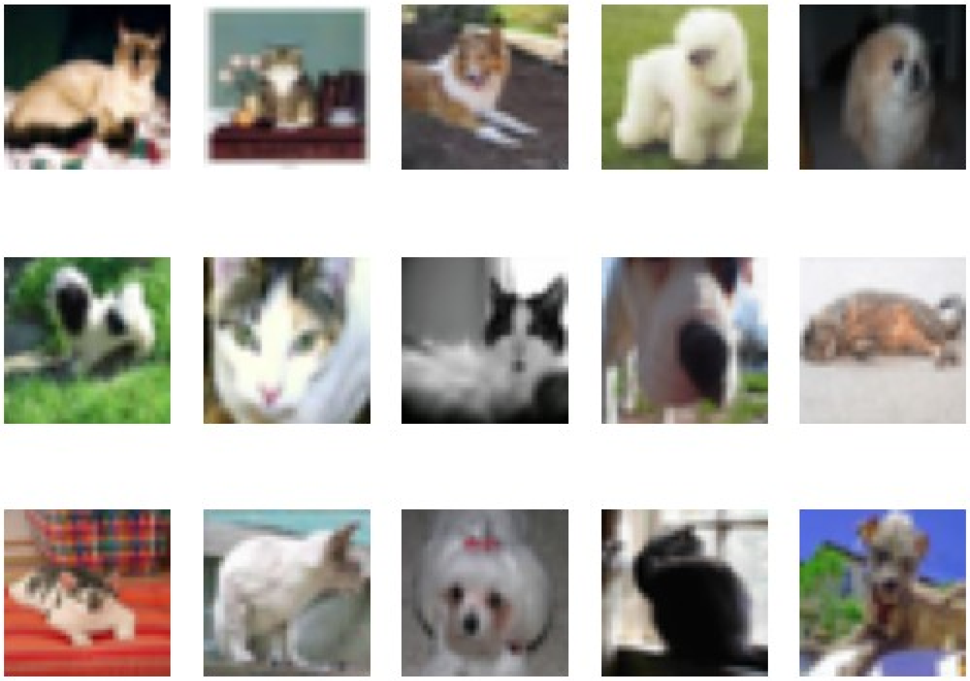
```
Downloading https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz to
./data/cifar-10-python.tar.gz

100%|██████████| 170498071/170498071 [00:01<00:00, 105791520.74it/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?

```
print("Training examples:", len(train_loader.dataset))
print("Validation examples:", len(val_loader.dataset))
print("Test examples:", len(test_loader.dataset))

Training examples: 50000
Validation examples: 50000
Test examples: 10000
```

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?

```
# A validation set is needed to test the model on unseen data, helping
to avoid
# overfitting by ensuring the model doesn't just memorize the training
data but
```

```
# learns to generalize. We would also need something to track
validation
# accuracy in the training curve.

# Judging a model only by its performance on the training set can
mislead you
# into thinking it's better than it actually is, as it may not perform
well on
# new, unseen data.
```

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.

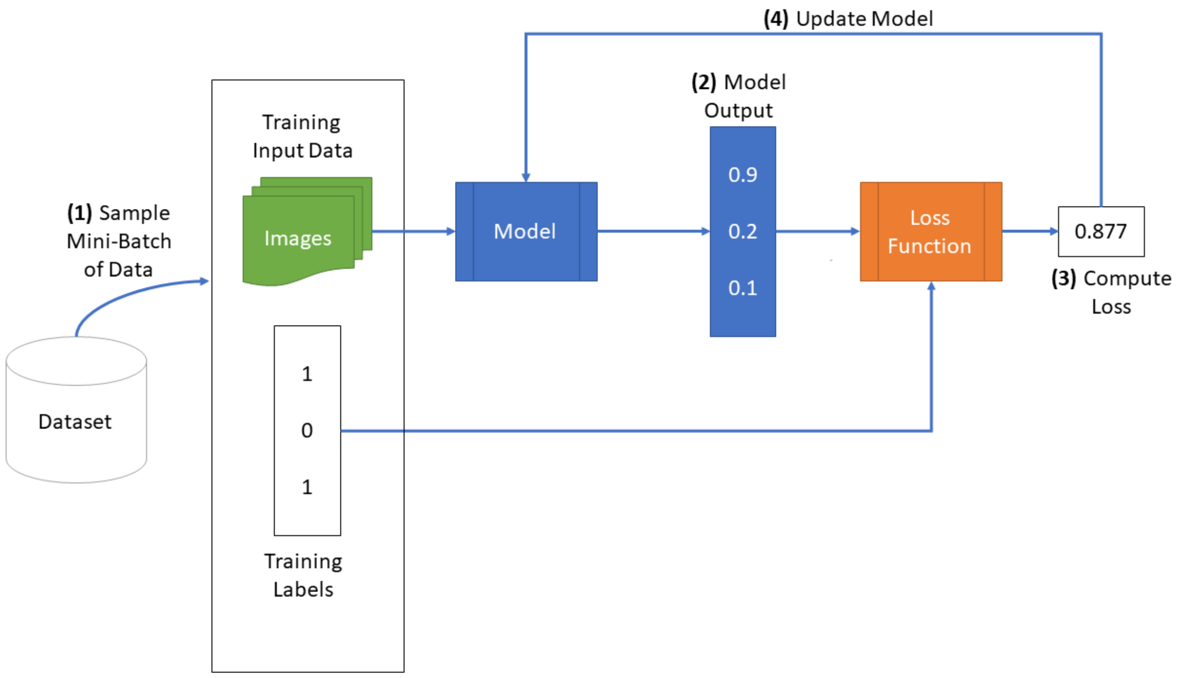
We haven't learned how how the parameters in these high-dimensional tensors will be used, but we should be able to count the number of parameters. Measuring the number of parameters in a network is one way of measuring the "size" of a network.

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)
# The total number of parameters in small_net is:
# (5*3*3*3)+(5)+(1*245)+(1)=386

for param in large_net.parameters():
    print(param.shape)
# The total number of parameters in large_net is:
# (5*3*5*5)+(5)+(10*5*5*5)+(10)+(32*250)+(32)+(1*32)+(1)=9705

torch.Size([5, 3, 3, 3])
torch.Size([5])
torch.Size([1, 245])
torch.Size([1])
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])
```

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`?

```
# batch_size = 64
# learning_rate = 0.01
# num_epochs = 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.

```
small_net = SmallNet()
train_net(small_net, num_epochs=5)

# Files written to disk

# model_small_bs64_lr0.01_epoch0: checkpoint after epoch 0
# model_small_bs64_lr0.01_epoch1: checkpoint after epoch 1
# model_small_bs64_lr0.01_epoch2: checkpoint after epoch 2
# model_small_bs64_lr0.01_epoch3: checkpoint after epoch 3
# model_small_bs64_lr0.01_epoch4: checkpoint after epoch 4

# model_small_bs64_lr0.01_epoch4_train_err.csv: file containing
training error
# model_small_bs64_lr0.01_epoch4_train_loss.csv: file containing
```

```
training loss
# model_small_bs64_lr0.01_epoch4_val_err.csv: file containing
validation error
# model_small_bs64_lr0.01_epoch4_val_loss.csv: file containing
validation loss

Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.43275, Train loss: 0.6750623955726623 |
Validation err: 0.381, Validation loss: 0.6581626161932945
Epoch 2: Train err: 0.371875, Train loss: 0.6496369152069091 |
Validation err: 0.384, Validation loss: 0.6638244986534119
Epoch 3: Train err: 0.35025, Train loss: 0.6355056324005127 |
Validation err: 0.353, Validation loss: 0.6260157078504562
Epoch 4: Train err: 0.339375, Train loss: 0.6214285769462585 |
Validation err: 0.354, Validation loss: 0.624940775334835
Epoch 5: Train err: 0.334125, Train loss: 0.6118814716339112 |
Validation err: 0.3265, Validation loss: 0.6122822929173708
Finished Training
Total time elapsed: 15.39 seconds
```

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')

Mounted at /content/gdrive

train_net(small_net) # Total time elapsed: 87.89 seconds
train_net(large_net) # Total time elapsed: 97.51 seconds

# large_net took longer to train because it has more parameters

Files already downloaded and verified
Files already downloaded and verified
```

```
Epoch 1: Train err: 0.32075, Train loss: 0.6001654999256134 |
Validation err: 0.3375, Validation loss: 0.6160770282149315
Epoch 2: Train err: 0.315375, Train loss: 0.5937726888656616 |
Validation err: 0.3385, Validation loss: 0.6340117994695902
Epoch 3: Train err: 0.30825, Train loss: 0.5896465487480164 |
Validation err: 0.314, Validation loss: 0.606388745829463
Epoch 4: Train err: 0.311375, Train loss: 0.5856761095523835 |
Validation err: 0.328, Validation loss: 0.6113690435886383
Epoch 5: Train err: 0.30225, Train loss: 0.5831401715278626 |
Validation err: 0.308, Validation loss: 0.6056779511272907
Epoch 6: Train err: 0.302875, Train loss: 0.5780168986320495 |
Validation err: 0.3105, Validation loss: 0.6076986379921436
Epoch 7: Train err: 0.3015, Train loss: 0.5758937051296235 |Validation
err: 0.323, Validation loss: 0.6030783243477345
Epoch 8: Train err: 0.301875, Train loss: 0.5725233724117279 |
Validation err: 0.32, Validation loss: 0.6055176518857479
Epoch 9: Train err: 0.298, Train loss: 0.5728731179237365 |Validation
err: 0.328, Validation loss: 0.6091796448454261
Epoch 10: Train err: 0.294375, Train loss: 0.5680857949256897 |
Validation err: 0.324, Validation loss: 0.6034962432458997
Epoch 11: Train err: 0.29575, Train loss: 0.5672789976596833 |
Validation err: 0.323, Validation loss: 0.6053986735641956
Epoch 12: Train err: 0.292375, Train loss: 0.5627782278060913 |
Validation err: 0.316, Validation loss: 0.6011649258434772
Epoch 13: Train err: 0.294875, Train loss: 0.5666881003379822 |
Validation err: 0.3215, Validation loss: 0.6052737953141332
Epoch 14: Train err: 0.288625, Train loss: 0.5624566309452057 |
Validation err: 0.3305, Validation loss: 0.6153043657541275
Epoch 15: Train err: 0.29175, Train loss: 0.5615632283687592 |
Validation err: 0.3285, Validation loss: 0.6142218951135874
Epoch 16: Train err: 0.292, Train loss: 0.5672653877735138 |Validation
err: 0.327, Validation loss: 0.6161343650892377
Epoch 17: Train err: 0.291, Train loss: 0.5630094616413116 |Validation
err: 0.3215, Validation loss: 0.6008257139474154
Epoch 18: Train err: 0.290875, Train loss: 0.5610948503017426 |
Validation err: 0.3275, Validation loss: 0.599173647351563
Epoch 19: Train err: 0.285375, Train loss: 0.5566081831455231 |
Validation err: 0.33, Validation loss: 0.6196505427360535
Epoch 20: Train err: 0.283875, Train loss: 0.5579070656299591 |
Validation err: 0.3185, Validation loss: 0.6068644756451249
Epoch 21: Train err: 0.28775, Train loss: 0.5599466969966889 |
Validation err: 0.317, Validation loss: 0.6008214484900236
Epoch 22: Train err: 0.289375, Train loss: 0.5601010990142822 |
Validation err: 0.3245, Validation loss: 0.6129764560610056
Epoch 23: Train err: 0.284, Train loss: 0.5576876988410949 |Validation
err: 0.313, Validation loss: 0.6002160776406527
Epoch 24: Train err: 0.28275, Train loss: 0.5538270087242126 |
Validation err: 0.3075, Validation loss: 0.6007529767230153
Epoch 25: Train err: 0.286, Train loss: 0.5545855436325073 |Validation
```

```
err: 0.3225, Validation loss: 0.6041560107842088
Epoch 26: Train err: 0.284625, Train loss: 0.5557803564071655 |
Validation err: 0.3205, Validation loss: 0.6072382936254144
Epoch 27: Train err: 0.2805, Train loss: 0.5539706726074218 |
Validation err: 0.315, Validation loss: 0.6098390519618988
Epoch 28: Train err: 0.28075, Train loss: 0.5540334072113037 |
Validation err: 0.3205, Validation loss: 0.5990819809958339
Epoch 29: Train err: 0.286, Train loss: 0.5562302494049072 |Validation
err: 0.315, Validation loss: 0.6086240578442812
Epoch 30: Train err: 0.2775, Train loss: 0.5522372324466706 |
Validation err: 0.3255, Validation loss: 0.6091442313045263
Finished Training
Total time elapsed: 87.89 seconds
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.455875, Train loss: 0.6898005332946777 |
Validation err: 0.42, Validation loss: 0.6789227221161127
Epoch 2: Train err: 0.42075, Train loss: 0.677659417629242 |Validation
err: 0.433, Validation loss: 0.6792405322194099
Epoch 3: Train err: 0.401875, Train loss: 0.6654470906257629 |
Validation err: 0.3815, Validation loss: 0.6485890541225672
Epoch 4: Train err: 0.368875, Train loss: 0.6469981565475463 |
Validation err: 0.3705, Validation loss: 0.6400767955929041
Epoch 5: Train err: 0.356, Train loss: 0.6308781847953796 |Validation
err: 0.349, Validation loss: 0.6240914296358824
Epoch 6: Train err: 0.337625, Train loss: 0.6159418187141419 |
Validation err: 0.331, Validation loss: 0.6148061752319336
Epoch 7: Train err: 0.32725, Train loss: 0.6027624526023865 |
Validation err: 0.337, Validation loss: 0.6064695063978434
Epoch 8: Train err: 0.311625, Train loss: 0.5864601356983185 |
Validation err: 0.3285, Validation loss: 0.6002039462327957
Epoch 9: Train err: 0.305, Train loss: 0.580260261297226 |Validation
err: 0.3245, Validation loss: 0.5950973657891154
Epoch 10: Train err: 0.295125, Train loss: 0.5654756438732147 |
Validation err: 0.316, Validation loss: 0.589879828505218
Epoch 11: Train err: 0.28775, Train loss: 0.5537578790187836 |
Validation err: 0.3085, Validation loss: 0.5859386436641216
Epoch 12: Train err: 0.273375, Train loss: 0.539053367137909 |
Validation err: 0.309, Validation loss: 0.5814298605546355
Epoch 13: Train err: 0.2735, Train loss: 0.5335126321315765 |
Validation err: 0.315, Validation loss: 0.5896247252821922
Epoch 14: Train err: 0.259625, Train loss: 0.5164484293460846 |
Validation err: 0.3055, Validation loss: 0.5819545490667224
Epoch 15: Train err: 0.25325, Train loss: 0.5125630114078522 |
Validation err: 0.2935, Validation loss: 0.5702709592878819
Epoch 16: Train err: 0.25225, Train loss: 0.5099849009513855 |
Validation err: 0.2945, Validation loss: 0.5685750562697649
Epoch 17: Train err: 0.244625, Train loss: 0.49768942093849183 |
Validation err: 0.2945, Validation loss: 0.5717707984149456
```

```
Epoch 18: Train err: 0.242625, Train loss: 0.4826437952518463 |
Validation err: 0.308, Validation loss: 0.5783763285726309
Epoch 19: Train err: 0.239125, Train loss: 0.4783159794807434 |
Validation err: 0.294, Validation loss: 0.5751320468261838
Epoch 20: Train err: 0.225625, Train loss: 0.46587873005867003 |
Validation err: 0.2975, Validation loss: 0.5719575732946396
Epoch 21: Train err: 0.2275, Train loss: 0.4578790512084961 |
Validation err: 0.295, Validation loss: 0.5854484271258116
Epoch 22: Train err: 0.212875, Train loss: 0.4426322093009949 |
Validation err: 0.2895, Validation loss: 0.6023599095642567
Epoch 23: Train err: 0.211625, Train loss: 0.439261545419693 |
Validation err: 0.297, Validation loss: 0.5798414368182421
Epoch 24: Train err: 0.201625, Train loss: 0.42281155157089234 |
Validation err: 0.29, Validation loss: 0.5895498618483543
Epoch 25: Train err: 0.192, Train loss: 0.4079967005252838 |Validation
err: 0.2955, Validation loss: 0.6151111563667655
Epoch 26: Train err: 0.183125, Train loss: 0.38918790316581725 |
Validation err: 0.282, Validation loss: 0.6292725810781121
Epoch 27: Train err: 0.178625, Train loss: 0.3870407974720001 |
Validation err: 0.299, Validation loss: 0.6327890455722809
Epoch 28: Train err: 0.175125, Train loss: 0.3769093055725098 |
Validation err: 0.2955, Validation loss: 0.6174397924914956
Epoch 29: Train err: 0.16725, Train loss: 0.3661430332660675 |
Validation err: 0.3115, Validation loss: 0.7061819490045309
Epoch 30: Train err: 0.162, Train loss: 0.35297489547729494 |
Validation err: 0.3, Validation loss: 0.6480715395882726
Finished Training
Total time elapsed: 97.51 seconds
```

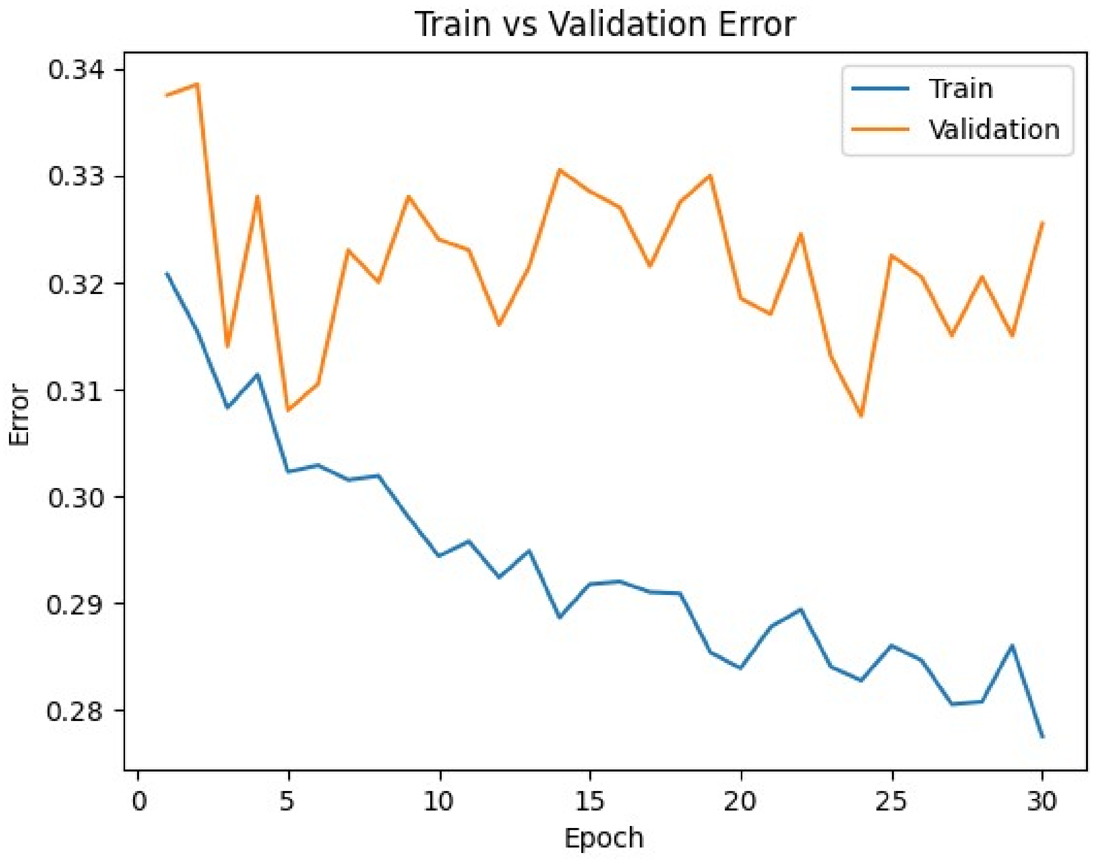
Part (e) - 2pt

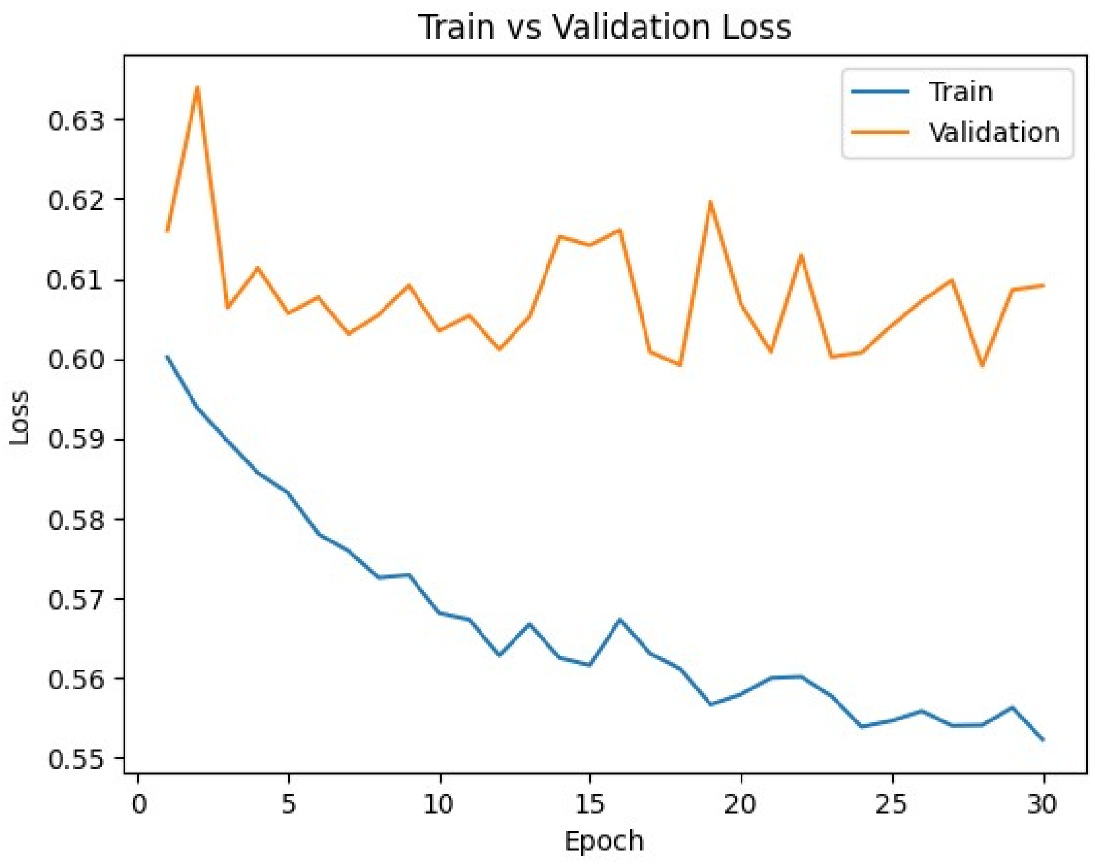
Use the function `plot_training_curve` to display the trajectory of the training/validation error and the training/validation loss. You will need to use the function `get_model_name` to generate the argument to the `plot_training_curve` function.

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

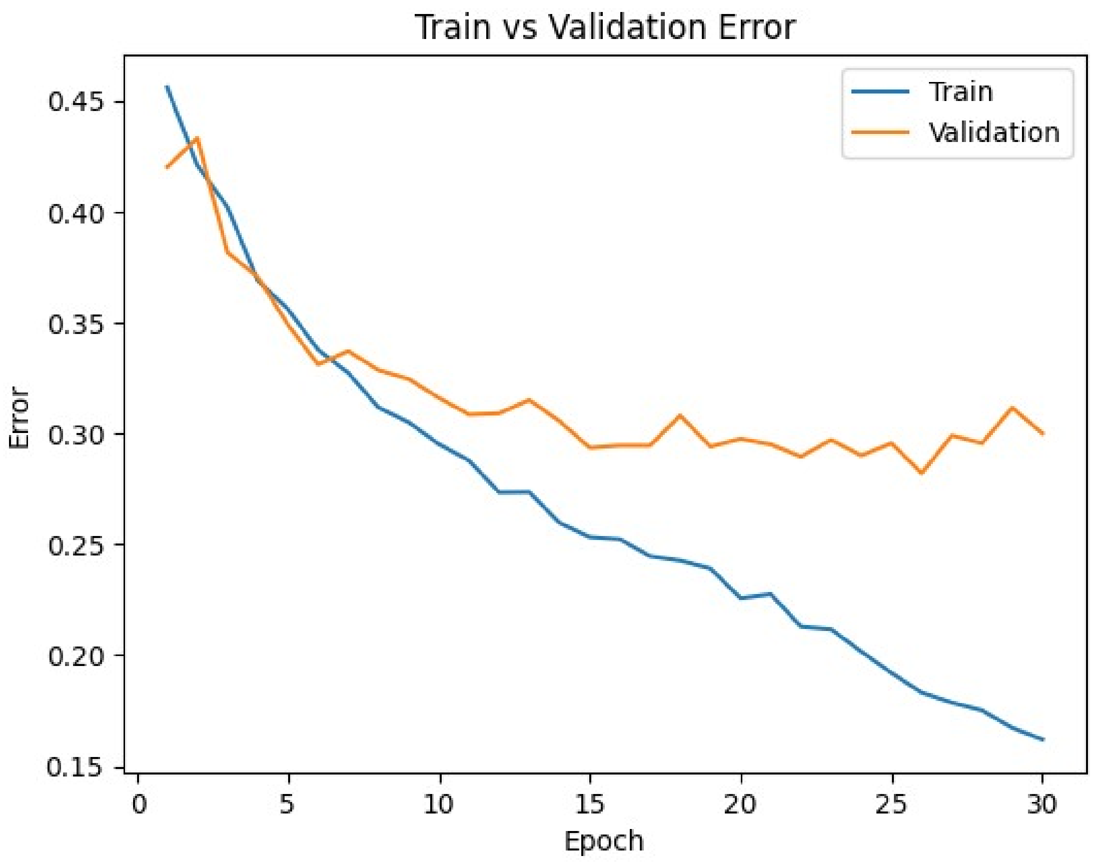
```
#model_path = get_model_name("small", batch_size=??, learning_rate=??,
epoch=29)

print("Training curve: small_net")
model_path_small = get_model_name("small", batch_size=64,
learning_rate=0.01, epoch=29)
plot_training_curve(model_path_small)
print("Training curve: large_net")
model_path_large = get_model_name("large", batch_size=64,
learning_rate=0.01, epoch=29)
plot_training_curve(model_path_large)
```

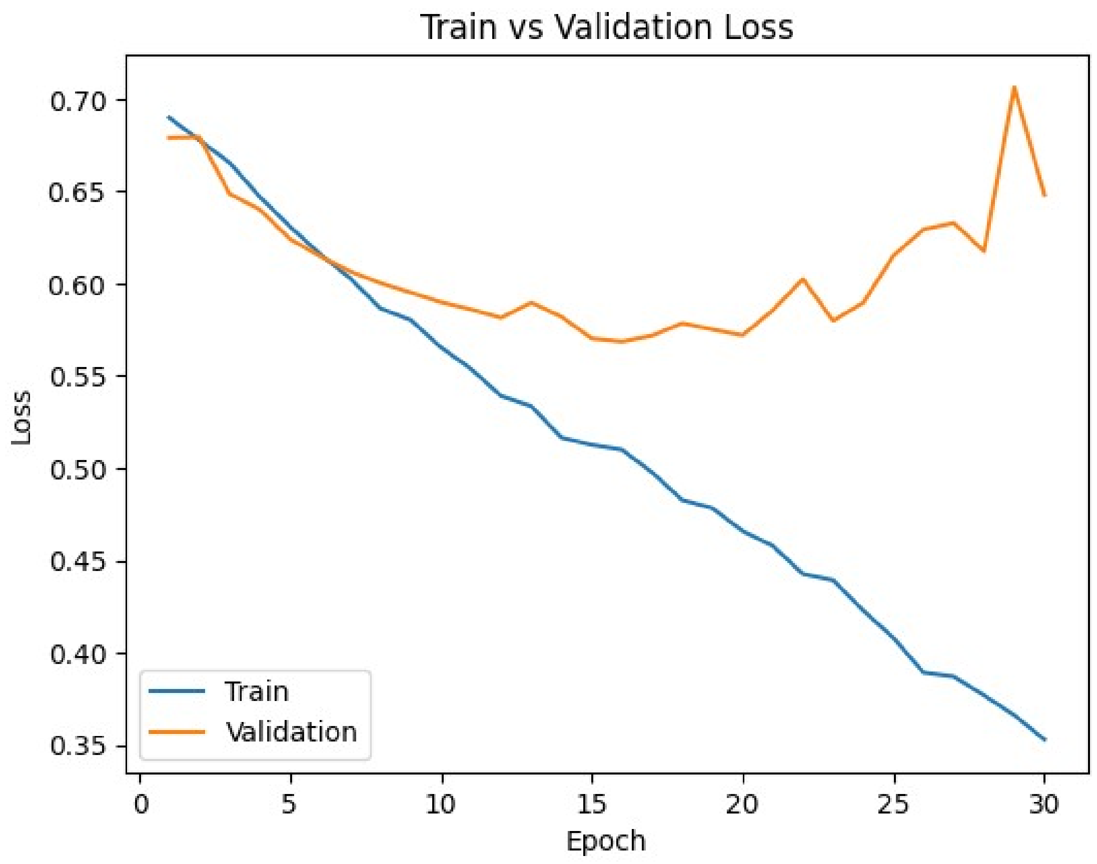
```
Training curve: small_net
```





```
Training curve: large_net
```


Train vs Validation Error
Train
Validation
Error
Epoch
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0
5
10
15
20
25
30



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.

```
# For small_net, the model shows underfitting near the beginning of the curves
# for both validation error and loss graphs. The train and validation curves are
# also qutie far apart.

# For large_net, the model shows underfitting near the beginning and it
# eventually leads to overfitting near the end. The training error and loss
# continues decreasing as epoch increases, but validation error and loss slowly
# stops decreasing around the half-way point.
```

Part 3. Optimization Parameters [12 pt]

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

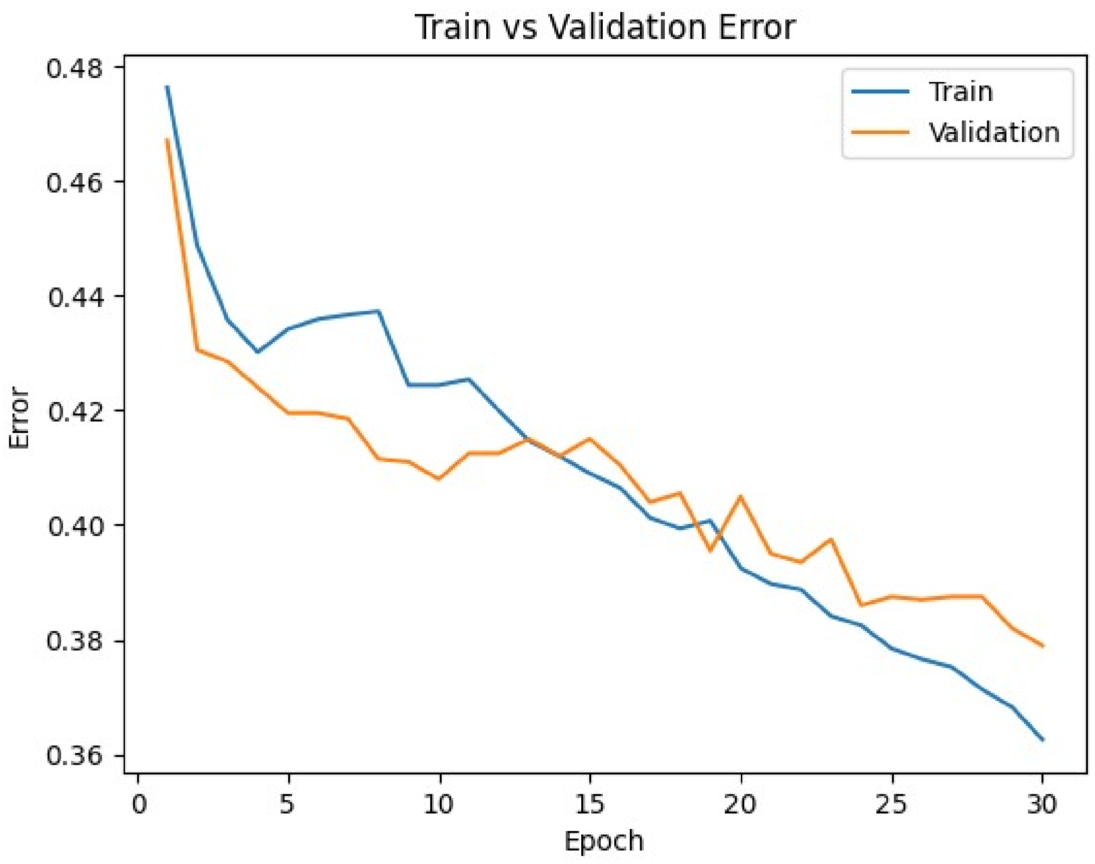
Part (a) - 3pt

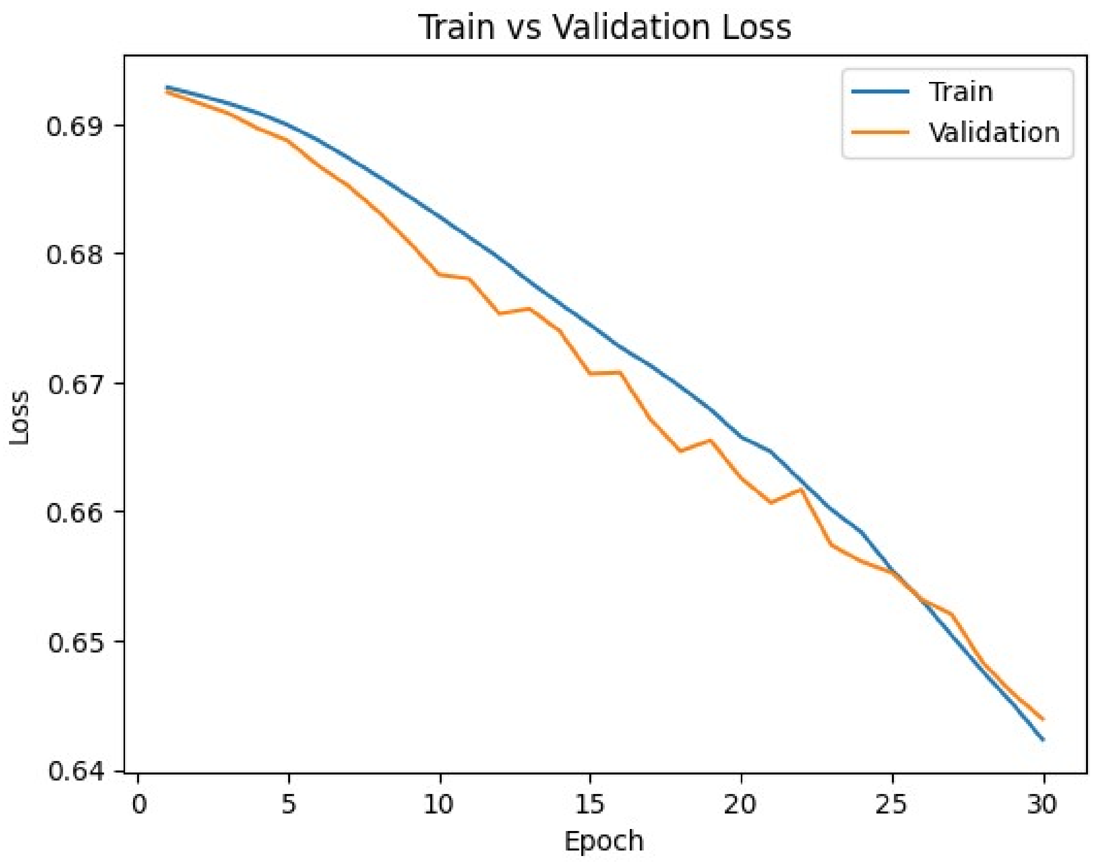
Train `large_net` with all default parameters, except set `learning_rate=0.001`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *lowering* the learning rate.

```
# 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()
train_net(large_net, 64, 0.001, 30)
model_path_large = get_model_name("large", batch_size=64,
learning_rate=0.001, epoch=29)
plot_training_curve(model_path_large)

# Total time elapsed: 94.83 seconds
# The model takes approximately the same to train.
# Lowering the learning rate does not significantly change the
training time but
# results in higher error and loss on the training data. For
validation data,
# while the error is higher, the lower learning rate helps avoid
overfitting,
# indicating that 0.001 may be too slow for efficient training in this
case.
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.47625, Train loss: 0.6928360028266907 |
Validation err: 0.467, Validation loss: 0.6924686599522829
Epoch 2: Train err: 0.448625, Train loss: 0.6922589740753173 |
Validation err: 0.4305, Validation loss: 0.6916493307799101
Epoch 3: Train err: 0.43575, Train loss: 0.6916067419052124 |
Validation err: 0.4285, Validation loss: 0.6908544395118952
Epoch 4: Train err: 0.430125, Train loss: 0.6908613877296448 |
Validation err: 0.424, Validation loss: 0.6896596923470497
Epoch 5: Train err: 0.434125, Train loss: 0.6899198365211486 |
Validation err: 0.4195, Validation loss: 0.6886942777782679
Epoch 6: Train err: 0.435875, Train loss: 0.6887419753074646 |
Validation err: 0.4195, Validation loss: 0.6867837514728308
Epoch 7: Train err: 0.436625, Train loss: 0.6873781814575195 |
Validation err: 0.4185, Validation loss: 0.6851996649056673
Epoch 8: Train err: 0.43725, Train loss: 0.6859267921447754 |
Validation err: 0.4115, Validation loss: 0.6831991747021675
Epoch 9: Train err: 0.424375, Train loss: 0.6844045443534851 |
Validation err: 0.411, Validation loss: 0.6808868050575256
Epoch 10: Train err: 0.424375, Train loss: 0.682848952293396 |
Validation err: 0.408, Validation loss: 0.6783499345183372
Epoch 11: Train err: 0.425375, Train loss: 0.6812354407310486 |
Validation err: 0.4125, Validation loss: 0.6780234910547733
```

```
Epoch 12: Train err: 0.419875, Train loss: 0.6796327586174011 |
Validation err: 0.4125, Validation loss: 0.6753160189837217
Epoch 13: Train err: 0.414625, Train loss: 0.6777928824424744 |
Validation err: 0.415, Validation loss: 0.6757084671407938
Epoch 14: Train err: 0.412, Train loss: 0.6761129403114319 |Validation
err: 0.412, Validation loss: 0.6739710867404938
Epoch 15: Train err: 0.409, Train loss: 0.6744727687835693 |Validation
err: 0.415, Validation loss: 0.6706812102347612
Epoch 16: Train err: 0.4065, Train loss: 0.67274143409729 |Validation
err: 0.4105, Validation loss: 0.670768965035677
Epoch 17: Train err: 0.40125, Train loss: 0.6713059720993042 |
Validation err: 0.404, Validation loss: 0.66715326346457
Epoch 18: Train err: 0.399375, Train loss: 0.6696724286079406 |
Validation err: 0.4055, Validation loss: 0.6646785754710436
Epoch 19: Train err: 0.40075, Train loss: 0.6679023985862732 |
Validation err: 0.3955, Validation loss: 0.6655161324888468
Epoch 20: Train err: 0.3925, Train loss: 0.6657856888771058 |
Validation err: 0.405, Validation loss: 0.6625996753573418
Epoch 21: Train err: 0.38975, Train loss: 0.6646266269683838 |
Validation err: 0.395, Validation loss: 0.6606872715055943
Epoch 22: Train err: 0.38875, Train loss: 0.6623701963424683 |
Validation err: 0.3935, Validation loss: 0.6617010589689016
Epoch 23: Train err: 0.384125, Train loss: 0.6601490645408631 |
Validation err: 0.3975, Validation loss: 0.6573988571763039
Epoch 24: Train err: 0.3825, Train loss: 0.6583953781127929 |
Validation err: 0.386, Validation loss: 0.6561295725405216
Epoch 25: Train err: 0.3785, Train loss: 0.6554959454536438 |
Validation err: 0.3875, Validation loss: 0.6552845854312181
Epoch 26: Train err: 0.376625, Train loss: 0.6531237239837646 |
Validation err: 0.387, Validation loss: 0.6531836222857237
Epoch 27: Train err: 0.37525, Train loss: 0.6503791484832764 |
Validation err: 0.3875, Validation loss: 0.652014534920454
Epoch 28: Train err: 0.371375, Train loss: 0.6476589822769165 |
Validation err: 0.3875, Validation loss: 0.6483639199286699
Epoch 29: Train err: 0.36825, Train loss: 0.6451378240585327 |
Validation err: 0.382, Validation loss: 0.6459472719579935
Epoch 30: Train err: 0.362625, Train loss: 0.6423516173362732 |
Validation err: 0.379, Validation loss: 0.6439454797655344
Finished Training
Total time elapsed: 94.83 seconds
```


Train vs Validation Error
Train
Validation
Error
Epoch
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0
5
10
15
20
25
30



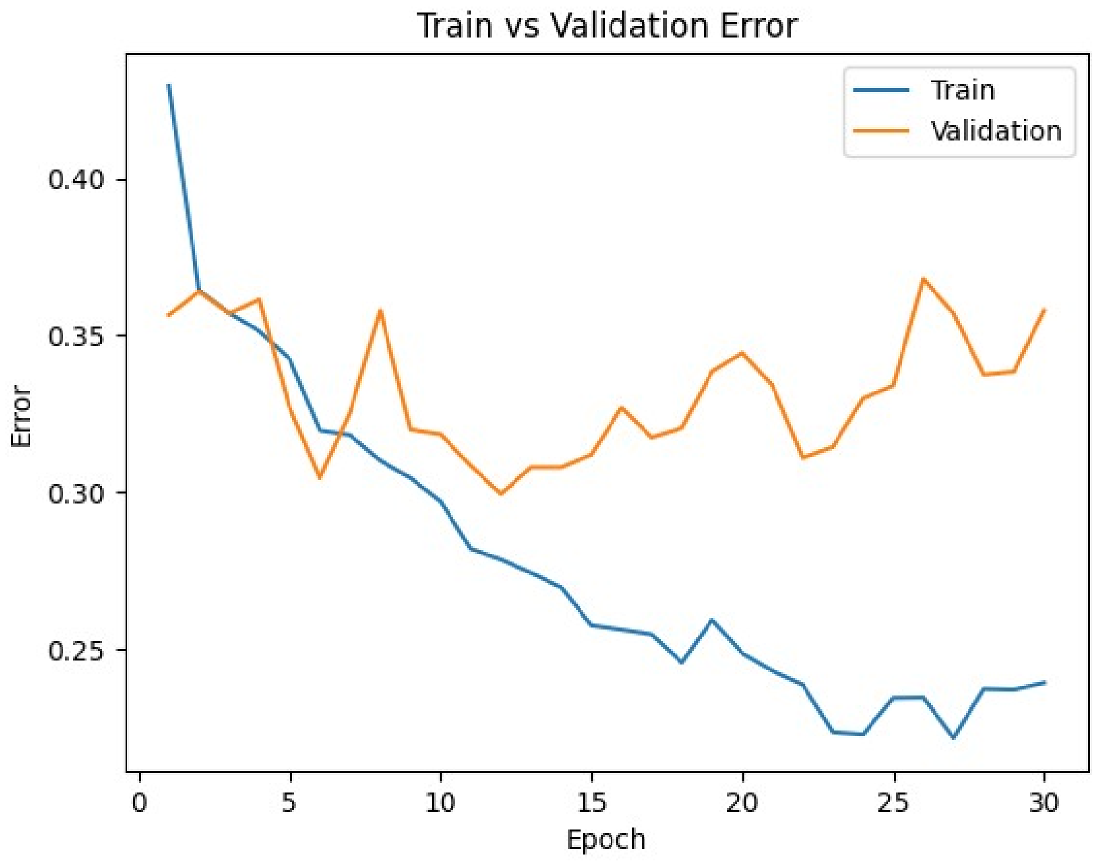
Part (b) - 3pt

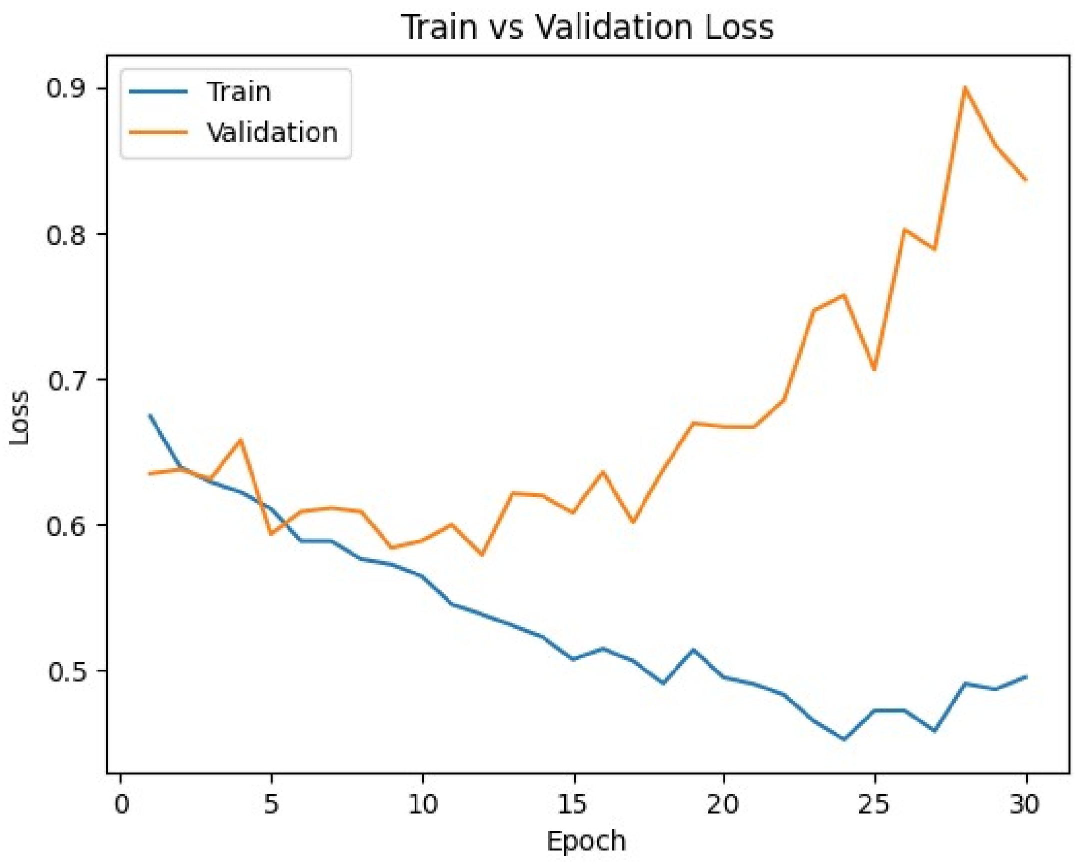
Train `large_net` with all default parameters, except set `learning_rate=0.1`. Does the model take longer/shorter to train? Plot the training curve. Describe the effect of *increasing* the learning rate.

```
large_net = LargeNet()
train_net(large_net, 64, 0.1, 30)
model_path_large = get_model_name("large", batch_size=64,
learning_rate=0.1, epoch=29)
plot_training_curve(model_path_large)

# Total time elapsed: 94.88 seconds
# The model takes approximately the same to train.
# Increasing the learning rate does not significantly change the
training time
# but results in slightly higher error and loss on the training data.
For
# validation data, it increases around the half-way point indicated
overfitting.
# This indicates that 0.1 may be too fast.
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.4295, Train loss: 0.6743808498382569 |Validation
err: 0.3565, Validation loss: 0.6350402869284153
Epoch 2: Train err: 0.364375, Train loss: 0.6394594783782959 |
Validation err: 0.364, Validation loss: 0.6380155384540558
Epoch 3: Train err: 0.357125, Train loss: 0.6292509632110596 |
Validation err: 0.357, Validation loss: 0.6313505992293358
Epoch 4: Train err: 0.351375, Train loss: 0.6222558770179748 |
Validation err: 0.3615, Validation loss: 0.6581139843910933
Epoch 5: Train err: 0.3425, Train loss: 0.6109966540336609 |Validation
err: 0.327, Validation loss: 0.593532383441925
Epoch 6: Train err: 0.31975, Train loss: 0.5888414912223816 |
Validation err: 0.3045, Validation loss: 0.6088876193389297
Epoch 7: Train err: 0.31825, Train loss: 0.5887727000713349 |
Validation err: 0.3255, Validation loss: 0.6114899981766939
Epoch 8: Train err: 0.310125, Train loss: 0.5762689855098725 |
Validation err: 0.358, Validation loss: 0.6087798178195953
Epoch 9: Train err: 0.304625, Train loss: 0.5726798589229584 |
Validation err: 0.32, Validation loss: 0.5841292049735785
Epoch 10: Train err: 0.297125, Train loss: 0.5647666845321655 |
Validation err: 0.3185, Validation loss: 0.5889163985848427
Epoch 11: Train err: 0.282, Train loss: 0.5454324214458466 |Validation
err: 0.3085, Validation loss: 0.600019222125411
Epoch 12: Train err: 0.278625, Train loss: 0.5384270005226135 |
Validation err: 0.2995, Validation loss: 0.5790340006351471
Epoch 13: Train err: 0.274375, Train loss: 0.5309341120719909 |
Validation err: 0.308, Validation loss: 0.6213697791099548
Epoch 14: Train err: 0.26975, Train loss: 0.5229758756160736 |
Validation err: 0.308, Validation loss: 0.6198801156133413
Epoch 15: Train err: 0.257625, Train loss: 0.5075466320514679 |
Validation err: 0.312, Validation loss: 0.6081355484202504
Epoch 16: Train err: 0.25625, Train loss: 0.5148655683994293 |
Validation err: 0.327, Validation loss: 0.6360824098810554
Epoch 17: Train err: 0.25475, Train loss: 0.5065258400440216 |
Validation err: 0.3175, Validation loss: 0.601697607897222
Epoch 18: Train err: 0.24575, Train loss: 0.49124235701560975 |
Validation err: 0.3205, Validation loss: 0.6378643093630672
Epoch 19: Train err: 0.259375, Train loss: 0.5141446299552918 |
Validation err: 0.3385, Validation loss: 0.6695924252271652
Epoch 20: Train err: 0.24875, Train loss: 0.4952861943244934 |
Validation err: 0.3445, Validation loss: 0.6670713275671005
Epoch 21: Train err: 0.243125, Train loss: 0.4907743418216705 |
Validation err: 0.334, Validation loss: 0.6669150963425636
Epoch 22: Train err: 0.23875, Train loss: 0.48334857559204103 |
Validation err: 0.311, Validation loss: 0.6853150613605976
Epoch 23: Train err: 0.223625, Train loss: 0.4652157464027405 |
Validation err: 0.3145, Validation loss: 0.7470605578273535
Epoch 24: Train err: 0.222875, Train loss: 0.4526974799633026 |
Validation err: 0.33, Validation loss: 0.7572380006313324
```

```
Epoch 25: Train err: 0.2345, Train loss: 0.4724377233982086 |
Validation err: 0.334, Validation loss: 0.7064428050071001
Epoch 26: Train err: 0.234625, Train loss: 0.4725676612854004 |
Validation err: 0.368, Validation loss: 0.8023080676794052
Epoch 27: Train err: 0.22175, Train loss: 0.45844222140312196 |
Validation err: 0.357, Validation loss: 0.7886781524866819
Epoch 28: Train err: 0.237375, Train loss: 0.49102354764938355 |
Validation err: 0.3375, Validation loss: 0.8998023774474859
Epoch 29: Train err: 0.237125, Train loss: 0.4870765597820282 |
Validation err: 0.3385, Validation loss: 0.8601288255304098
Epoch 30: Train err: 0.239375, Train loss: 0.4954684257507324 |
Validation err: 0.358, Validation loss: 0.8366707749664783
Finished Training
Total time elapsed: 94.88 seconds
```



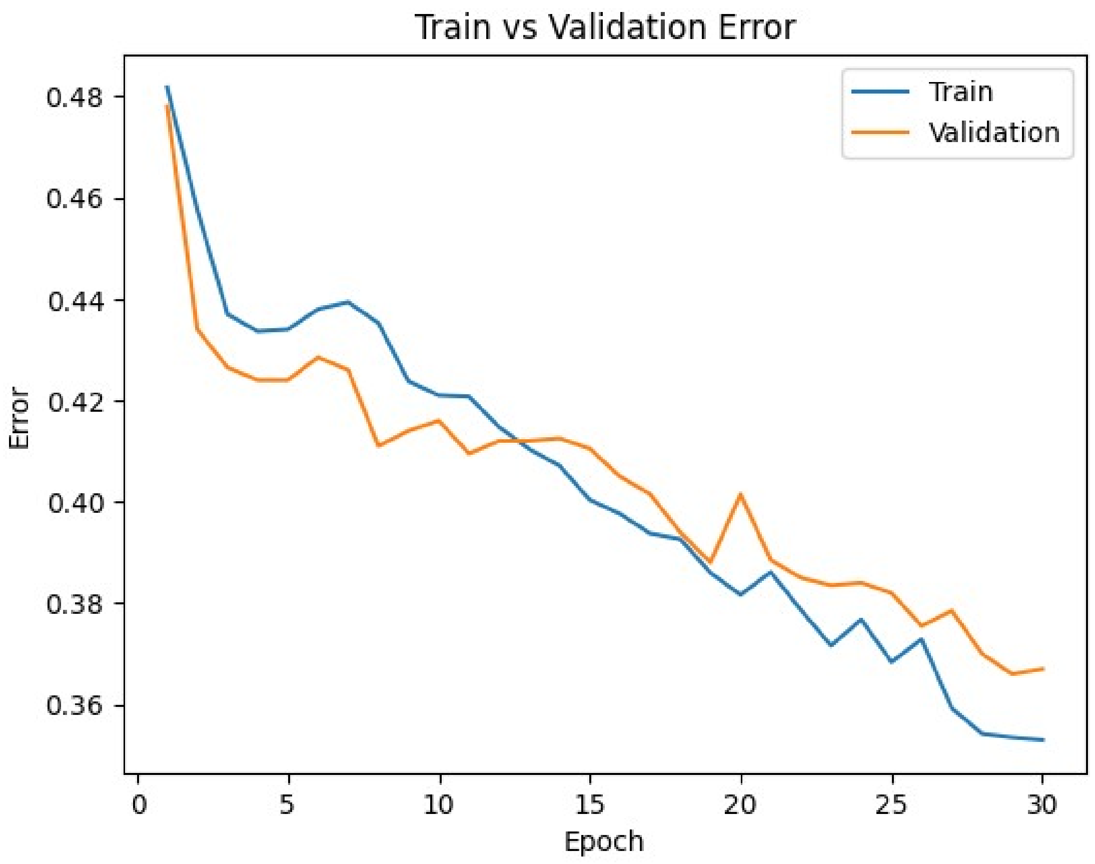


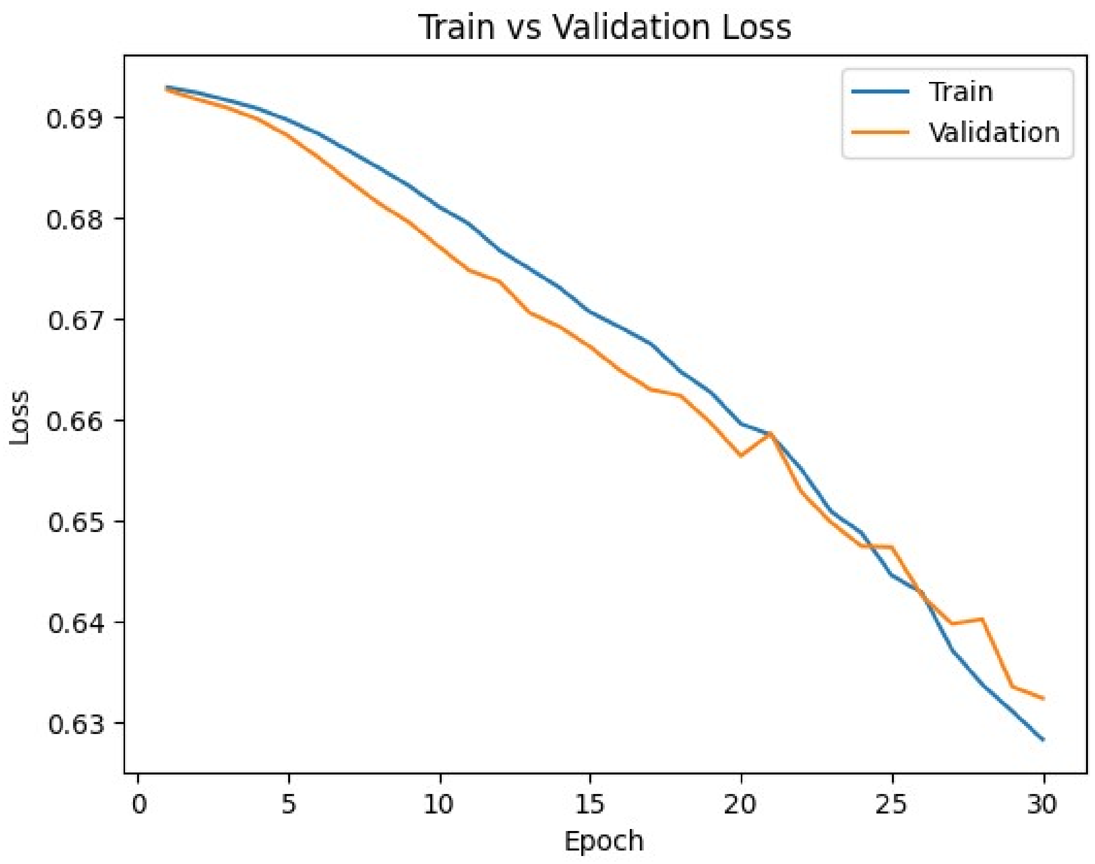
Part (c) - 3pt

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()
train_net(large_net, 512, 0.01, 30)
model_path_large = get_model_name("large", batch_size=512,
learning_rate=0.01, epoch=29)
plot_training_curve(model_path_large)

# Total time elapsed: 82.25 seconds
# The model takes shorter time to train.
# The increase in batch size means the number of iterations within
each epoch is
# smaller, reducing the training time. Increasing the batch size
eliminated the
# signs of overfitting.

Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.48175, Train loss: 0.6929379515349865 |
Validation err: 0.478, Validation loss: 0.6926823854446411
Epoch 2: Train err: 0.457625, Train loss: 0.6924104019999504 |
Validation err: 0.434, Validation loss: 0.6917425245046616
Epoch 3: Train err: 0.437, Train loss: 0.6916500590741634 |Validation
err: 0.4265, Validation loss: 0.6909129917621613
Epoch 4: Train err: 0.433625, Train loss: 0.6908449940383434 |
Validation err: 0.424, Validation loss: 0.6897870153188705
Epoch 5: Train err: 0.434, Train loss: 0.6896935552358627 |Validation
err: 0.424, Validation loss: 0.6881355047225952
Epoch 6: Train err: 0.438, Train loss: 0.6883531995117664 |Validation
err: 0.4285, Validation loss: 0.686011865735054
Epoch 7: Train err: 0.439375, Train loss: 0.6866871826350689 |
Validation err: 0.426, Validation loss: 0.6836968660354614
Epoch 8: Train err: 0.43525, Train loss: 0.6849770732223988 |
Validation err: 0.411, Validation loss: 0.6814672648906708
Epoch 9: Train err: 0.42375, Train loss: 0.6832008771598339 |
Validation err: 0.414, Validation loss: 0.6795914322137833
Epoch 10: Train err: 0.421, Train loss: 0.6811087839305401 |Validation
err: 0.416, Validation loss: 0.677154079079628
Epoch 11: Train err: 0.42075, Train loss: 0.6794031001627445 |
Validation err: 0.4095, Validation loss: 0.6748126447200775
Epoch 12: Train err: 0.41475, Train loss: 0.6768064312636852 |
Validation err: 0.412, Validation loss: 0.6737105250358582
Epoch 13: Train err: 0.410375, Train loss: 0.6749707795679569 |
Validation err: 0.412, Validation loss: 0.6706106513738632
Epoch 14: Train err: 0.407125, Train loss: 0.6730907596647739 |
Validation err: 0.4125, Validation loss: 0.6692123562097549
Epoch 15: Train err: 0.400375, Train loss: 0.6706820242106915 |
Validation err: 0.4105, Validation loss: 0.6672529578208923
Epoch 16: Train err: 0.397625, Train loss: 0.6691752374172211 |
Validation err: 0.405, Validation loss: 0.6649040132761002
Epoch 17: Train err: 0.39375, Train loss: 0.6675728745758533 |
Validation err: 0.4015, Validation loss: 0.6630261093378067
Epoch 18: Train err: 0.392625, Train loss: 0.6647983901202679 |
Validation err: 0.394, Validation loss: 0.6623890697956085
Epoch 19: Train err: 0.386, Train loss: 0.6627401672303677 |Validation
err: 0.388, Validation loss: 0.6597096621990204
Epoch 20: Train err: 0.381625, Train loss: 0.6596098616719246 |
Validation err: 0.4015, Validation loss: 0.6564301252365112
Epoch 21: Train err: 0.386125, Train loss: 0.6584997698664665 |
Validation err: 0.3885, Validation loss: 0.6586556434631348
Epoch 22: Train err: 0.378625, Train loss: 0.6551188267767429 |
Validation err: 0.385, Validation loss: 0.6528644561767578
Epoch 23: Train err: 0.371625, Train loss: 0.6508826948702335 |
Validation err: 0.3835, Validation loss: 0.649808794260025
Epoch 24: Train err: 0.37675, Train loss: 0.6487980298697948 |
Validation err: 0.384, Validation loss: 0.6474767625331879
Epoch 25: Train err: 0.368375, Train loss: 0.6445756293833256 |
Validation err: 0.382, Validation loss: 0.6473795771598816
```

```
Epoch 26: Train err: 0.372875, Train loss: 0.6428777538239956 |
Validation err: 0.3755, Validation loss: 0.6425858736038208
Epoch 27: Train err: 0.35925, Train loss: 0.6372104585170746 |
Validation err: 0.3785, Validation loss: 0.6397744864225388
Epoch 28: Train err: 0.35425, Train loss: 0.6337734051048756 |
Validation err: 0.37, Validation loss: 0.6402499973773956
Epoch 29: Train err: 0.3535, Train loss: 0.6310990080237389 |
Validation err: 0.366, Validation loss: 0.6335441172122955
Epoch 30: Train err: 0.353, Train loss: 0.6283206455409527 |Validation
err: 0.367, Validation loss: 0.6324219256639481
Finished Training
Total time elapsed: 82.25 seconds
```



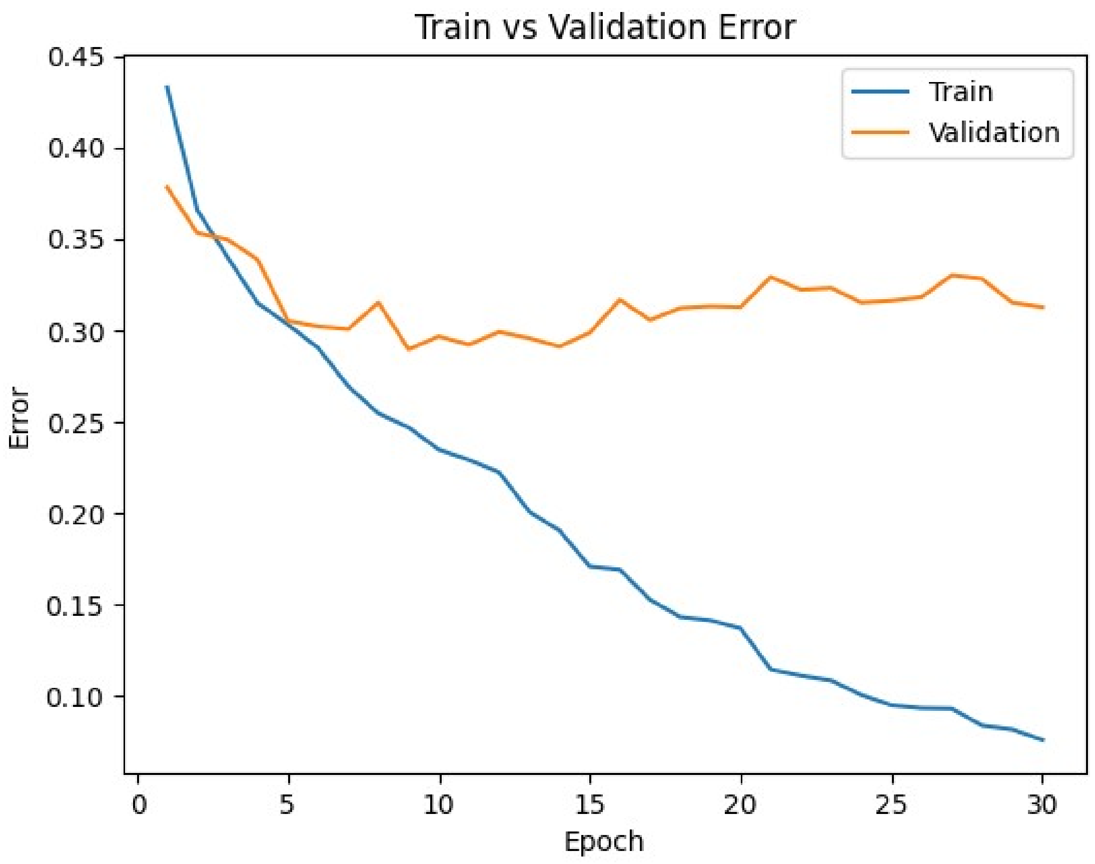


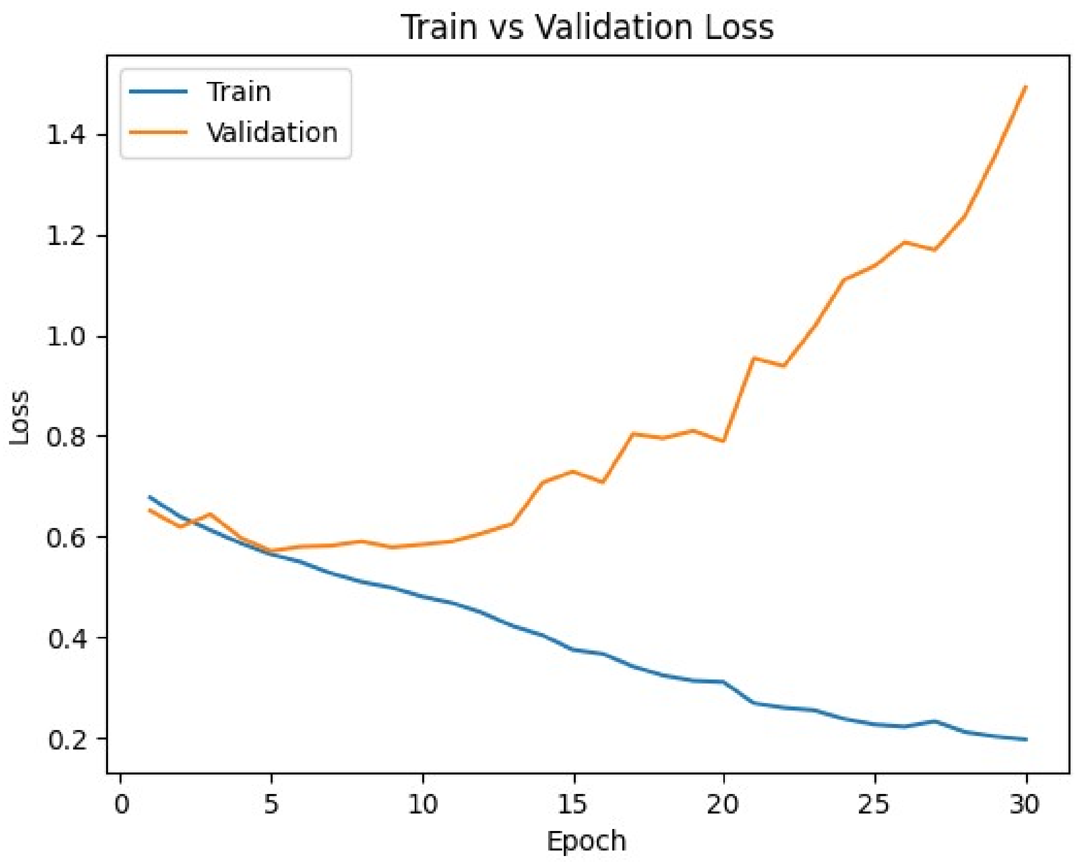
Part (d) - 3pt

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()
train_net(large_net, 16, 0.01, 30)
model_path_large = get_model_name("large", batch_size=16,
learning_rate=0.01, epoch=29)
plot_training_curve(model_path_large)

# Total time elapsed: 133.49 seconds
# The model takes longer time to train.
# The decrease in batch size means the number of iterations within
each epoch is
# larger, increasing the training time. The validation error and loss
both show
# overfitting.

Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.432625, Train loss: 0.6775506158471107 |
Validation err: 0.378, Validation loss: 0.6512571625709533
Epoch 2: Train err: 0.3655, Train loss: 0.6395608481168747 |Validation
err: 0.353, Validation loss: 0.6191524927616119
Epoch 3: Train err: 0.339875, Train loss: 0.6127814228534698 |
Validation err: 0.3495, Validation loss: 0.6442944076061249
Epoch 4: Train err: 0.31475, Train loss: 0.5870258185863495 |
Validation err: 0.3385, Validation loss: 0.5978640830516815
Epoch 5: Train err: 0.303, Train loss: 0.5651368154883385 |Validation
err: 0.305, Validation loss: 0.5715659594535828
Epoch 6: Train err: 0.29025, Train loss: 0.5493593747615815 |
Validation err: 0.302, Validation loss: 0.5801575357913971
Epoch 7: Train err: 0.26925, Train loss: 0.5272505192756652 |
Validation err: 0.3005, Validation loss: 0.5818900580406189
Epoch 8: Train err: 0.254375, Train loss: 0.5104012369215488 |
Validation err: 0.315, Validation loss: 0.5906455669403076
Epoch 9: Train err: 0.24675, Train loss: 0.4989313832819462 |
Validation err: 0.2895, Validation loss: 0.5788275961875915
Epoch 10: Train err: 0.234625, Train loss: 0.4812071683704853 |
Validation err: 0.2965, Validation loss: 0.58406099319458
Epoch 11: Train err: 0.229, Train loss: 0.4685571998953819 |Validation
err: 0.292, Validation loss: 0.5905215789079666
Epoch 12: Train err: 0.22225, Train loss: 0.44902220405638216 |
Validation err: 0.299, Validation loss: 0.6065930938720703
Epoch 13: Train err: 0.200625, Train loss: 0.4229303933084011 |
Validation err: 0.2955, Validation loss: 0.6251139466762543
Epoch 14: Train err: 0.190375, Train loss: 0.4043408792465925 |
Validation err: 0.291, Validation loss: 0.7069108620882034
Epoch 15: Train err: 0.17075, Train loss: 0.3758661460578442 |
Validation err: 0.2985, Validation loss: 0.7291838767528533
Epoch 16: Train err: 0.169, Train loss: 0.36747281277179716 |
Validation err: 0.3165, Validation loss: 0.7076600217819213
Epoch 17: Train err: 0.1525, Train loss: 0.34249910655617716 |
Validation err: 0.3055, Validation loss: 0.8037151482105255
Epoch 18: Train err: 0.143125, Train loss: 0.3244629814103246 |
Validation err: 0.312, Validation loss: 0.7955756268501282
Epoch 19: Train err: 0.14125, Train loss: 0.31422823867201805 |
Validation err: 0.313, Validation loss: 0.8098329643011093
Epoch 20: Train err: 0.136875, Train loss: 0.3117204641513526 |
Validation err: 0.3125, Validation loss: 0.788938661813736
Epoch 21: Train err: 0.114375, Train loss: 0.2696312564909458 |
Validation err: 0.329, Validation loss: 0.9542041051387787
Epoch 22: Train err: 0.111, Train loss: 0.26029947843030093 |
Validation err: 0.322, Validation loss: 0.9382650710344315
Epoch 23: Train err: 0.108375, Train loss: 0.2555502322986722 |
Validation err: 0.323, Validation loss: 1.0157140600681305
Epoch 24: Train err: 0.1005, Train loss: 0.23835007748007775 |
Validation err: 0.315, Validation loss: 1.109861346244812
Epoch 25: Train err: 0.094875, Train loss: 0.2270894316267222 |
Validation err: 0.316, Validation loss: 1.1367672670185567
```

```
Epoch 26: Train err: 0.09325, Train loss: 0.2228318989351392 |
Validation err: 0.318, Validation loss: 1.1843619964122771
Epoch 27: Train err: 0.093, Train loss: 0.23337606593593954 |
Validation err: 0.33, Validation loss: 1.1684871008992195
Epoch 28: Train err: 0.08375, Train loss: 0.21251985063403844 |
Validation err: 0.328, Validation loss: 1.2360798382759095
Epoch 29: Train err: 0.081625, Train loss: 0.2035546142552048 |
Validation err: 0.315, Validation loss: 1.356388526082039
Epoch 30: Train err: 0.075875, Train loss: 0.19755484854709357 |
Validation err: 0.3125, Validation loss: 1.4912220520973205
Finished Training
Total time elapsed: 133.49 seconds
```





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.

```
# Hyperparameters were chosen as:
  # network = large_net
  # batch_size = 256
  # learning_rate = 0.01
  # epoch = 30
# In the parts above, we saw that:
  # large_net works better than small_net
  # 0.01 was the better learning rate between 0.001, 0.01, and 0.1
  # Smaller batch_size resulted in overfitting, therefore having a
larger
  # batch_size would result in better curves
  # The number of epochs was kept the same
```

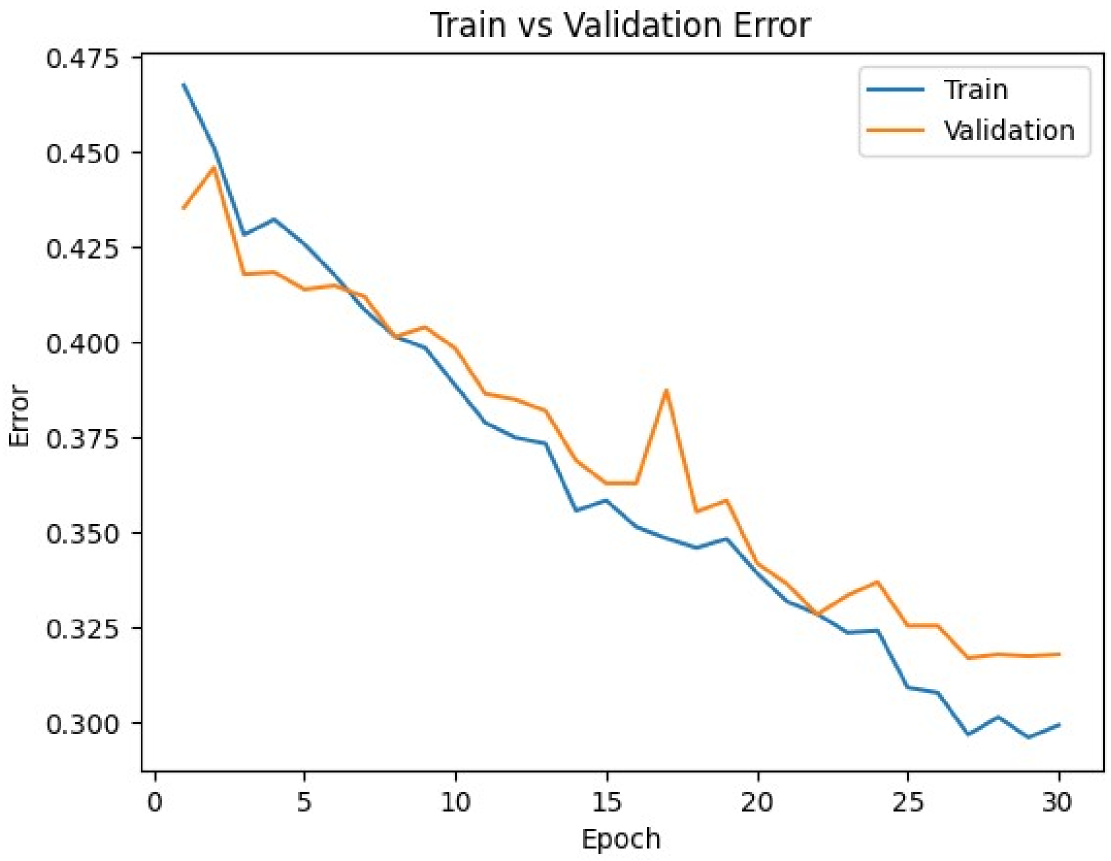
Part (b) - 1pt

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

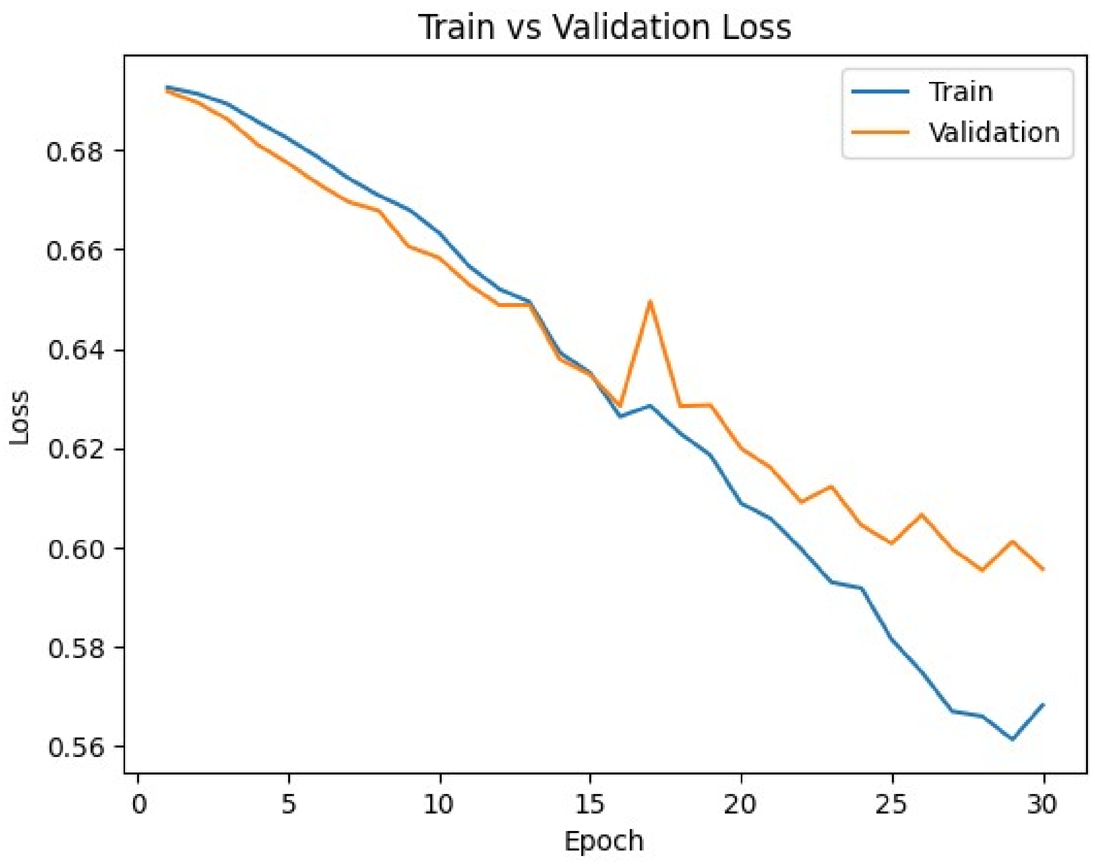
```
large_net = LargeNet()
train_net(large_net, 256, 0.01, 30)
model_path_large = get_model_name("large", batch_size=256,
learning_rate=0.01, epoch=29)
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.467625, Train loss: 0.6926687732338905 |
Validation err: 0.4355, Validation loss: 0.6918838396668434
Epoch 2: Train err: 0.45125, Train loss: 0.6913921386003494 |
Validation err: 0.446, Validation loss: 0.689614325761795
Epoch 3: Train err: 0.428375, Train loss: 0.6892956364899874 |
Validation err: 0.418, Validation loss: 0.6862076073884964
Epoch 4: Train err: 0.432375, Train loss: 0.6857246831059456 |
Validation err: 0.4185, Validation loss: 0.6810905113816261
Epoch 5: Train err: 0.425875, Train loss: 0.6823424454778433 |
Validation err: 0.414, Validation loss: 0.6773988157510757
Epoch 6: Train err: 0.41775, Train loss: 0.6785747222602367 |
Validation err: 0.415, Validation loss: 0.6732195988297462
Epoch 7: Train err: 0.4085, Train loss: 0.674360191449523 |Validation
err: 0.412, Validation loss: 0.669593334197998
Epoch 8: Train err: 0.401625, Train loss: 0.6709097884595394 |
Validation err: 0.4015, Validation loss: 0.6678433567285538
Epoch 9: Train err: 0.398625, Train loss: 0.6680476255714893 |
Validation err: 0.404, Validation loss: 0.6605530977249146
Epoch 10: Train err: 0.38875, Train loss: 0.6633832901716232 |
Validation err: 0.3985, Validation loss: 0.6583485454320908
Epoch 11: Train err: 0.378875, Train loss: 0.6566182859241962 |
Validation err: 0.3865, Validation loss: 0.6529050841927528
Epoch 12: Train err: 0.375, Train loss: 0.6520354263484478 |Validation
err: 0.385, Validation loss: 0.6487870514392853
Epoch 13: Train err: 0.373375, Train loss: 0.6494291331619024 |
Validation err: 0.382, Validation loss: 0.6488054469227791
Epoch 14: Train err: 0.35575, Train loss: 0.6392552871257067 |
Validation err: 0.369, Validation loss: 0.637849822640419
Epoch 15: Train err: 0.3585, Train loss: 0.6351705007255077 |
Validation err: 0.363, Validation loss: 0.6348292082548141
Epoch 16: Train err: 0.3515, Train loss: 0.6263151150196791 |
Validation err: 0.363, Validation loss: 0.6284611001610756
Epoch 17: Train err: 0.3485, Train loss: 0.6285038739442825 |
Validation err: 0.3875, Validation loss: 0.6495563760399818
Epoch 18: Train err: 0.346, Train loss: 0.6229071728885174 |Validation
err: 0.3555, Validation loss: 0.628441222012043
Epoch 19: Train err: 0.348375, Train loss: 0.6185130663216114 |
Validation err: 0.3585, Validation loss: 0.628648966550827
```

```
Epoch 20: Train err: 0.339375, Train loss: 0.608886506408453 |
Validation err: 0.342, Validation loss: 0.6199510842561722
Epoch 21: Train err: 0.331875, Train loss: 0.6057094093412161 |
Validation err: 0.3365, Validation loss: 0.6159674450755119
Epoch 22: Train err: 0.328625, Train loss: 0.5996328052133322 |
Validation err: 0.3285, Validation loss: 0.6090726181864738
Epoch 23: Train err: 0.32375, Train loss: 0.59294911660254 |Validation
err: 0.3335, Validation loss: 0.6122196018695831
Epoch 24: Train err: 0.32425, Train loss: 0.5917343720793724 |
Validation err: 0.337, Validation loss: 0.6043870896100998
Epoch 25: Train err: 0.30925, Train loss: 0.5813672374933958 |
Validation err: 0.3255, Validation loss: 0.6007594466209412
Epoch 26: Train err: 0.307875, Train loss: 0.5748253837227821 |
Validation err: 0.3255, Validation loss: 0.6065291538834572
Epoch 27: Train err: 0.296875, Train loss: 0.5669098161160946 |
Validation err: 0.317, Validation loss: 0.5996565371751785
Epoch 28: Train err: 0.3015, Train loss: 0.5659177647903562 |
Validation err: 0.318, Validation loss: 0.5953392386436462
Epoch 29: Train err: 0.296125, Train loss: 0.56122862175107 |
Validation err: 0.3175, Validation loss: 0.6011282876133919
Epoch 30: Train err: 0.299375, Train loss: 0.5681498721241951 |
Validation err: 0.318, Validation loss: 0.5956272780895233
Finished Training
Total time elapsed: 82.97 seconds
```



Train vs Validation Error
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
Error
0
5
10
15
20
25
30
Epoch
Train
Validation



Part (c) - 2pt

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

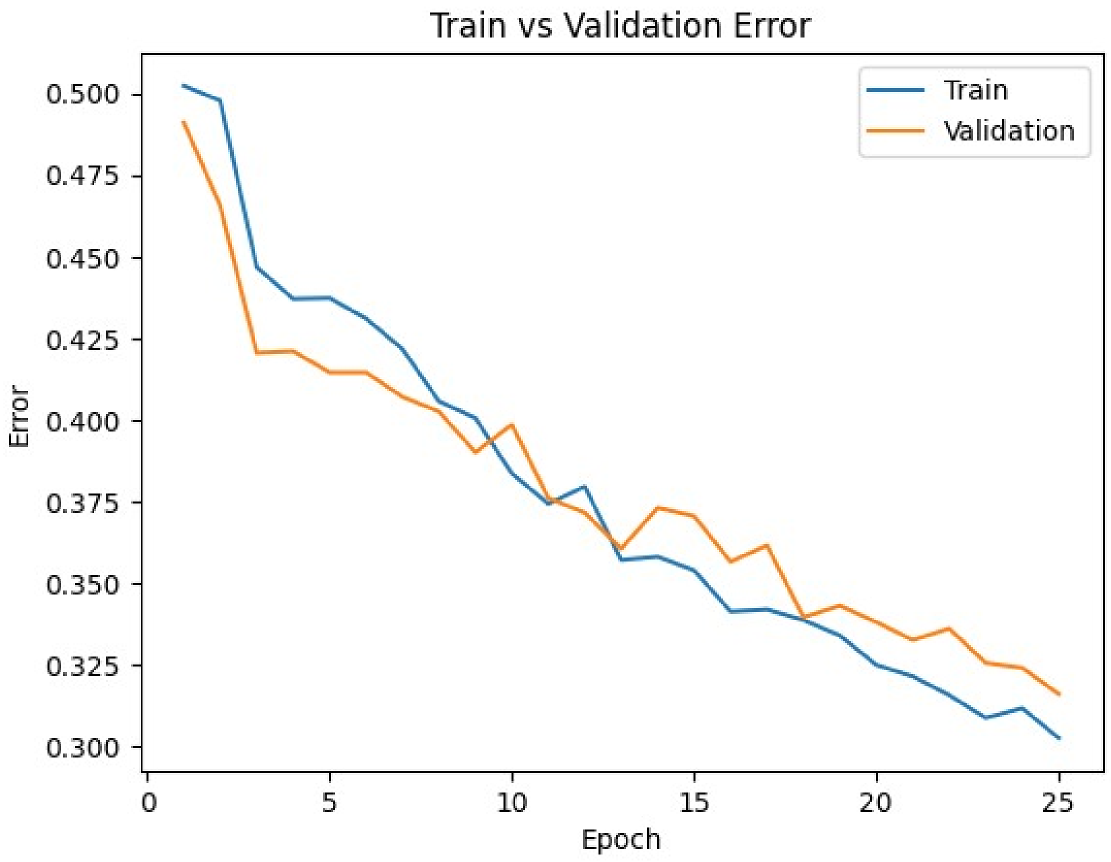
```
# Hyperparameters were chosen as:
  # network = large_net
  # batch_size = 256
  # learning_rate = 0.01
  # epoch = 25
# The results in Part(a) were good, but there was still slight
overfitting near
# the end, starting from approximately epoch 21-22.
```

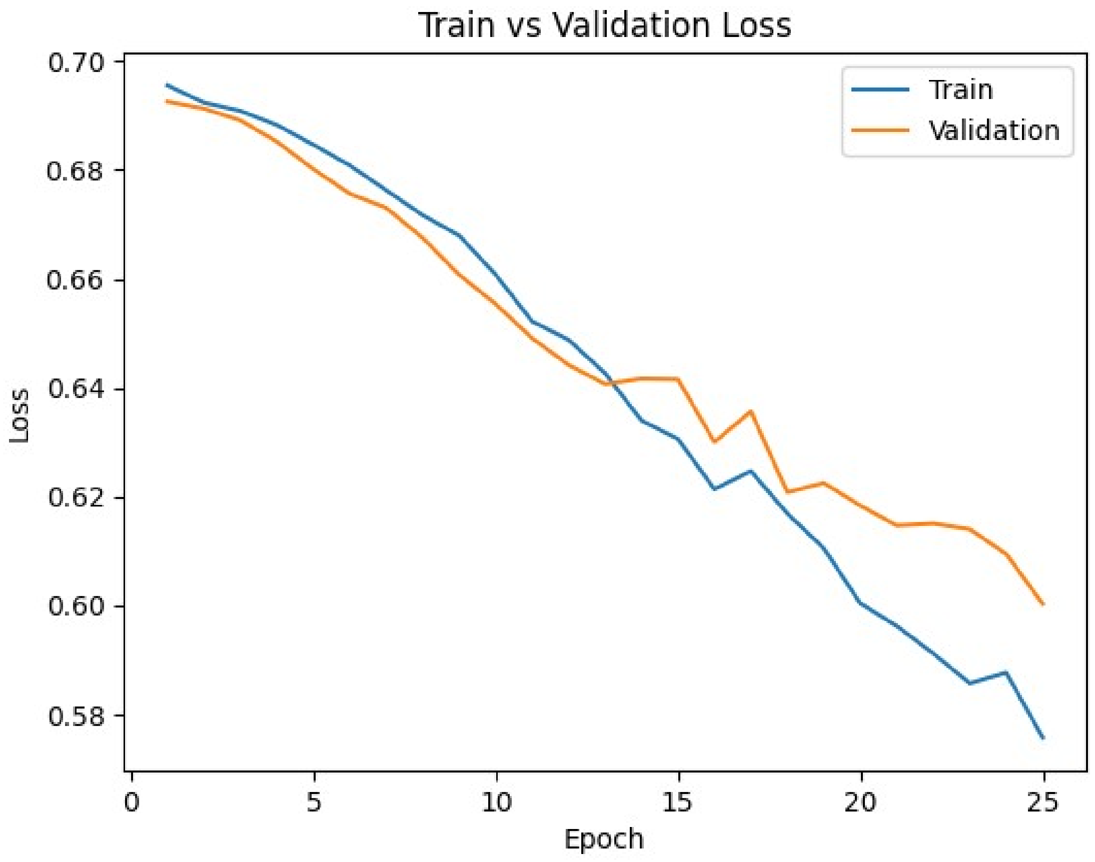
Part (d) - 1pt

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

```
large_net = LargeNet()
train_net(large_net, 256, 0.01, 25)
model_path_large = get_model_name("large", batch_size=256,
learning_rate=0.01, epoch=24)
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.50225, Train loss: 0.6955268159508705 |
Validation err: 0.491, Validation loss: 0.6925421804189682
Epoch 2: Train err: 0.49775, Train loss: 0.6923610251396894 |
Validation err: 0.4655, Validation loss: 0.6912638545036316
Epoch 3: Train err: 0.44675, Train loss: 0.6908448059111834 |
Validation err: 0.4205, Validation loss: 0.6891277506947517
Epoch 4: Train err: 0.437, Train loss: 0.6882675737142563 |Validation
err: 0.421, Validation loss: 0.6852065697312355
Epoch 5: Train err: 0.43725, Train loss: 0.6846398003399372 |
Validation err: 0.4145, Validation loss: 0.6801528334617615
Epoch 6: Train err: 0.431, Train loss: 0.6808352507650852 |Validation
err: 0.4145, Validation loss: 0.6756336018443108
Epoch 7: Train err: 0.421625, Train loss: 0.6762709021568298 |
Validation err: 0.407, Validation loss: 0.6730251237750053
Epoch 8: Train err: 0.405625, Train loss: 0.6716891080141068 |
Validation err: 0.4025, Validation loss: 0.6675112992525101
Epoch 9: Train err: 0.4005, Train loss: 0.6679535750299692 |Validation
err: 0.39, Validation loss: 0.6607388854026794
Epoch 10: Train err: 0.3835, Train loss: 0.6607740316540003 |
Validation err: 0.3985, Validation loss: 0.6553630828857422
Epoch 11: Train err: 0.37425, Train loss: 0.6521737668663263 |
Validation err: 0.376, Validation loss: 0.6490888521075249
Epoch 12: Train err: 0.3795, Train loss: 0.6487875431776047 |
Validation err: 0.3715, Validation loss: 0.6441735848784447
Epoch 13: Train err: 0.357, Train loss: 0.6426474433392286 |Validation
err: 0.3605, Validation loss: 0.6406564712524414
Epoch 14: Train err: 0.358, Train loss: 0.6339474860578775 |Validation
err: 0.373, Validation loss: 0.641641654074192
Epoch 15: Train err: 0.353875, Train loss: 0.6305643077939749 |
Validation err: 0.3705, Validation loss: 0.64152792096138
Epoch 16: Train err: 0.34125, Train loss: 0.6213253419846296 |
Validation err: 0.3565, Validation loss: 0.62999027967453
Epoch 17: Train err: 0.341875, Train loss: 0.6246551889926195 |
Validation err: 0.3615, Validation loss: 0.6356113106012344
Epoch 18: Train err: 0.338625, Train loss: 0.6168491505086422 |
Validation err: 0.3395, Validation loss: 0.6207610294222832
Epoch 19: Train err: 0.333875, Train loss: 0.6104864776134491 |
Validation err: 0.343, Validation loss: 0.6224529445171356
Epoch 20: Train err: 0.324875, Train loss: 0.6003531944006681 |
Validation err: 0.338, Validation loss: 0.6183240413665771
Epoch 21: Train err: 0.321375, Train loss: 0.5961896348744631 |
Validation err: 0.3325, Validation loss: 0.6146606802940369
Epoch 22: Train err: 0.315625, Train loss: 0.5911471806466579 |
Validation err: 0.336, Validation loss: 0.6150308176875114
Epoch 23: Train err: 0.308625, Train loss: 0.5856778360903263 |
Validation err: 0.3255, Validation loss: 0.6139866262674332
Epoch 24: Train err: 0.311625, Train loss: 0.5876005031168461 |
Validation err: 0.324, Validation loss: 0.6094432324171066
Epoch 25: Train err: 0.3025, Train loss: 0.5757022220641375 |
Validation err: 0.316, Validation loss: 0.6002651676535606
Finished Training
Total time elapsed: 71.39 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()
train_net(net, 256, 0.01, 25)
model_path = get_model_name(net.name, batch_size=256,
learning_rate=0.01, epoch=24)
state = torch.load(model_path)
net.load_state_dict(state)

Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.497125, Train loss: 0.6934096086770296 |
Validation err: 0.468, Validation loss: 0.6913570985198021
Epoch 2: Train err: 0.453125, Train loss: 0.6905003543943167 |
Validation err: 0.44, Validation loss: 0.688907079398632
```

```
Epoch 3: Train err: 0.445875, Train loss: 0.6875452101230621 |
Validation err: 0.434, Validation loss: 0.6848585233092308
Epoch 4: Train err: 0.43575, Train loss: 0.6822220403701067 |
Validation err: 0.4335, Validation loss: 0.6786830052733421
Epoch 5: Train err: 0.431375, Train loss: 0.676894897595048 |
Validation err: 0.417, Validation loss: 0.673255443572998
Epoch 6: Train err: 0.421375, Train loss: 0.6736960113048553 |
Validation err: 0.405, Validation loss: 0.66932263225317
Epoch 7: Train err: 0.405, Train loss: 0.6672013718634844 |Validation
err: 0.388, Validation loss: 0.6631332784891129
Epoch 8: Train err: 0.393875, Train loss: 0.6621953304857016 |
Validation err: 0.3795, Validation loss: 0.6555878296494484
Epoch 9: Train err: 0.382375, Train loss: 0.6557383760809898 |
Validation err: 0.37, Validation loss: 0.6476695016026497
Epoch 10: Train err: 0.368875, Train loss: 0.6490027382969856 |
Validation err: 0.367, Validation loss: 0.6428123041987419
Epoch 11: Train err: 0.36475, Train loss: 0.642054982483387 |
Validation err: 0.368, Validation loss: 0.6401692926883698
Epoch 12: Train err: 0.36, Train loss: 0.6374363955110312 |Validation
err: 0.3725, Validation loss: 0.6437254026532173
Epoch 13: Train err: 0.3525, Train loss: 0.635645866394043 |Validation
err: 0.3645, Validation loss: 0.6336137726902962
Epoch 14: Train err: 0.3475, Train loss: 0.6250239498913288 |
Validation err: 0.3625, Validation loss: 0.6324087083339691
Epoch 15: Train err: 0.34875, Train loss: 0.6219928823411465 |
Validation err: 0.3575, Validation loss: 0.6280075907707214
Epoch 16: Train err: 0.3345, Train loss: 0.6132696438580751 |
Validation err: 0.351, Validation loss: 0.6226278096437454
Epoch 17: Train err: 0.332625, Train loss: 0.6122955922037363 |
Validation err: 0.357, Validation loss: 0.6286576688289642
Epoch 18: Train err: 0.327875, Train loss: 0.6045868936926126 |
Validation err: 0.336, Validation loss: 0.6162997633218765
Epoch 19: Train err: 0.3265, Train loss: 0.6010097619146109 |
Validation err: 0.3375, Validation loss: 0.6118751764297485
Epoch 20: Train err: 0.318375, Train loss: 0.591007798910141 |
Validation err: 0.331, Validation loss: 0.6103062033653259
Epoch 21: Train err: 0.31275, Train loss: 0.5846749544143677 |
Validation err: 0.3355, Validation loss: 0.6062348783016205
Epoch 22: Train err: 0.308125, Train loss: 0.5792908165603876 |
Validation err: 0.3305, Validation loss: 0.6022427529096603
Epoch 23: Train err: 0.30575, Train loss: 0.5745287388563156 |
Validation err: 0.3195, Validation loss: 0.6053818762302399
Epoch 24: Train err: 0.3035, Train loss: 0.5721510984003544 |
Validation err: 0.326, Validation loss: 0.5991306826472282
Epoch 25: Train err: 0.294125, Train loss: 0.5622412748634815 |
Validation err: 0.3165, Validation loss: 0.5889866054058075
Finished Training
Total time elapsed: 71.98 seconds

<All keys matched successfully>
```

Part (b) - 2pt

Justify your choice of model from part (a).

```
# It resulted in a slightly smaller validation error and loss.
```

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=256)

criterion = nn.BCEWithLogitsLoss()
test_error, test_loss = evaluate(net, test_loader, criterion)
print("Test classification error:", test_error, test_loss)

Files already downloaded and verified
Files already downloaded and verified
Test classification error: 0.3105 0.5830739140510559
```

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 marginally lower than the
validation error
# The test error is often higher than the validation error because the
model is
# tuned to perform well on the validation set during development, but
the test
# set is completely unseen, providing a more unbiased measure of the
model's
# performance on new data.
```

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?

```
# We use the test dataset at the very end to ensure that the
evaluation of the
# model's performance is as unbiased and accurate as possible. It's
important to
# use the test data as little as possible to avoid the risk of
inadvertently
# tuning the model to this dataset as well, which would compromise its
ability
# to generalize to new data.
```

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.

```
# 2 layer ANN model:
import torch
import torch.nn as nn
import torch.nn.functional as F
from torchvision import datasets, transforms
import matplotlib.pyplot as plt # for plotting
import torch.optim as optim

torch.manual_seed(1) # set the random seed

class Lab1ANN(nn.Module):
    def __init__(self):
        super(Lab1ANN, self).__init__()
        self.name = "Lab1ANN"
        self.layer1 = nn.Linear(32 * 32 * 3, 30)
        self.layer2 = nn.Linear(30, 1)
    def forward(self, img):
        flattened = img.view(-1, 32 * 32 * 3)
        activation1 = self.layer1(flattened)
        activation1 = F.relu(activation1)
        activation2 = self.layer2(activation1)
        activation2 = activation2.squeeze(1)
        return activation2

Lab1ANN = Lab1ANN()
train_net(Lab1ANN, batch_size = 256, learning_rate = 0.01, num_epochs
= 29 )
```

```
criterion = nn.BCEWithLogitsLoss()
test_error, test_loss = evaluate(net,test_loader,criterion)
print("Test classification error and loss:", test_error, test_loss)

# CNN performed better and had smaller errors compared to the ANN
model.
# Validation err: 0.392, Validation loss: 0.8267480581998825
```

```
Files already downloaded and verified
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Epoch 1: Train err: 0.421875, Train loss: 0.6742314212024212 |
Validation err: 0.3945, Validation loss: 0.6581188961863518
Epoch 2: Train err: 0.38075, Train loss: 0.650376234203577 |Validation
err: 0.39, Validation loss: 0.6518372967839241
Epoch 3: Train err: 0.371, Train loss: 0.6385549809783697 |Validation
err: 0.38, Validation loss: 0.6489328816533089
Epoch 4: Train err: 0.358875, Train loss: 0.6303329616785049 |
Validation err: 0.3875, Validation loss: 0.6505187824368477
Epoch 5: Train err: 0.353, Train loss: 0.6234526988118887 |Validation
err: 0.379, Validation loss: 0.6453062519431114
Epoch 6: Train err: 0.340125, Train loss: 0.6170223131775856 |
Validation err: 0.379, Validation loss: 0.6477555632591248
Epoch 7: Train err: 0.336625, Train loss: 0.6100924164056778 |
Validation err: 0.374, Validation loss: 0.643535666167736
Epoch 8: Train err: 0.32775, Train loss: 0.6041284091770649 |
Validation err: 0.374, Validation loss: 0.645165205001831
Epoch 9: Train err: 0.32125, Train loss: 0.5959411058574915 |
Validation err: 0.384, Validation loss: 0.6470723003149033
Epoch 10: Train err: 0.312125, Train loss: 0.5877368673682213 |
Validation err: 0.3695, Validation loss: 0.6487203687429428
Epoch 11: Train err: 0.30275, Train loss: 0.5800998397171497 |
Validation err: 0.367, Validation loss: 0.6472310572862625
Epoch 12: Train err: 0.293625, Train loss: 0.5699734576046467 |
Validation err: 0.365, Validation loss: 0.6479431167244911
Epoch 13: Train err: 0.293875, Train loss: 0.5669378507882357 |
Validation err: 0.368, Validation loss: 0.6554356440901756
Epoch 14: Train err: 0.280875, Train loss: 0.5559590179473162 |
Validation err: 0.373, Validation loss: 0.6492954865098
Epoch 15: Train err: 0.269, Train loss: 0.5451897978782654 |Validation
err: 0.369, Validation loss: 0.6529053822159767
Epoch 16: Train err: 0.271625, Train loss: 0.5401697484776378 |
Validation err: 0.374, Validation loss: 0.6571093574166298
Epoch 17: Train err: 0.264375, Train loss: 0.5304668704047799 |
Validation err: 0.3585, Validation loss: 0.6480053588747978
Epoch 18: Train err: 0.248875, Train loss: 0.5231432868167758 |
Validation err: 0.3665, Validation loss: 0.6499830931425095
Epoch 19: Train err: 0.24675, Train loss: 0.509241764433682 |
Validation err: 0.3775, Validation loss: 0.6848082914948463
Epoch 20: Train err: 0.243125, Train loss: 0.5054017417132854 |
Validation err: 0.3715, Validation loss: 0.659767858684063
Epoch 21: Train err: 0.23375, Train loss: 0.49454705603420734 |
Validation err: 0.3685, Validation loss: 0.6676343679428101
Epoch 22: Train err: 0.223375, Train loss: 0.4882209366187453 |
Validation err: 0.371, Validation loss: 0.6717003881931305
Epoch 23: Train err: 0.2185, Train loss: 0.47743367310613394 |
Validation err: 0.3685, Validation loss: 0.6796082779765129
Epoch 24: Train err: 0.210625, Train loss: 0.4681494077667594 |
Validation err: 0.3695, Validation loss: 0.7015681117773056
Epoch 25: Train err: 0.215875, Train loss: 0.4645947962999344 |
Validation err: 0.3575, Validation loss: 0.6696438789367676
Epoch 26: Train err: 0.20125, Train loss: 0.4485793886706233 |
Validation err: 0.367, Validation loss: 0.7097871229052544
Epoch 27: Train err: 0.196625, Train loss: 0.44094559643417597 |
Validation err: 0.354, Validation loss: 0.6874147802591324
Epoch 28: Train err: 0.18625, Train loss: 0.4256433192640543 |
Validation err: 0.3595, Validation loss: 0.7027585431933403
Epoch 29: Train err: 0.19, Train loss: 0.4227746408432722 |Validation
err: 0.392, Validation loss: 0.8267480581998825
Finished Training
Total time elapsed: 68.07 seconds
Test classification error and loss: 0.3105 0.5833320766687393
```