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/1Q4JPoZ-waVviCBAh00Cekd4hPYhTFY2b?usp=sharing

In [ ]:
```
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.

In [ ]:
```
################################################################################
# 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.

In [ ]:
```
# 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
```

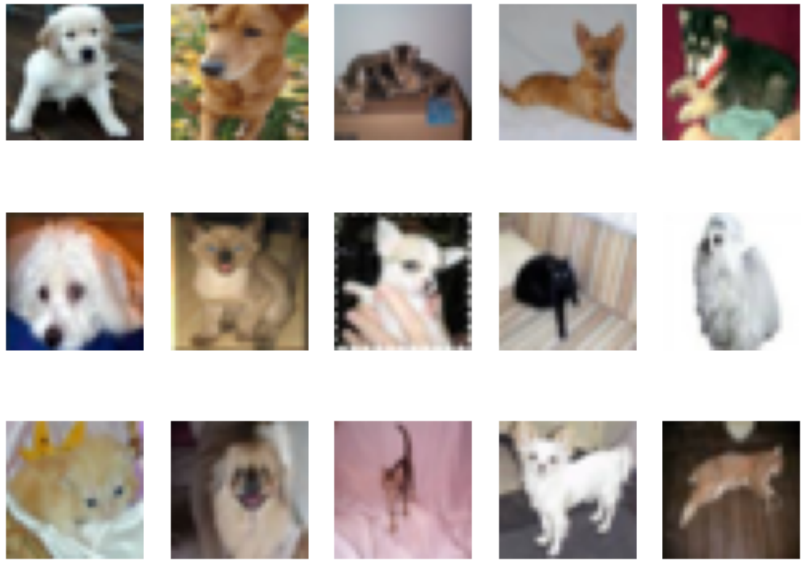
```
Downloading https://www.cs.toronto.edu/~kriz/cifar-10-python.tar.gz to ./data/cifar-10-python.tar.gz
100%|██████████| 170498071/170498071 [00:02<00:00, 75318910.27it/s]
Extracting ./data/cifar-10-python.tar.gz to ./data
Files already downloaded and verified
```

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.)

In [ ]:
```
import matplotlib.pyplot as plt

k = 0
for images, labels in val_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?

In [ ]:
```
print("Total training examples: ", len(train_loader)) # There are a total of 8000 training examples for the combined cat and dog classes
print("Total validation examples: " , len(val_loader)) # There are a total of 2000 validation examples
print("Total test examples: ", len(test_loader)) # There are a total of 2000 test examples
```

```
Total training examples:  8000
Total validation examples:  2000
Total test examples:  2000
```

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?

We need a validation set to test our various combinations of hyperparameter values. It allows us to detect overfitting or underfitting and compare it to the training set. If we were to only to use the training set loss/error, it could the model performing really well with the training set,

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.

In [ ]:
```
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
```

In [ ]:
```
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
```

In [ ]:
```
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.

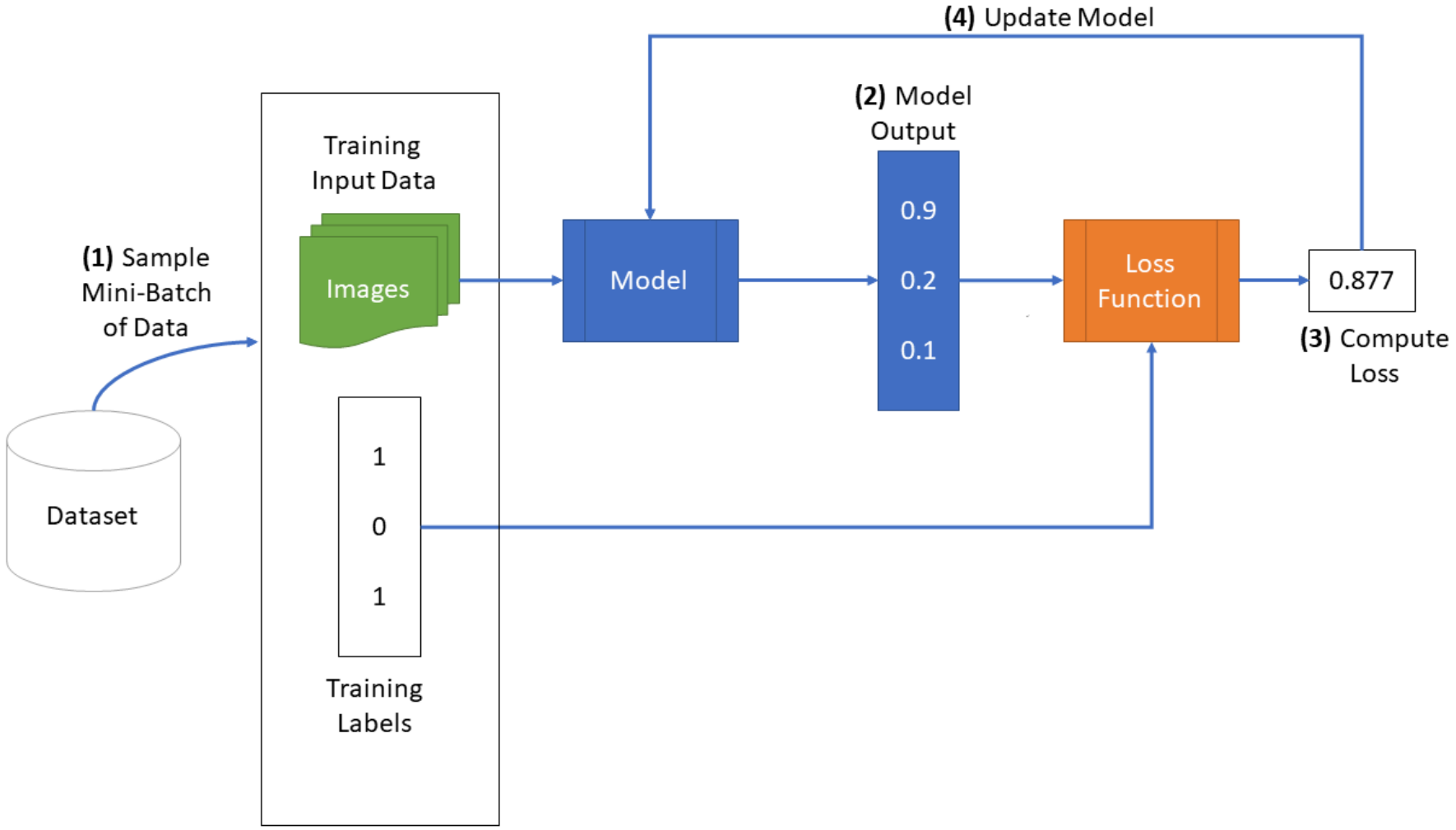
What is the total number of parameters in `small_net` and in `large_net`? (Hint: how many numbers are in each tensor?)

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

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

print("There are ", 5*3*3*3 + 5 + 245 + 1, "small parameters")
print("There are ", 5*3*5*5 + 5 + 10*5*5*5 + 10 + 32 * 250 + 32 + 32 + 1, "large parameters")
```

```
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])
There are  386 small parameters
There are  9705 large 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:



In [ ]:
```python
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/errruracy
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 batch size is 64 the learning rate is 0.01 the number os epochs is 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.

In [ ]:
```
train_net(small_net, batch_size=64, learning_rate=0.01, num_epochs=5)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.319875, Train loss: 0.5905068278312683 |Validation err: 0.3205, Validation loss: 0.6083906032145023
Epoch 2: Train err: 0.30975, Train loss: 0.5848583085536957 |Validation err: 0.342, Validation loss: 0.6189945060759783
Epoch 3: Train err: 0.30475, Train loss: 0.5814946296215058 |Validation err: 0.3165, Validation loss: 0.5972246937453747
Epoch 4: Train err: 0.3035, Train loss: 0.5765783853530884 |Validation err: 0.323, Validation loss: 0.606000492349267
Epoch 5: Train err: 0.298125, Train loss: 0.5718194470405579 |Validation err: 0.3145, Validation loss: 0.5921918312087655
Finished Training
Total time elapsed: 23.42 seconds
```

There are 4 csv files that contain the training error and loss, as well as the validation error and loss:

- "model_small_bs64_lr0.01_epoch4_train_err.csv" contains the training error
- "model_small_bs64_lr0.01_epoch4_train_loss.csv" contains the training loss
- "model_small_bs64_lr0.01_epoch4_val_err.csv" contains validation error
- "model_small_bs64_lr0.01_epoch4_val_loss.csv" contains validation loss

There are also five checkpoints where the current model is saved:

- "model_small_bs64_lr0.01_epoch0" at epoch 0
- "model_small_bs64_lr0.01_epoch1" at epoch 1
- "model_small_bs64_lr0.01_epoch2" at epoch 2
- "model_small_bs64_lr0.01_epoch3" at epoch 3
- "model_small_bs64_lr0.01_epoch4" at epoch 4

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?

In [ ]:
```
# 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
```

In [ ]:
```
train_net(small_net, batch_size=64, learning_rate=0.01, num_epochs=30)
train_net(large_net, batch_size=64, learning_rate=0.01, num_epochs=30)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.295625, Train loss: 0.5673375496864319 |Validation err: 0.3105, Validation loss: 0.5914709605276585
Epoch 2: Train err: 0.287875, Train loss: 0.5631002013683319 |Validation err: 0.319, Validation loss: 0.5902515174821019
Epoch 3: Train err: 0.28825, Train loss: 0.559383695602417 |Validation err: 0.3075, Validation loss: 0.5856206249445677
Epoch 4: Train err: 0.293375, Train loss: 0.5600644299983978 |Validation err: 0.3145, Validation loss: 0.5994032323360443
Epoch 5: Train err: 0.280375, Train loss: 0.552890187740326 |Validation err: 0.3065, Validation loss: 0.5758328270167112
Epoch 6: Train err: 0.28125, Train loss: 0.5475241587162017 |Validation err: 0.292, Validation loss: 0.5795201109722257
Epoch 7: Train err: 0.279875, Train loss: 0.5449734947681427 |Validation err: 0.301, Validation loss: 0.5732828425243497
Epoch 8: Train err: 0.280625, Train loss: 0.5419265604019166 |Validation err: 0.296, Validation loss: 0.5690147941932082
Epoch 9: Train err: 0.279625, Train loss: 0.5456948714256287 |Validation err: 0.309, Validation loss: 0.5803078589960933
Epoch 10: Train err: 0.273625, Train loss: 0.5412445206642151 |Validation err: 0.2895, Validation loss: 0.5676947860047221
Epoch 11: Train err: 0.27325, Train loss: 0.5391211895942688 |Validation err: 0.298, Validation loss: 0.577270264737308
Epoch 12: Train err: 0.272375, Train loss: 0.5342720906734466 |Validation err: 0.293, Validation loss: 0.5844055917114019
Epoch 13: Train err: 0.27, Train loss: 0.5377062871456146 |Validation err: 0.288, Validation loss: 0.5666856355965137
Epoch 14: Train err: 0.26875, Train loss: 0.5313395533561707 |Validation err: 0.2845, Validation loss: 0.5732379369437695
Epoch 15: Train err: 0.26875, Train loss: 0.5325421574115753 |Validation err: 0.2865, Validation loss: 0.5646333554759622
Epoch 16: Train err: 0.27425, Train loss: 0.535918984413147 |Validation err: 0.2935, Validation loss: 0.5719301449134946
Epoch 17: Train err: 0.271875, Train loss: 0.537940582036972 |Validation err: 0.289, Validation loss: 0.5632453430444002
Epoch 18: Train err: 0.266875, Train loss: 0.5290518009662628 |Validation err: 0.294, Validation loss: 0.5722421826794744
Epoch 19: Train err: 0.263, Train loss: 0.5286789619922638 |Validation err: 0.3035, Validation loss: 0.5887712212279439
Epoch 20: Train err: 0.267625, Train loss: 0.5287052876949311 |Validation err: 0.2925, Validation loss: 0.574053792282939
Epoch 21: Train err: 0.264375, Train loss: 0.532199324131012 |Validation err: 0.2875, Validation loss: 0.5676590735092759
Epoch 22: Train err: 0.26775, Train loss: 0.5310517206192017 |Validation err: 0.295, Validation loss: 0.599622736684978
Epoch 23: Train err: 0.268, Train loss: 0.5320754451751709 |Validation err: 0.2915, Validation loss: 0.5685260742902756
Epoch 24: Train err: 0.25975, Train loss: 0.525796021938324 |Validation err: 0.2845, Validation loss: 0.5691603431478143
Epoch 25: Train err: 0.262125, Train loss: 0.5238744103908539 |Validation err: 0.283, Validation loss: 0.5643868111073971
Epoch 26: Train err: 0.262, Train loss: 0.5245180952548981 |Validation err: 0.2975, Validation loss: 0.5713316788896918
Epoch 27: Train err: 0.265, Train loss: 0.524055998802185 |Validation err: 0.2885, Validation loss: 0.5742393415421247
Epoch 28: Train err: 0.260625, Train loss: 0.5277359845638275 |Validation err: 0.283, Validation loss: 0.5634836824610829
Epoch 29: Train err: 0.2635, Train loss: 0.5259283409118652 |Validation err: 0.2925, Validation loss: 0.5782049242407084
Epoch 30: Train err: 0.262625, Train loss: 0.5289928641319275 |Validation err: 0.2895, Validation loss: 0.5702067501842976
Finished Training
Total time elapsed: 148.22 seconds
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.458, Train loss: 0.6882815480232238 |Validation err: 0.414, Validation loss: 0.67512296885252
Epoch 2: Train err: 0.40875, Train loss: 0.6738240513801574 |Validation err: 0.42, Validation loss: 0.6784770525991917
Epoch 3: Train err: 0.390375, Train loss: 0.6579039559364319 |Validation err: 0.3665, Validation loss: 0.640207851305604
Epoch 4: Train err: 0.359625, Train loss: 0.6385969967842102 |Validation err: 0.3995, Validation loss: 0.6538781449198723
Epoch 5: Train err: 0.3465, Train loss: 0.6230313973426819 |Validation err: 0.3415, Validation loss: 0.6184800341725349
Epoch 6: Train err: 0.331, Train loss: 0.6052607107162475 |Validation err: 0.341, Validation loss: 0.6239043399691582
Epoch 7: Train err: 0.321875, Train loss: 0.5973682770729065 |Validation err: 0.333, Validation loss: 0.6071885209530592
Epoch 8: Train err: 0.307125, Train loss: 0.5788449437618256 |Validation err: 0.3205, Validation loss: 0.5940718036144972
Epoch 9: Train err: 0.29375, Train loss: 0.5684884352684021 |Validation err: 0.315, Validation loss: 0.5895672161132097
Epoch 10: Train err: 0.288, Train loss: 0.5549469397068024 |Validation err: 0.3085, Validation loss: 0.5803534043952823
Epoch 11: Train err: 0.27525, Train loss: 0.54416433095932 |Validation err: 0.305, Validation loss: 0.5862869275733829
Epoch 12: Train err: 0.26925, Train loss: 0.5297010049819947 |Validation err: 0.297, Validation loss: 0.5876985099166632
Epoch 13: Train err: 0.26, Train loss: 0.5217569029331207 |Validation err: 0.303, Validation loss: 0.5758601045235991
Epoch 14: Train err: 0.252375, Train loss: 0.5081476881504059 |Validation err: 0.2965, Validation loss: 0.5876841144636273
Epoch 15: Train err: 0.2445, Train loss: 0.4993256530761719 |Validation err: 0.2875, Validation loss: 0.5823690695688128
Epoch 16: Train err: 0.2435, Train loss: 0.4995723218917847 |Validation err: 0.2965, Validation loss: 0.5790938176214695
Epoch 17: Train err: 0.23825, Train loss: 0.48458114624023435 |Validation err: 0.3005, Validation loss: 0.5846413802355528
Epoch 18: Train err: 0.227625, Train loss: 0.4710596251487732 |Validation err: 0.297, Validation loss: 0.5900164125487208
Epoch 19: Train err: 0.22025, Train loss: 0.46191117429733275 |Validation err: 0.298, Validation loss: 0.6033184817060828
Epoch 20: Train err: 0.206875, Train loss: 0.44458395409584045 |Validation err: 0.306, Validation loss: 0.6321440227329731
Epoch 21: Train err: 0.204125, Train loss: 0.4356986334323883 |Validation err: 0.285, Validation loss: 0.6175286192446947
```

```
Epoch 22: Train err: 0.192875, Train loss: 0.4152004120349884 |Validation err: 0.294, Validation loss: 0.6314494637772441
Epoch 23: Train err: 0.187625, Train loss: 0.41379578232765196 |Validation err: 0.3055, Validation loss: 0.6079854415729642
Epoch 24: Train err: 0.180125, Train loss: 0.39548411881923673 |Validation err: 0.308, Validation loss: 0.6782940588891506
Epoch 25: Train err: 0.176, Train loss: 0.38506368768215177 |Validation err: 0.324, Validation loss: 0.6653119930997491
Epoch 26: Train err: 0.164125, Train loss: 0.3661659426689148 |Validation err: 0.3085, Validation loss: 0.7048197947442532
Epoch 27: Train err: 0.156375, Train loss: 0.34531402933597566 |Validation err: 0.3135, Validation loss: 0.744884766638279
Epoch 28: Train err: 0.149625, Train loss: 0.33693434512615206 |Validation err: 0.308, Validation loss: 0.7487826887518167
Epoch 29: Train err: 0.138125, Train loss: 0.3153934038877487 |Validation err: 0.3205, Validation loss: 0.7983444016426802
Epoch 30: Train err: 0.134875, Train loss: 0.3031927341222763 |Validation err: 0.317, Validation loss: 0.7590902303345501
Finished Training
Total time elapsed: 193.21 seconds
```

The small net took 148.22 seconds while the large net took 193.21 seconds. The large net was visibly slower because there were more parameters, pooling layers, and convolutional layers in the large net than the small net.

Part (e) - 2pt

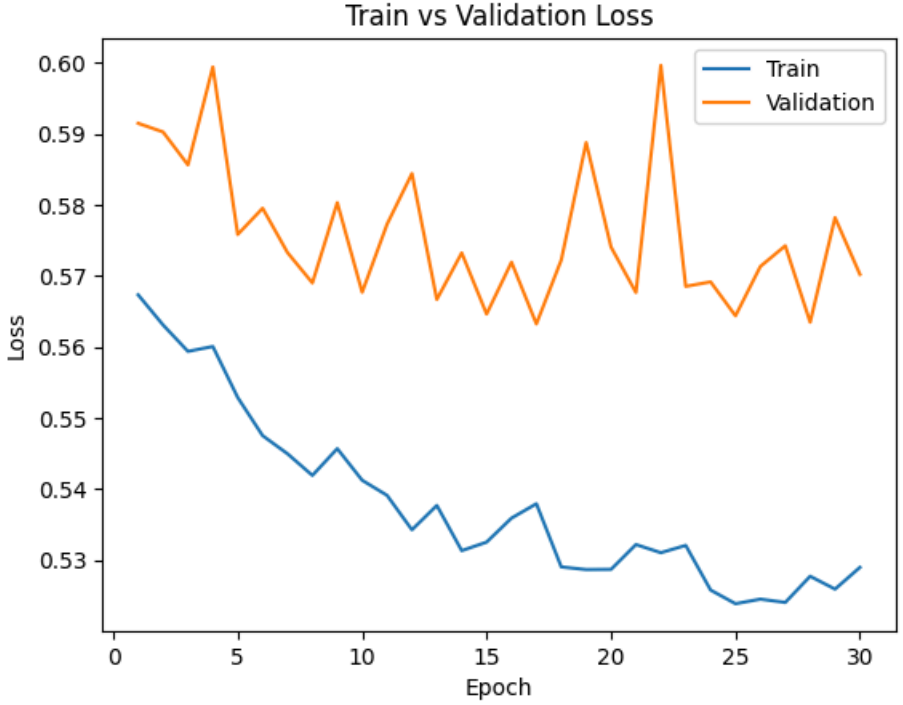
Use the function `plot_training_curve` to display the trajectory of the training/validation error and the training/validation loss. You will need to use the function `get_model_name` to generate the argument to the `plot_training_curve` function.

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

In [ ]:
```
model_path_small_train = get_model_name("small", batch_size=64, learning_rate=0.01, epoch=29)
print("SMALL MODEL")
plot_training_curve(model_path_small_train)

model_path_large = get_model_name("large", batch_size=64, learning_rate=0.01, epoch=29)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

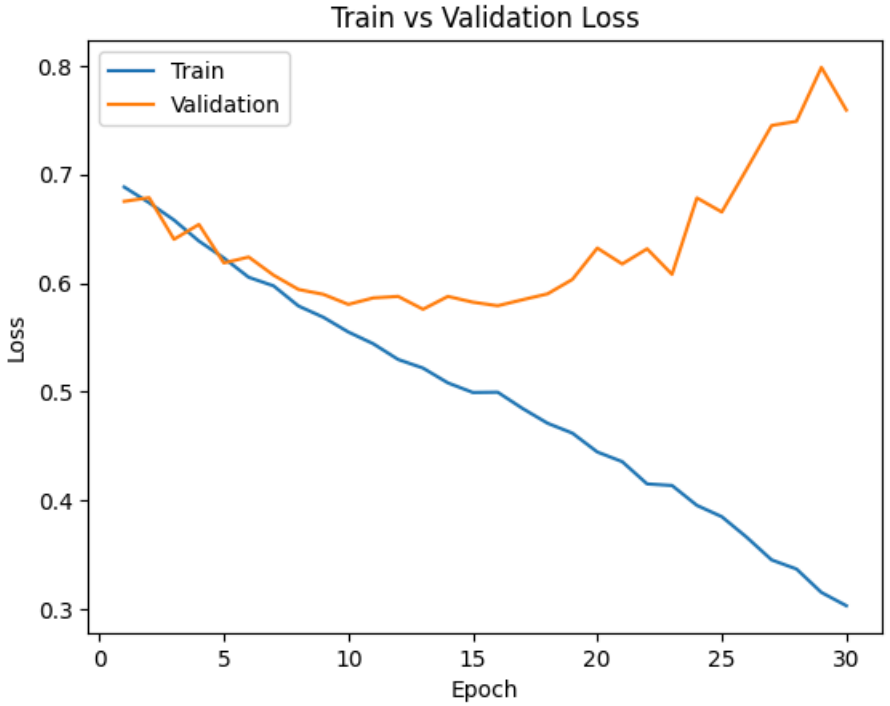
```
SMALL MODEL
```


Train vs Validation Error
Train
Validation
Error
Epoch
0.32
0.31
0.30
0.29
0.28
0.27
0.26
0
5
10
15
20
25
30


Train vs Validation Loss
Train
Validation
Loss
Epoch
0.60
0.59
0.58
0.57
0.56
0.55
0.54
0.53
0
5
10
15
20
25
30

LARGE MODEL


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


Train vs Validation Loss
Train
Validation
Loss
Epoch
0.8
0.7
0.6
0.5
0.4
0.3
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.

```
Small Model Training/Validation Error:
  The error is overall on a downwards trend, but varies significantly between
  testing and training. There are many jumps and spikes on the graph, especially in the validation curve.

Small Model Training/Validation Loss:
  This graph shows that there is a significant gap between training and validation curve.
  Both the training and validation curves fluctuate potentially indicating that the learning rate is too high.
  While the general trend is downwards, the training curve does not converge and there is still room for learning.
  This model is underfitted

Large Model Training/Validation Error:
  Both the training and validation error seem to be going in a downwards trend,
  but as the epoch increases, the training error is continuously decreasing, which the validation error remains at around 0.30.

Large Model Training/Validation Loss:
  This model begins with a steep drop, and then slowly the training curve and validation curve begin to diverge around the 8 epoch.
  The training curve still has room to learn, as it has not plateaued.
  However, the validation curve increases in loss as the epoch increases,
  leadering to overfitting.

Compared:
  Overall, the small model shows signs of underfitting with a large gap between the validation and training loss,
  and room for further learning. The large model shows signs of overfitting and has a worse learning ability.
  As well, the small model has many more spikes and fluctuates a lot more than the large model.
```

Part 3. Optimization Parameters [12 pt]

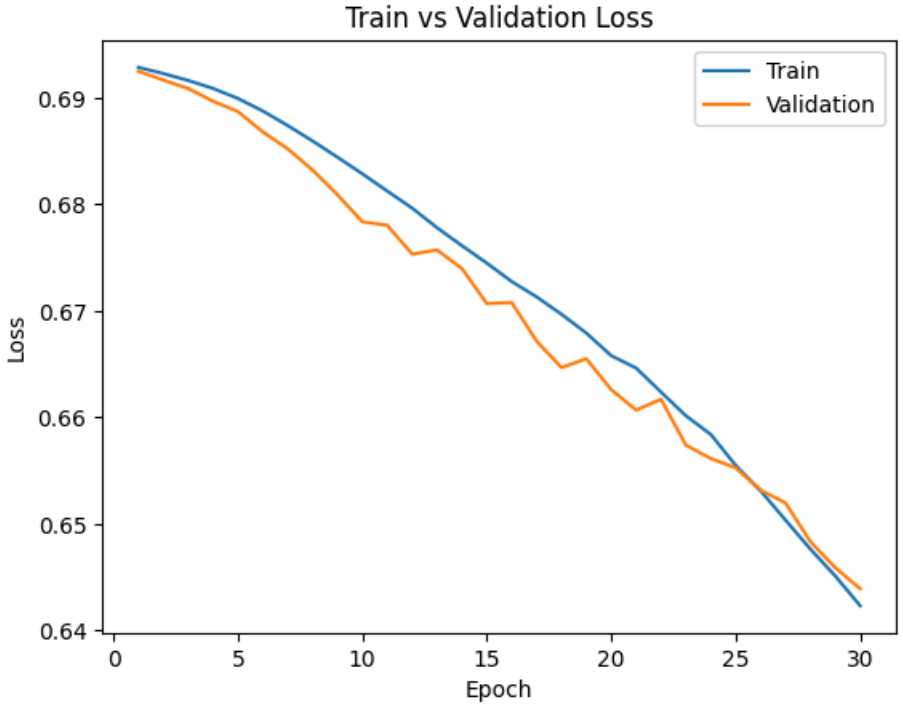
For this section, we will work with `large_net` only.

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.

In [ ]:
```
# 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, batch_size=64, learning_rate=0.001, num_epochs=30)
model_path_large = get_model_name("large", batch_size=64, learning_rate=0.001, epoch=29)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.47625, Train loss: 0.6928360004425049 |Validation err: 0.467, Validation loss: 0.6924686580896378
Epoch 2: Train err: 0.448625, Train loss: 0.6922589740753173 |Validation err: 0.4305, Validation loss: 0.6916493494063616
Epoch 3: Train err: 0.43575, Train loss: 0.6916067256927491 |Validation err: 0.4285, Validation loss: 0.6908544301986694
Epoch 4: Train err: 0.43, Train loss: 0.6908613419532776 |Validation err: 0.424, Validation loss: 0.6896595824509859
Epoch 5: Train err: 0.434125, Train loss: 0.6899194955825806 |Validation err: 0.4195, Validation loss: 0.6886935662478209
Epoch 6: Train err: 0.43575, Train loss: 0.688741192817688 |Validation err: 0.4195, Validation loss: 0.6867824867367744
Epoch 7: Train err: 0.437125, Train loss: 0.6873774199485779 |Validation err: 0.4185, Validation loss: 0.6851983051747084
Epoch 8: Train err: 0.4375, Train loss: 0.6859278454780579 |Validation err: 0.412, Validation loss: 0.6831997763365507
Epoch 9: Train err: 0.424375, Train loss: 0.6844058051109314 |Validation err: 0.411, Validation loss: 0.6808880735188723
Epoch 10: Train err: 0.424, Train loss: 0.6828502945899964 |Validation err: 0.408, Validation loss: 0.6783502567559481
Epoch 11: Train err: 0.425375, Train loss: 0.6812348775863647 |Validation err: 0.4125, Validation loss: 0.6780214440077543
Epoch 12: Train err: 0.42, Train loss: 0.6796319665908813 |Validation err: 0.4125, Validation loss: 0.6753159128129482
Epoch 13: Train err: 0.414875, Train loss: 0.6777918725013733 |Validation err: 0.415, Validation loss: 0.6757059413939714
Epoch 14: Train err: 0.412375, Train loss: 0.6761112008094787 |Validation err: 0.412, Validation loss: 0.673973485827446
Epoch 15: Train err: 0.40925, Train loss: 0.6744726777076722 |Validation err: 0.415, Validation loss: 0.6706762481480837
Epoch 16: Train err: 0.406375, Train loss: 0.6727448830604553 |Validation err: 0.4105, Validation loss: 0.6707733031362295
Epoch 17: Train err: 0.4015, Train loss: 0.6713076605796814 |Validation err: 0.4045, Validation loss: 0.6671545337885618
Epoch 18: Train err: 0.3995, Train loss: 0.6696742882728577 |Validation err: 0.4055, Validation loss: 0.6646782532334328
Epoch 19: Train err: 0.40075, Train loss: 0.6679086318016052 |Validation err: 0.396, Validation loss: 0.6655019484460354
Epoch 20: Train err: 0.392375, Train loss: 0.6657879824638366 |Validation err: 0.405, Validation loss: 0.6626011151820421
Epoch 21: Train err: 0.38975, Train loss: 0.6646300611495972 |Validation err: 0.394, Validation loss: 0.6606878526508808
Epoch 22: Train err: 0.388875, Train loss: 0.6623730535507202 |Validation err: 0.393, Validation loss: 0.6616998631507158
Epoch 23: Train err: 0.38425, Train loss: 0.6601516304016113 |Validation err: 0.3975, Validation loss: 0.6573981866240501
Epoch 24: Train err: 0.382375, Train loss: 0.6584009370803833 |Validation err: 0.386, Validation loss: 0.6561364699155092
Epoch 25: Train err: 0.37875, Train loss: 0.6554971733093262 |Validation err: 0.388, Validation loss: 0.6552744191139936
Epoch 26: Train err: 0.376625, Train loss: 0.6531173238754272 |Validation err: 0.3875, Validation loss: 0.6531743723899126
Epoch 27: Train err: 0.375, Train loss: 0.6503696317672729 |Validation err: 0.387, Validation loss: 0.6519789230078459
Epoch 28: Train err: 0.371375, Train loss: 0.6476435804367066 |Validation err: 0.3875, Validation loss: 0.6483502611517906
Epoch 29: Train err: 0.368375, Train loss: 0.645125765323639 |Validation err: 0.3825, Validation loss: 0.6459067296236753
Epoch 30: Train err: 0.362625, Train loss: 0.6423329501152039 |Validation err: 0.3785, Validation loss: 0.6439236979931593
Finished Training
Total time elapsed: 180.40 seconds
LARGE  MODEL
```



Effect of lowering the learning rate: large model

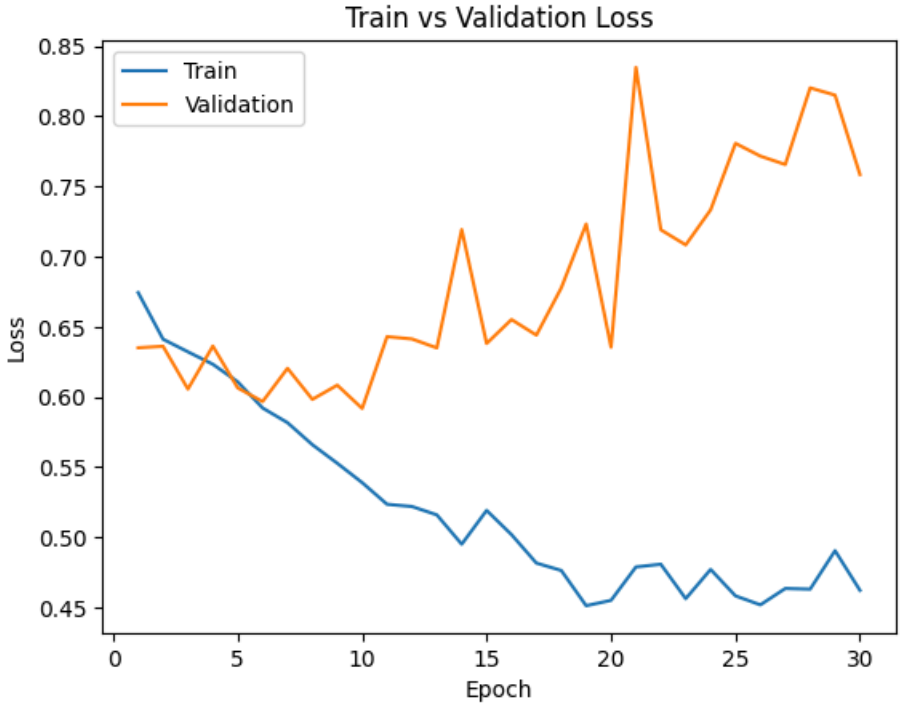
Overall, by lowering the training rate the time taken to train the model decreased. We can see that the training and validation curve are more closely aligned, going in a downwards trend. Overall it took a shorter amount of time to train. At the 30 epoch, there is still room for further training as the fluctuation of loss at the 0 epoch and 30 epoch does not differ by a significant amount. This is a sign of underfitting.

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.

In [ ]:
```
large_net = LargeNet()
train_net(large_net, batch_size=64, learning_rate=0.1, num_epochs=30)
model_path_large = get_model_name("large", batch_size=64, learning_rate=0.1, epoch=29)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.4295, Train loss: 0.6743778004646301 |Validation err: 0.3595, Validation loss: 0.6350856963545084
Epoch 2: Train err: 0.36075, Train loss: 0.6411805462837219 |Validation err: 0.3535, Validation loss: 0.6361209936439991
Epoch 3: Train err: 0.365125, Train loss: 0.6321813464164734 |Validation err: 0.3385, Validation loss: 0.6056603863835335
Epoch 4: Train err: 0.352625, Train loss: 0.623345623254776 |Validation err: 0.3575, Validation loss: 0.6362800160422921
Epoch 5: Train err: 0.34075, Train loss: 0.610801386833191 |Validation err: 0.3305, Validation loss: 0.6064918749034405
Epoch 6: Train err: 0.323375, Train loss: 0.5921835992336273 |Validation err: 0.317, Validation loss: 0.5967769687995315
Epoch 7: Train err: 0.3145, Train loss: 0.5817317562103271 |Validation err: 0.3365, Validation loss: 0.6204487904906273
Epoch 8: Train err: 0.29825, Train loss: 0.5660300071239471 |Validation err: 0.3285, Validation loss: 0.5983372181653976
Epoch 9: Train err: 0.290875, Train loss: 0.5528094999790192 |Validation err: 0.3315, Validation loss: 0.6084455195814371
Epoch 10: Train err: 0.278625, Train loss: 0.5390326056480408 |Validation err: 0.306, Validation loss: 0.5918631944805384
Epoch 11: Train err: 0.272375, Train loss: 0.5236025860309601 |Validation err: 0.33, Validation loss: 0.6430060267448425
Epoch 12: Train err: 0.267375, Train loss: 0.5220149426460267 |Validation err: 0.2925, Validation loss: 0.6413561562076211
Epoch 13: Train err: 0.266, Train loss: 0.5160510141849518 |Validation err: 0.3125, Validation loss: 0.6349832899868488
Epoch 14: Train err: 0.24875, Train loss: 0.49515900206565855 |Validation err: 0.3145, Validation loss: 0.7193072661757469
Epoch 15: Train err: 0.264625, Train loss: 0.5192319476604461 |Validation err: 0.314, Validation loss: 0.6381420735269785
Epoch 16: Train err: 0.252625, Train loss: 0.5020012385845184 |Validation err: 0.3225, Validation loss: 0.6551959468051791
Epoch 17: Train err: 0.23875, Train loss: 0.48171478748321533 |Validation err: 0.357, Validation loss: 0.6440742611885071
Epoch 18: Train err: 0.23375, Train loss: 0.4764550621509552 |Validation err: 0.3375, Validation loss: 0.6777342865243554
Epoch 19: Train err: 0.218125, Train loss: 0.45134368777275086 |Validation err: 0.3445, Validation loss: 0.7232250459492207
Epoch 20: Train err: 0.217875, Train loss: 0.45516351199150085 |Validation err: 0.3245, Validation loss: 0.6354951094835997
Epoch 21: Train err: 0.23275, Train loss: 0.47897080254554747 |Validation err: 0.3255, Validation loss: 0.8348111072555184
Epoch 22: Train err: 0.234875, Train loss: 0.4808810555934906 |Validation err: 0.334, Validation loss: 0.7191346473991871
Epoch 23: Train err: 0.21575, Train loss: 0.45636477398872377 |Validation err: 0.316, Validation loss: 0.7083508120849729
Epoch 24: Train err: 0.2355, Train loss: 0.477182511806488 |Validation err: 0.327, Validation loss: 0.7333047613501549
Epoch 25: Train err: 0.22025, Train loss: 0.45834142971038816 |Validation err: 0.3315, Validation loss: 0.7806987632066011
Epoch 26: Train err: 0.209625, Train loss: 0.4519626944065094 |Validation err: 0.3435, Validation loss: 0.7715998683124781
Epoch 27: Train err: 0.22175, Train loss: 0.4636160418987274 |Validation err: 0.3215, Validation loss: 0.7656293641775846
Epoch 28: Train err: 0.219375, Train loss: 0.4631477723121643 |Validation err: 0.348, Validation loss: 0.8202023096382618
Epoch 29: Train err: 0.235875, Train loss: 0.49053542375564574 |Validation err: 0.326, Validation loss: 0.8150459919124842
Epoch 30: Train err: 0.22, Train loss: 0.4623157210350037 |Validation err: 0.3165, Validation loss: 0.7585078477859497
Finished Training
Total time elapsed: 179.16 seconds
LARGE  MODEL
```



Effect of increasing the learning rate: Large Model

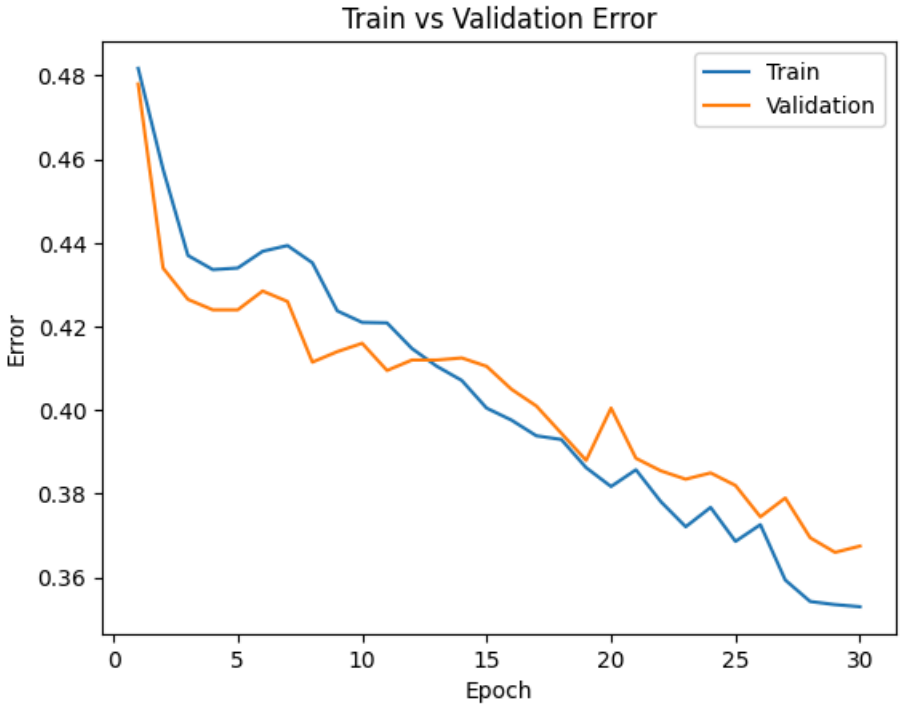
Overall, the time taken to train the model has decreased, By increasing the learning rate there are signs of overfitting and rapid change in training and validation curve. This could mean that the learning rate is too large and cannot capture the points in between. Overfitting also remains as a problem and has worsened with the increase of learning rate, as we can see that near the 6 epoch the two curves begin to diverge and end up diverging significantly as the epoch increases.

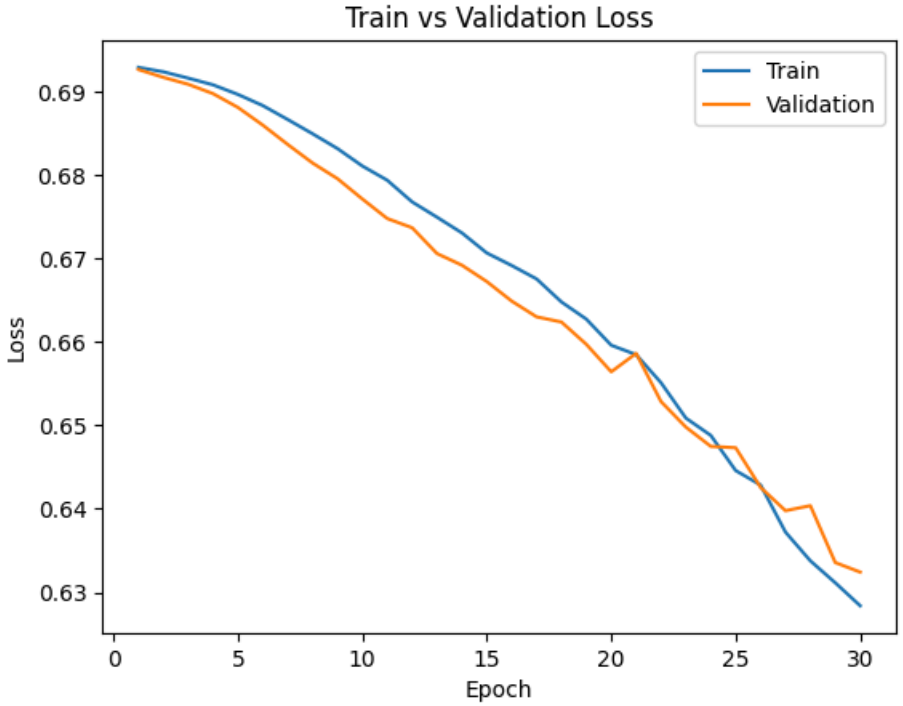
Part (c) - 3pt

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.

In [ ]:
```
large_net = LargeNet()
train_net(large_net, batch_size=512, learning_rate=0.01, num_epochs=30)
model_path_large = get_model_name("large", batch_size=512, learning_rate=0.01, epoch=29)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

```
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 loss: 0.6926824003458023
Epoch 2: Train err: 0.457625, Train loss: 0.6924104057252407 |Validation err: 0.434, Validation loss: 0.6917425245046616
Epoch 3: Train err: 0.437, Train loss: 0.6916500627994537 |Validation err: 0.4265, Validation loss: 0.6909129917621613
Epoch 4: Train err: 0.433625, Train loss: 0.6908449903130531 |Validation err: 0.424, Validation loss: 0.6897870302200317
Epoch 5: Train err: 0.434, Train loss: 0.6896935515105724 |Validation err: 0.424, Validation loss: 0.6881355047225952
Epoch 6: Train err: 0.438, Train loss: 0.6883532106876373 |Validation err: 0.4285, Validation loss: 0.686011865735054
Epoch 7: Train err: 0.439375, Train loss: 0.6866871751844883 |Validation err: 0.426, Validation loss: 0.6836968660354614
Epoch 8: Train err: 0.43525, Train loss: 0.6849770732223988 |Validation err: 0.4115, Validation loss: 0.68146713078022
Epoch 9: Train err: 0.42375, Train loss: 0.6832009293138981 |Validation err: 0.414, Validation loss: 0.679591491818428
Epoch 10: Train err: 0.421, Train loss: 0.6811089366674423 |Validation err: 0.416, Validation loss: 0.6771548539400101
Epoch 11: Train err: 0.420875, Train loss: 0.6794026605784893 |Validation err: 0.4095, Validation loss: 0.6748111099004745
Epoch 12: Train err: 0.41475, Train loss: 0.6768048144876957 |Validation err: 0.412, Validation loss: 0.6737060546875
Epoch 13: Train err: 0.4105, Train loss: 0.6749702766537666 |Validation err: 0.412, Validation loss: 0.6706101596355438
Epoch 14: Train err: 0.407125, Train loss: 0.6730880849063396 |Validation err: 0.4125, Validation loss: 0.6692148000001907
Epoch 15: Train err: 0.4005, Train loss: 0.6706806868314743 |Validation err: 0.4105, Validation loss: 0.6672526895999908
Epoch 16: Train err: 0.397625, Train loss: 0.6691771373152733 |Validation err: 0.405, Validation loss: 0.6649097055196762
Epoch 17: Train err: 0.393875, Train loss: 0.6675694584846497 |Validation err: 0.401, Validation loss: 0.6630225032567978
Epoch 18: Train err: 0.393, Train loss: 0.6648042872548103 |Validation err: 0.3945, Validation loss: 0.6624014377593994
Epoch 19: Train err: 0.38625, Train loss: 0.6627466157078743 |Validation err: 0.388, Validation loss: 0.6597220301628113
Epoch 20: Train err: 0.38175, Train loss: 0.6596181951463223 |Validation err: 0.4005, Validation loss: 0.6564337313175201
Epoch 21: Train err: 0.38575, Train loss: 0.6584899760782719 |Validation err: 0.3885, Validation loss: 0.6586423963308334
Epoch 22: Train err: 0.378125, Train loss: 0.6551233902573586 |Validation err: 0.3855, Validation loss: 0.6528600305318832
Epoch 23: Train err: 0.372125, Train loss: 0.6508794091641903 |Validation err: 0.3835, Validation loss: 0.6497963666915894
Epoch 24: Train err: 0.37675, Train loss: 0.6488028429448605 |Validation err: 0.385, Validation loss: 0.6474899798631668
Epoch 25: Train err: 0.368625, Train loss: 0.6445869281888008 |Validation err: 0.382, Validation loss: 0.6473268419504166
Epoch 26: Train err: 0.372625, Train loss: 0.6428566128015518 |Validation err: 0.3745, Validation loss: 0.6425703316926956
Epoch 27: Train err: 0.359375, Train loss: 0.6372117511928082 |Validation err: 0.379, Validation loss: 0.6397799849510193
Epoch 28: Train err: 0.35425, Train loss: 0.6337667480111122 |Validation err: 0.3695, Validation loss: 0.6403782963752747
Epoch 29: Train err: 0.3535, Train loss: 0.6311352998018265 |Validation err: 0.366, Validation loss: 0.6335585117340088
Epoch 30: Train err: 0.353, Train loss: 0.6283832415938377 |Validation err: 0.3675, Validation loss: 0.6324127167463303
Finished Training
Total time elapsed: 146.56 seconds
LARGE  MODEL
```





Effect of increasing the batch size: Large Model

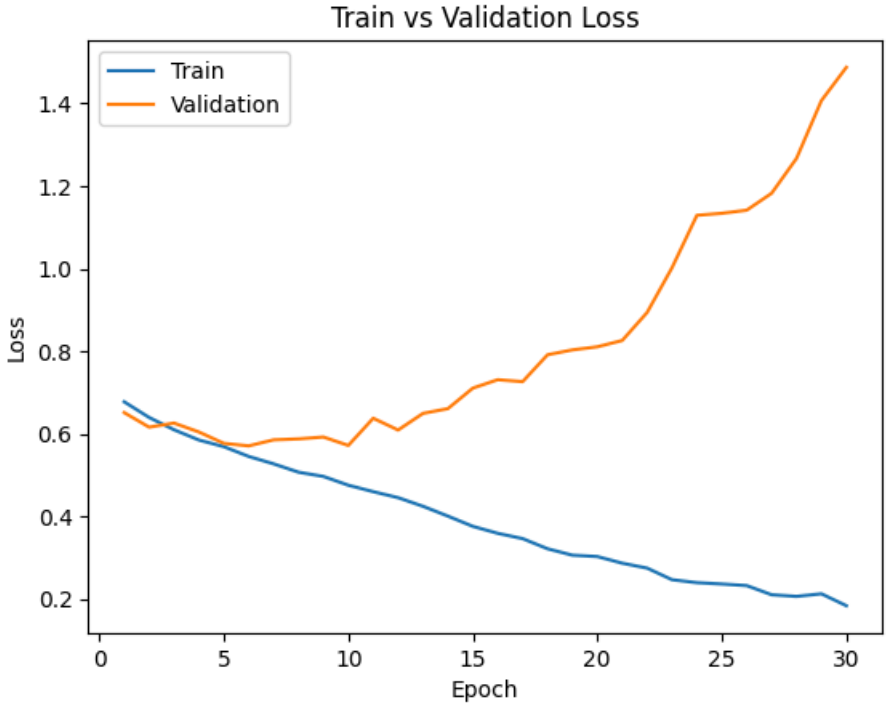
Overall by increasing the batch size the training time decreases. Increasing the batch size also helps with aligning the training curve and validation curve, and reducing the overall error. It also helps reduce the overfitting in the default parameter model, but could now be underfitting. There is more room for learning after the 30 epoch.

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.

In [ ]:
```
large_net = LargeNet()
train_net(large_net, batch_size=16, learning_rate=0.01, num_epochs=30)
model_path_large = get_model_name("large", batch_size=16, learning_rate=0.01, epoch=29)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.43175, Train loss: 0.6774994033575058 |Validation err: 0.382, Validation loss: 0.6513170146942139
Epoch 2: Train err: 0.369, Train loss: 0.6396398993134499 |Validation err: 0.3465, Validation loss: 0.6161113579273224
Epoch 3: Train err: 0.34375, Train loss: 0.6098222960829734 |Validation err: 0.3325, Validation loss: 0.6260210766792297
Epoch 4: Train err: 0.314375, Train loss: 0.584969149172306 |Validation err: 0.34, Validation loss: 0.6044013905525207
Epoch 5: Train err: 0.301125, Train loss: 0.5689119317531586 |Validation err: 0.3125, Validation loss: 0.5769183149337769
Epoch 6: Train err: 0.281, Train loss: 0.5452213580608368 |Validation err: 0.308, Validation loss: 0.570844743013382
Epoch 7: Train err: 0.270875, Train loss: 0.5272981309890747 |Validation err: 0.307, Validation loss: 0.5854293291568756
Epoch 8: Train err: 0.259375, Train loss: 0.507090549826622 |Validation err: 0.313, Validation loss: 0.5877130846977234
Epoch 9: Train err: 0.242375, Train loss: 0.49683444169163704 |Validation err: 0.313, Validation loss: 0.5922425067424775
Epoch 10: Train err: 0.236375, Train loss: 0.47561015680432317 |Validation err: 0.297, Validation loss: 0.5718690168857574
Epoch 11: Train err: 0.222125, Train loss: 0.45997694665193556 |Validation err: 0.2975, Validation loss: 0.6376970813274384
Epoch 12: Train err: 0.211, Train loss: 0.4454492364227772 |Validation err: 0.2995, Validation loss: 0.609202568769455
Epoch 13: Train err: 0.19875, Train loss: 0.42454217198491095 |Validation err: 0.3075, Validation loss: 0.6494987757205963
Epoch 14: Train err: 0.18675, Train loss: 0.4007472902536392 |Validation err: 0.3085, Validation loss: 0.6610016564130783
Epoch 15: Train err: 0.1645, Train loss: 0.3759974044710398 |Validation err: 0.3105, Validation loss: 0.7106090523004532
Epoch 16: Train err: 0.16125, Train loss: 0.35914554065465926 |Validation err: 0.3005, Validation loss: 0.7310364973545075
Epoch 17: Train err: 0.15775, Train loss: 0.3463234778419137 |Validation err: 0.307, Validation loss: 0.7263009355068207
Epoch 18: Train err: 0.141625, Train loss: 0.32175366409868 |Validation err: 0.3195, Validation loss: 0.7913952922821045
Epoch 19: Train err: 0.13375, Train loss: 0.3061810576841235 |Validation err: 0.335, Validation loss: 0.8032052783966065
Epoch 20: Train err: 0.126625, Train loss: 0.30290717820078134 |Validation err: 0.32, Validation loss: 0.8106685200929642
Epoch 21: Train err: 0.12025, Train loss: 0.28682796521484855 |Validation err: 0.3205, Validation loss: 0.8259474363327026
Epoch 22: Train err: 0.1165, Train loss: 0.2748908795714378 |Validation err: 0.352, Validation loss: 0.8937610728740693
Epoch 23: Train err: 0.104375, Train loss: 0.2467898515611887 |Validation err: 0.3315, Validation loss: 1.0021928179264068
Epoch 24: Train err: 0.101, Train loss: 0.23970085600204766 |Validation err: 0.331, Validation loss: 1.1290796512365342
Epoch 25: Train err: 0.09575, Train loss: 0.23643119525164366 |Validation err: 0.3315, Validation loss: 1.1338514356613159
Epoch 26: Train err: 0.094125, Train loss: 0.23259535063058137 |Validation err: 0.3365, Validation loss: 1.141426316022873
Epoch 27: Train err: 0.08425, Train loss: 0.21040759443677962 |Validation err: 0.3335, Validation loss: 1.182367821574211
Epoch 28: Train err: 0.0825, Train loss: 0.20643112601805477 |Validation err: 0.323, Validation loss: 1.2668361866474152
Epoch 29: Train err: 0.0845, Train loss: 0.21273409315384925 |Validation err: 0.3245, Validation loss: 1.406717713713646
Epoch 30: Train err: 0.071375, Train loss: 0.18387044004537165 |Validation err: 0.345, Validation loss: 1.4871552119255065
Finished Training
Total time elapsed: 232.35 seconds
LARGE  MODEL
```



Effect of decreasing the batch size: Large Model

Overall the training time due to decreasing the batch size is longer than the default parameters. This could be due to having to divide up the data into smaller chunks and therefore going through more cycles. Compared to the default parameters overfitting has gotten worse. The validation curve increases significantly after the fifth epoch, and the validation error hovers around 0.30 with a slight increase at the end.

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.

Using the small model: decrease the learning rate

I observe that in the large model, there tends to be instances of overfitting when batch size decreased and learning rate increased. But there also seems to be signs of underfitting once the batch size is increased and the learning rate is increased. This could potentially mean that the model is too complicated or the validation data is undersampled. We have yet to experiment with the small model. The small model shows many spikes which could mean the the learning rate is too high and needs to be decreased. By decreasing the learning rate we would be able to produce a smoother training and validation curve. Since the small model trains at a faster time we might be able to increase the number of epoch significantly later to see where is converges.

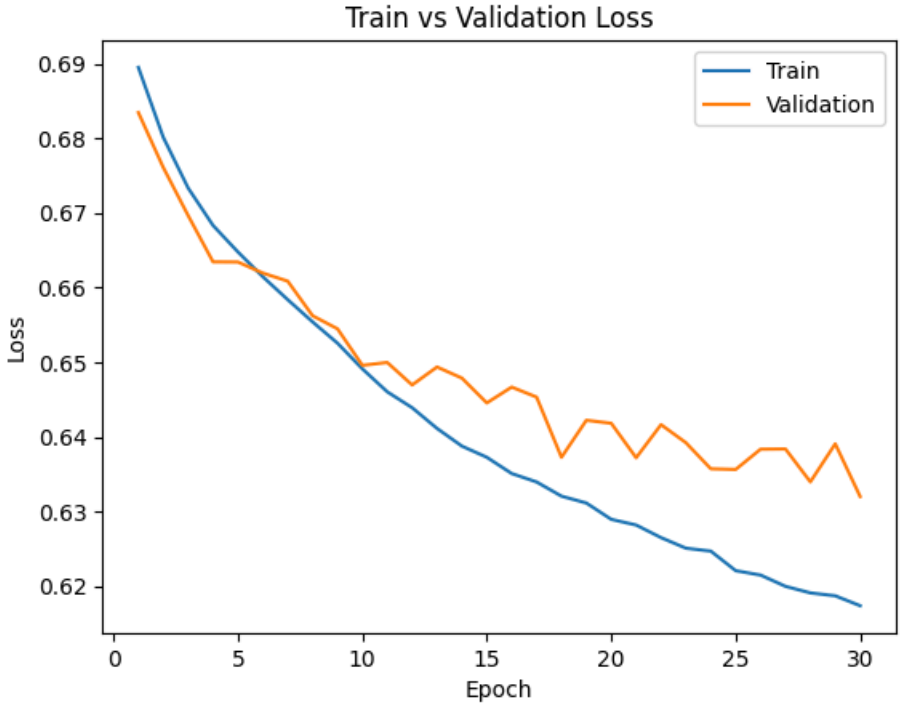
Part (b) - 1pt

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

In [ ]:
```
small_net = SmallNet()
train_net(small_net, batch_size=64, learning_rate=0.001, num_epochs=30)
model_path_small = get_model_name("small", batch_size=64, learning_rate=0.001, epoch=29)
print("SMALL  MODEL")
plot_training_curve(model_path_small)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.463125, Train loss: 0.6894975113868713 |Validation err: 0.4425, Validation loss: 0.6834452152252197
Epoch 2: Train err: 0.4235, Train loss: 0.6801317744255065 |Validation err: 0.4175, Validation loss: 0.6760942544788122
Epoch 3: Train err: 0.409625, Train loss: 0.6733395314216614 |Validation err: 0.4075, Validation loss: 0.6696472316980362
Epoch 4: Train err: 0.397875, Train loss: 0.6683243737220764 |Validation err: 0.401, Validation loss: 0.6634480096399784
Epoch 5: Train err: 0.3935, Train loss: 0.6647757997512818 |Validation err: 0.3955, Validation loss: 0.6634267326444387
Epoch 6: Train err: 0.387125, Train loss: 0.6614563946723938 |Validation err: 0.3955, Validation loss: 0.6619470771402121
Epoch 7: Train err: 0.385, Train loss: 0.6583882060050964 |Validation err: 0.3885, Validation loss: 0.6608655620366335
Epoch 8: Train err: 0.382625, Train loss: 0.6554060144424438 |Validation err: 0.3825, Validation loss: 0.6562327202409506
Epoch 9: Train err: 0.372, Train loss: 0.6525560159683228 |Validation err: 0.3725, Validation loss: 0.6544823255389929
Epoch 10: Train err: 0.3685, Train loss: 0.6491170692443847 |Validation err: 0.3785, Validation loss: 0.6495905108749866
Epoch 11: Train err: 0.366125, Train loss: 0.6460409154891967 |Validation err: 0.373, Validation loss: 0.6499733570963144
Epoch 12: Train err: 0.36225, Train loss: 0.643912501335144 |Validation err: 0.37, Validation loss: 0.6469589807093143
Epoch 13: Train err: 0.36175, Train loss: 0.6411379666328431 |Validation err: 0.369, Validation loss: 0.6493674386292696
Epoch 14: Train err: 0.358125, Train loss: 0.6387662529945374 |Validation err: 0.362, Validation loss: 0.6478758417069912
Epoch 15: Train err: 0.35775, Train loss: 0.6372727370262146 |Validation err: 0.366, Validation loss: 0.6445513311773539
Epoch 16: Train err: 0.357875, Train loss: 0.6350953216552735 |Validation err: 0.3675, Validation loss: 0.6466744169592857
Epoch 17: Train err: 0.355, Train loss: 0.6339662022590637 |Validation err: 0.365, Validation loss: 0.6453325171023607
Epoch 18: Train err: 0.353125, Train loss: 0.6320658617019653 |Validation err: 0.366, Validation loss: 0.6372709441930056
Epoch 19: Train err: 0.351125, Train loss: 0.6311459836959838 |Validation err: 0.365, Validation loss: 0.6422310117632151
Epoch 20: Train err: 0.34825, Train loss: 0.628958848953247 |Validation err: 0.3615, Validation loss: 0.6418254878371954
Epoch 21: Train err: 0.351625, Train loss: 0.628198093175888 |Validation err: 0.368, Validation loss: 0.6372125819325447
Epoch 22: Train err: 0.34975, Train loss: 0.6265126962661743 |Validation err: 0.3595, Validation loss: 0.6416434645652771
Epoch 23: Train err: 0.349375, Train loss: 0.6250933518409729 |Validation err: 0.3605, Validation loss: 0.6392231229692698
Epoch 24: Train err: 0.344625, Train loss: 0.6247038612365723 |Validation err: 0.3655, Validation loss: 0.6357307080179453
Epoch 25: Train err: 0.33875, Train loss: 0.6220828380584716 |Validation err: 0.3575, Validation loss: 0.6356430985033512
Epoch 26: Train err: 0.346125, Train loss: 0.6214947862625122 |Validation err: 0.3615, Validation loss: 0.6383554581552744
Epoch 27: Train err: 0.344, Train loss: 0.6199851284027099 |Validation err: 0.3565, Validation loss: 0.6383872032165527
Epoch 28: Train err: 0.343875, Train loss: 0.619106882572174 |Validation err: 0.3565, Validation loss: 0.6339792776852846
Epoch 29: Train err: 0.338875, Train loss: 0.6187170591354371 |Validation err: 0.354, Validation loss: 0.6390740070492029
Epoch 30: Train err: 0.33725, Train loss: 0.617390905380249 |Validation err: 0.351, Validation loss: 0.632019679993391
Finished Training
Total time elapsed: 178.34 seconds
SMALL  MODEL
```


Train vs Validation Error
Train
Validation
Error
Epoch
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0
5
10
15
20
25
30


Train vs Validation Loss
Train
Validation
Loss
Epoch
0.69
0.68
0.67
0.66
0.65
0.64
0.63
0.62
0
5
10
15
20
25
30

Part (c) - 2pt

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

Increasing Batch Size, Increasing the Epochs

The training and validation curve is now a lot less noisy compared to a higher learning rate. There are now signs of overfitting and a unstable validation curve. We would potentially increase the batch size so that each step has more training examples to reduce spikes. Near the 30th epoch, the training curve is still going downwards, showing room for learning. If we increase the number of epoch, we can see if the graph ends up flattening.

Part (d) - 1pt

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

In [ ]:
```
# decrease learning rate, increase epoch, increase batch size
small_net = SmallNet()
train_net(small_net, batch_size=512, learning_rate=0.001, num_epochs=250)
model_path_small = get_model_name("small", batch_size=512, learning_rate=0.001, epoch=249)
print("SMALL  MODEL")
plot_training_curve(model_path_small)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.5145, Train loss: 0.707811314612627 |Validation err: 0.523, Validation loss: 0.7004823684692383
Epoch 2: Train err: 0.523875, Train loss: 0.6988230310380459 |Validation err: 0.5185, Validation loss: 0.6971128284931183
Epoch 3: Train err: 0.508625, Train loss: 0.6958687342703342 |Validation err: 0.492, Validation loss: 0.6947224736213684
Epoch 4: Train err: 0.488, Train loss: 0.6935285143554211 |Validation err: 0.4825, Validation loss: 0.6921024471521378
Epoch 5: Train err: 0.477, Train loss: 0.6912660226225853 |Validation err: 0.476, Validation loss: 0.6897109597921371
Epoch 6: Train err: 0.461, Train loss: 0.689423993229866 |Validation err: 0.461, Validation loss: 0.6877316236495972
Epoch 7: Train err: 0.455625, Train loss: 0.687686026096344 |Validation err: 0.446, Validation loss: 0.6859051734209061
Epoch 8: Train err: 0.452875, Train loss: 0.6860525049269199 |Validation err: 0.4365, Validation loss: 0.6843619495630264
Epoch 9: Train err: 0.443125, Train loss: 0.6845325157046318 |Validation err: 0.4305, Validation loss: 0.6831013262271881
Epoch 10: Train err: 0.435, Train loss: 0.683290883898735 |Validation err: 0.426, Validation loss: 0.6818269789218903
Epoch 11: Train err: 0.434625, Train loss: 0.6819369979202747 |Validation err: 0.418, Validation loss: 0.6800411194562912
Epoch 12: Train err: 0.432, Train loss: 0.6804282180964947 |Validation err: 0.417, Validation loss: 0.6789858341217041
Epoch 13: Train err: 0.42775, Train loss: 0.6793721951544285 |Validation err: 0.415, Validation loss: 0.6777854561805725
Epoch 14: Train err: 0.4225, Train loss: 0.6780100725591183 |Validation err: 0.411, Validation loss: 0.6767515987157822
Epoch 15: Train err: 0.420875, Train loss: 0.6767804324626923 |Validation err: 0.4105, Validation loss: 0.6755550056695938
Epoch 16: Train err: 0.41725, Train loss: 0.6758895739912987 |Validation err: 0.403, Validation loss: 0.6745123267173767
Epoch 17: Train err: 0.412375, Train loss: 0.6746834479272366 |Validation err: 0.405, Validation loss: 0.673381119966507
Epoch 18: Train err: 0.41225, Train loss: 0.6736437752842903 |Validation err: 0.4035, Validation loss: 0.6723799705505371
Epoch 19: Train err: 0.407375, Train loss: 0.6725948229432106 |Validation err: 0.4035, Validation loss: 0.6710953861474991
Epoch 20: Train err: 0.40375, Train loss: 0.6713218800723553 |Validation err: 0.4015, Validation loss: 0.6705803573131561
Epoch 21: Train err: 0.40375, Train loss: 0.6703834496438503 |Validation err: 0.402, Validation loss: 0.6693789511919022
Epoch 22: Train err: 0.40125, Train loss: 0.6699112765491009 |Validation err: 0.3995, Validation loss: 0.6684918254613876
Epoch 23: Train err: 0.39975, Train loss: 0.6684717051684856 |Validation err: 0.3995, Validation loss: 0.6677698642015457
Epoch 24: Train err: 0.398875, Train loss: 0.6674101799726486 |Validation err: 0.397, Validation loss: 0.666822612285614
Epoch 25: Train err: 0.39725, Train loss: 0.6664796285331249 |Validation err: 0.3935, Validation loss: 0.6658728420734406
Epoch 26: Train err: 0.39575, Train loss: 0.6657836623489857 |Validation err: 0.395, Validation loss: 0.6649990379810333
Epoch 27: Train err: 0.3955, Train loss: 0.664541631937027 |Validation err: 0.394, Validation loss: 0.6640025526285172
Epoch 28: Train err: 0.391875, Train loss: 0.6641452461481094 |Validation err: 0.3905, Validation loss: 0.6636485308408737
Epoch 29: Train err: 0.38925, Train loss: 0.6626098640263081 |Validation err: 0.3905, Validation loss: 0.6625264585018158
Epoch 30: Train err: 0.387, Train loss: 0.662100724875927 |Validation err: 0.3875, Validation loss: 0.661830335855484
Epoch 31: Train err: 0.385375, Train loss: 0.6616446599364281 |Validation err: 0.3865, Validation loss: 0.6612448394298553
Epoch 32: Train err: 0.384125, Train loss: 0.6607042104005814 |Validation err: 0.3845, Validation loss: 0.6606510430574417
Epoch 33: Train err: 0.382625, Train loss: 0.6596252508461475 |Validation err: 0.3855, Validation loss: 0.6597900986671448
Epoch 34: Train err: 0.381375, Train loss: 0.6592475920915604 |Validation err: 0.3825, Validation loss: 0.6591608077287674
Epoch 35: Train err: 0.38025, Train loss: 0.6582107059657574 |Validation err: 0.3805, Validation loss: 0.6580298840999603
Epoch 36: Train err: 0.37925, Train loss: 0.6574103832244873 |Validation err: 0.38, Validation loss: 0.6576434969902039
Epoch 37: Train err: 0.380375, Train loss: 0.6567261815071106 |Validation err: 0.3825, Validation loss: 0.656748354434967
Epoch 38: Train err: 0.376375, Train loss: 0.6562856882810593 |Validation err: 0.3765, Validation loss: 0.6567858010530472
Epoch 39: Train err: 0.37925, Train loss: 0.6551814526319504 |Validation err: 0.376, Validation loss: 0.6557787656784058
Epoch 40: Train err: 0.37725, Train loss: 0.6550211496651173 |Validation err: 0.3765, Validation loss: 0.6551523059606552
Epoch 41: Train err: 0.37675, Train loss: 0.6542286388576031 |Validation err: 0.3735, Validation loss: 0.6543510258197784
Epoch 42: Train err: 0.375625, Train loss: 0.6535063199698925 |Validation err: 0.3725, Validation loss: 0.6542111337184906
Epoch 43: Train err: 0.373, Train loss: 0.6529897004365921 |Validation err: 0.37, Validation loss: 0.6534997969865799
Epoch 44: Train err: 0.375625, Train loss: 0.6525348946452141 |Validation err: 0.3685, Validation loss: 0.6525045931339264
Epoch 45: Train err: 0.372125, Train loss: 0.6508076675236225 |Validation err: 0.3665, Validation loss: 0.652264878153801
Epoch 46: Train err: 0.37175, Train loss: 0.6505957543849945 |Validation err: 0.367, Validation loss: 0.6519727259874344
Epoch 47: Train err: 0.37125, Train loss: 0.6499544121325016 |Validation err: 0.37, Validation loss: 0.6510183960199356
Epoch 48: Train err: 0.37075, Train loss: 0.6494588889181614 |Validation err: 0.365, Validation loss: 0.6511672139167786
Epoch 49: Train err: 0.36925, Train loss: 0.6495395377278328 |Validation err: 0.3665, Validation loss: 0.6505101919174194
Epoch 50: Train err: 0.369375, Train loss: 0.6489555723965168 |Validation err: 0.3625, Validation loss: 0.6497126668691635
Epoch 51: Train err: 0.368875, Train loss: 0.6482781246304512 |Validation err: 0.364, Validation loss: 0.6491996645927429
Epoch 52: Train err: 0.367625, Train loss: 0.6472485326230526 |Validation err: 0.3595, Validation loss: 0.6486450284719467
Epoch 53: Train err: 0.367, Train loss: 0.646990928798914 |Validation err: 0.3625, Validation loss: 0.6485754400491714
Epoch 54: Train err: 0.367625, Train loss: 0.6466190628707409 |Validation err: 0.3615, Validation loss: 0.6479571312665939
Epoch 55: Train err: 0.365625, Train loss: 0.6460633650422096 |Validation err: 0.359, Validation loss: 0.6476999968290329
```

```
Epoch 56: Train err: 0.365125, Train loss: 0.6451308205723763 |Validation err: 0.359, Validation loss: 0.647093877196312
Epoch 57: Train err: 0.365625, Train loss: 0.645039789378643 |Validation err: 0.3575, Validation loss: 0.6469733566045761
Epoch 58: Train err: 0.363875, Train loss: 0.6442928984761238 |Validation err: 0.3575, Validation loss: 0.64618793129920 96
Epoch 59: Train err: 0.363875, Train loss: 0.6441919431090355 |Validation err: 0.358, Validation loss: 0.6459071189165115
Epoch 60: Train err: 0.362, Train loss: 0.6439085714519024 |Validation err: 0.359, Validation loss: 0.6458090990781784
Epoch 61: Train err: 0.36375, Train loss: 0.6438652276992798 |Validation err: 0.3595, Validation loss: 0.6450797319412231
Epoch 62: Train err: 0.36375, Train loss: 0.6432329565286636 |Validation err: 0.3595, Validation loss: 0.6448621153831482
Epoch 63: Train err: 0.360625, Train loss: 0.642468947917223 |Validation err: 0.3555, Validation loss: 0.6450527757406235
Epoch 64: Train err: 0.359625, Train loss: 0.6413585655391216 |Validation err: 0.357, Validation loss: 0.6447354108095169
Epoch 65: Train err: 0.361, Train loss: 0.6419324092566967 |Validation err: 0.3615, Validation loss: 0.6432842314243317
Epoch 66: Train err: 0.36175, Train loss: 0.6413925141096115 |Validation err: 0.3615, Validation loss: 0.6437753736972809
Epoch 67: Train err: 0.36075, Train loss: 0.64061064645648 |Validation err: 0.361, Validation loss: 0.6433550268411636
Epoch 68: Train err: 0.3605, Train loss: 0.6402234323322773 |Validation err: 0.361, Validation loss: 0.6431528776884079
Epoch 69: Train err: 0.35975, Train loss: 0.6405599489808083 |Validation err: 0.36, Validation loss: 0.6425362974405289
Epoch 70: Train err: 0.359375, Train loss: 0.6396571435034275 |Validation err: 0.359, Validation loss: 0.6424469947814941
Epoch 71: Train err: 0.359125, Train loss: 0.6392537131905556 |Validation err: 0.359, Validation loss: 0.642054408788681
Epoch 72: Train err: 0.359625, Train loss: 0.6394261457026005 |Validation err: 0.361, Validation loss: 0.642097681760788
Epoch 73: Train err: 0.3595, Train loss: 0.6385824047029018 |Validation err: 0.3585, Validation loss: 0.6420339941978455
Epoch 74: Train err: 0.358875, Train loss: 0.6390829309821129 |Validation err: 0.362, Validation loss: 0.641590490937233
Epoch 75: Train err: 0.35925, Train loss: 0.6387186869978905 |Validation err: 0.3605, Validation loss: 0.6416404992341995
Epoch 76: Train err: 0.358625, Train loss: 0.638222236186266 |Validation err: 0.36, Validation loss: 0.6412669718265533
Epoch 77: Train err: 0.35825, Train loss: 0.6372838132083416 |Validation err: 0.3605, Validation loss: 0.6414507180452347
Epoch 78: Train err: 0.357625, Train loss: 0.6374281086027622 |Validation err: 0.357, Validation loss: 0.6410665214061737
Epoch 79: Train err: 0.358, Train loss: 0.6376838199794292 |Validation err: 0.3595, Validation loss: 0.6411137878894806
Epoch 80: Train err: 0.358, Train loss: 0.6370247453451157 |Validation err: 0.3585, Validation loss: 0.6402088403701782
Epoch 81: Train err: 0.356875, Train loss: 0.6368623524904251 |Validation err: 0.359, Validation loss: 0.6401740312576294
Epoch 82: Train err: 0.358125, Train loss: 0.6365542225539684 |Validation err: 0.3625, Validation loss: 0.6404523402452469
Epoch 83: Train err: 0.35575, Train loss: 0.6366952806711197 |Validation err: 0.356, Validation loss: 0.640213742852211
Epoch 84: Train err: 0.355625, Train loss: 0.6357868500053883 |Validation err: 0.3555, Validation loss: 0.6402648985385895
Epoch 85: Train err: 0.357, Train loss: 0.6354229599237442 |Validation err: 0.3585, Validation loss: 0.6394219547510147
Epoch 86: Train err: 0.355875, Train loss: 0.6354322582483292 |Validation err: 0.3545, Validation loss: 0.6395950466394424
Epoch 87: Train err: 0.356125, Train loss: 0.6359982192516327 |Validation err: 0.3535, Validation loss: 0.6392102837562561
Epoch 88: Train err: 0.35575, Train loss: 0.6352418400347233 |Validation err: 0.3565, Validation loss: 0.6388134956359863
Epoch 89: Train err: 0.354375, Train loss: 0.6345243342220783 |Validation err: 0.3525, Validation loss: 0.6393062919378281
Epoch 90: Train err: 0.35425, Train loss: 0.6346972584724426 |Validation err: 0.3505, Validation loss: 0.6391123831272125
Epoch 91: Train err: 0.353375, Train loss: 0.6345832534134388 |Validation err: 0.352, Validation loss: 0.6391706615686417
Epoch 92: Train err: 0.3555, Train loss: 0.6339886635541916 |Validation err: 0.356, Validation loss: 0.6384537518024445
Epoch 93: Train err: 0.3545, Train loss: 0.6342583075165749 |Validation err: 0.35, Validation loss: 0.6383952498435974
Epoch 94: Train err: 0.35275, Train loss: 0.633907925337553 |Validation err: 0.3505, Validation loss: 0.6388602554798126
Epoch 95: Train err: 0.355, Train loss: 0.6331399232149124 |Validation err: 0.3545, Validation loss: 0.6378570795059204
Epoch 96: Train err: 0.353375, Train loss: 0.6332902684807777 |Validation err: 0.351, Validation loss: 0.6379783153533936
Epoch 97: Train err: 0.353, Train loss: 0.633279986679554 |Validation err: 0.3505, Validation loss: 0.6381801962852478
Epoch 98: Train err: 0.352375, Train loss: 0.6334796249866486 |Validation err: 0.3495, Validation loss: 0.6378464996814728
Epoch 99: Train err: 0.35325, Train loss: 0.6327228024601936 |Validation err: 0.354, Validation loss: 0.6378540843725204
Epoch 100: Train err: 0.352375, Train loss: 0.6321308612823486 |Validation err: 0.3505, Validation loss: 0.6378798931837082
Epoch 101: Train err: 0.35275, Train loss: 0.6322108320891857 |Validation err: 0.3515, Validation loss: 0.63747638463974
Epoch 102: Train err: 0.35275, Train loss: 0.6325760930776596 |Validation err: 0.355, Validation loss: 0.6374028921127319
Epoch 103: Train err: 0.352625, Train loss: 0.631387934088707 |Validation err: 0.354, Validation loss: 0.6373313665390015
Epoch 104: Train err: 0.351, Train loss: 0.631487425416708 |Validation err: 0.353, Validation loss: 0.6367296576499939
Epoch 105: Train err: 0.3515, Train loss: 0.6313845701515675 |Validation err: 0.3545, Validation loss: 0.6367811113595963
Epoch 106: Train err: 0.3515, Train loss: 0.6306237243115902 |Validation err: 0.3535, Validation loss: 0.6367632448673248
Epoch 107: Train err: 0.352375, Train loss: 0.630835022777319 |Validation err: 0.3545, Validation loss: 0.6367148011922836
Epoch 108: Train err: 0.352, Train loss: 0.6305651888251305 |Validation err: 0.356, Validation loss: 0.6366153508424759
Epoch 109: Train err: 0.351, Train loss: 0.6305119544267654 |Validation err: 0.356, Validation loss: 0.6368687152862549
Epoch 110: Train err: 0.350125, Train loss: 0.6302394010126591 |Validation err: 0.3535, Validation loss: 0.6367109268903732
Epoch 111: Train err: 0.34925, Train loss: 0.629891149699688 |Validation err: 0.356, Validation loss: 0.6366457939147949
Epoch 112: Train err: 0.350375, Train loss: 0.6300570033490658 |Validation err: 0.356, Validation loss: 0.636231318116188
```

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Epoch 113: Train err: 0.349625, Train loss: 0.6294922642409801 |Validation err: 0.358, Validation loss: 0.6362227648496628
Epoch 114: Train err: 0.3495, Train loss: 0.629747424274683 |Validation err: 0.354, Validation loss: 0.6361384987831116
Epoch 115: Train err: 0.349, Train loss: 0.6289324350655079 |Validation err: 0.357, Validation loss: 0.6362996101379395
Epoch 116: Train err: 0.349125, Train loss: 0.6295245252549648 |Validation err: 0.3555, Validation loss: 0.6354174613952637
Epoch 117: Train err: 0.34775, Train loss: 0.6291282661259174 |Validation err: 0.3545, Validation loss: 0.6357104331254959
Epoch 118: Train err: 0.349625, Train loss: 0.6288918107748032 |Validation err: 0.3565, Validation loss: 0.6355745196342468
Epoch 119: Train err: 0.34925, Train loss: 0.6283559873700142 |Validation err: 0.3525, Validation loss: 0.6355653703212738
Epoch 120: Train err: 0.34875, Train loss: 0.6284306272864342 |Validation err: 0.355, Validation loss: 0.6350242495536804
Epoch 121: Train err: 0.34925, Train loss: 0.6284630559384823 |Validation err: 0.3535, Validation loss: 0.6351171135902405
Epoch 122: Train err: 0.348875, Train loss: 0.6272247284650803 |Validation err: 0.356, Validation loss: 0.6355871707201004
Epoch 123: Train err: 0.3485, Train loss: 0.6276227869093418 |Validation err: 0.354, Validation loss: 0.6347109526395798
Epoch 124: Train err: 0.34675, Train loss: 0.6282103583216667 |Validation err: 0.3545, Validation loss: 0.6347234696149826
Epoch 125: Train err: 0.346875, Train loss: 0.6278632394969463 |Validation err: 0.356, Validation loss: 0.6345994770526886
Epoch 126: Train err: 0.346625, Train loss: 0.627439595758915 |Validation err: 0.354, Validation loss: 0.6348249018192291
Epoch 127: Train err: 0.34775, Train loss: 0.6272891648113728 |Validation err: 0.3555, Validation loss: 0.6346807926893234
Epoch 128: Train err: 0.34475, Train loss: 0.626315500587225 |Validation err: 0.3555, Validation loss: 0.6346171796321869
Epoch 129: Train err: 0.345625, Train loss: 0.6267836391925812 |Validation err: 0.3525, Validation loss: 0.6343911588191986
Epoch 130: Train err: 0.345625, Train loss: 0.6260085068643093 |Validation err: 0.356, Validation loss: 0.6339811682701111
Epoch 131: Train err: 0.345125, Train loss: 0.6259797774255276 |Validation err: 0.3565, Validation loss: 0.6338239461183548
Epoch 132: Train err: 0.345375, Train loss: 0.6249520480632782 |Validation err: 0.355, Validation loss: 0.6344120800495148
Epoch 133: Train err: 0.344875, Train loss: 0.6259172037243843 |Validation err: 0.356, Validation loss: 0.633523017168045
Epoch 134: Train err: 0.344, Train loss: 0.6263289302587509 |Validation err: 0.3555, Validation loss: 0.6330902874469757
Epoch 135: Train err: 0.3455, Train loss: 0.6255360841751099 |Validation err: 0.353, Validation loss: 0.6337833404541016
Epoch 136: Train err: 0.34625, Train loss: 0.6253656260669231 |Validation err: 0.3545, Validation loss: 0.6337136328220367
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Epoch 138: Train err: 0.34325, Train loss: 0.624861266463995 |Validation err: 0.355, Validation loss: 0.6332639455795288
Epoch 139: Train err: 0.345, Train loss: 0.6239499635994434 |Validation err: 0.358, Validation loss: 0.6331413686275482
Epoch 140: Train err: 0.34325, Train loss: 0.6235706619918346 |Validation err: 0.359, Validation loss: 0.6328604519367218
Epoch 141: Train err: 0.342875, Train loss: 0.6244029365479946 |Validation err: 0.355, Validation loss: 0.6327940225601196
Epoch 142: Train err: 0.343875, Train loss: 0.6243608631193638 |Validation err: 0.3555, Validation loss: 0.6328138113021851
Epoch 143: Train err: 0.343375, Train loss: 0.6232083328068256 |Validation err: 0.3575, Validation loss: 0.6330635994672775
Epoch 144: Train err: 0.34325, Train loss: 0.6228847205638885 |Validation err: 0.358, Validation loss: 0.6326312720775604
Epoch 145: Train err: 0.343, Train loss: 0.6236615478992462 |Validation err: 0.357, Validation loss: 0.6323348879814148
Epoch 146: Train err: 0.343125, Train loss: 0.6235132664442062 |Validation err: 0.357, Validation loss: 0.6330711543560028
Epoch 147: Train err: 0.341625, Train loss: 0.6232522279024124 |Validation err: 0.358, Validation loss: 0.6319105327129364
Epoch 148: Train err: 0.343625, Train loss: 0.6228346303105354 |Validation err: 0.3575, Validation loss: 0.6322095096111298
Epoch 149: Train err: 0.343, Train loss: 0.6223812140524387 |Validation err: 0.358, Validation loss: 0.6316407024860382
Epoch 150: Train err: 0.342125, Train loss: 0.6221497431397438 |Validation err: 0.359, Validation loss: 0.63224658370018
Epoch 151: Train err: 0.343125, Train loss: 0.6222857683897018 |Validation err: 0.3575, Validation loss: 0.6320741027593613
Epoch 152: Train err: 0.341375, Train loss: 0.621929194778204 |Validation err: 0.358, Validation loss: 0.6318821161985397
Epoch 153: Train err: 0.342, Train loss: 0.6216624826192856 |Validation err: 0.3605, Validation loss: 0.631663367152214
Epoch 154: Train err: 0.34175, Train loss: 0.6213132925331593 |Validation err: 0.3595, Validation loss: 0.6320470124483109
Epoch 155: Train err: 0.34025, Train loss: 0.6211025044322014 |Validation err: 0.356, Validation loss: 0.6311769187450409
Epoch 156: Train err: 0.34175, Train loss: 0.6226983405649662 |Validation err: 0.359, Validation loss: 0.6308878809213638
Epoch 157: Train err: 0.34075, Train loss: 0.6211601980030537 |Validation err: 0.3545, Validation loss: 0.6316892504692078
Epoch 158: Train err: 0.34, Train loss: 0.6209302432835102 |Validation err: 0.3545, Validation loss: 0.6313531398773193
Epoch 159: Train err: 0.341, Train loss: 0.6204689219594002 |Validation err: 0.3575, Validation loss: 0.6311793327331543
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Epoch 161: Train err: 0.34225, Train loss: 0.6208910383284092 |Validation err: 0.3565, Validation loss: 0.630661353468895
Epoch 162: Train err: 0.3405, Train loss: 0.6198949404060841 |Validation err: 0.3525, Validation loss: 0.6307846158742905
Epoch 163: Train err: 0.339625, Train loss: 0.6200152821838856 |Validation err: 0.3555, Validation loss: 0.6302201896905899
Epoch 164: Train err: 0.338625, Train loss: 0.6201991997659206 |Validation err: 0.3535, Validation loss: 0.6308016926050186
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Epoch 166: Train err: 0.339125, Train loss: 0.6198852881789207 |Validation err: 0.354, Validation loss: 0.6297946572303772
Epoch 167: Train err: 0.338875, Train loss: 0.6189946308732033 |Validation err: 0.352, Validation loss: 0.630961000919342
Epoch 168: Train err: 0.338125, Train loss: 0.6190926916897297 |Validation err: 0.353, Validation loss: 0.6304440051317215
Epoch 169: Train err: 0.338875, Train loss: 0.6186299249529839 |Validation err: 0.3525, Validation loss: 0.6297284215688705
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Epoch 170: Train err: 0.339625, Train loss: 0.619093906134367 |Validation err: 0.3505, Validation loss: 0.6306273639202118
Epoch 171: Train err: 0.339125, Train loss: 0.6183311529457569 |Validation err: 0.3545, Validation loss: 0.6296466737985611
Epoch 172: Train err: 0.338875, Train loss: 0.6192910857498646 |Validation err: 0.35, Validation loss: 0.6299954950809479
Epoch 173: Train err: 0.338375, Train loss: 0.6177308037877083 |Validation err: 0.353, Validation loss: 0.6288337111473083
Epoch 174: Train err: 0.338125, Train loss: 0.6184308119118214 |Validation err: 0.35, Validation loss: 0.6298260390758514
Epoch 175: Train err: 0.3375, Train loss: 0.6174632348120213 |Validation err: 0.3505, Validation loss: 0.6295937597751617
Epoch 176: Train err: 0.337, Train loss: 0.6178608424961567 |Validation err: 0.349, Validation loss: 0.6295566707849503
Epoch 177: Train err: 0.337, Train loss: 0.617268081754446 |Validation err: 0.3505, Validation loss: 0.629280298948288
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Epoch 179: Train err: 0.337, Train loss: 0.6170872375369072 |Validation err: 0.351, Validation loss: 0.6289963275194168
Epoch 180: Train err: 0.33475, Train loss: 0.6172002479434013 |Validation err: 0.3485, Validation loss: 0.6290636211633682
Epoch 181: Train err: 0.3365, Train loss: 0.6161586120724678 |Validation err: 0.3525, Validation loss: 0.6280769407749176
Epoch 182: Train err: 0.335375, Train loss: 0.6168719790875912 |Validation err: 0.3485, Validation loss: 0.6288028210401535
Epoch 183: Train err: 0.334375, Train loss: 0.616526760160923 |Validation err: 0.351, Validation loss: 0.628565102815628
Epoch 184: Train err: 0.334625, Train loss: 0.616709940135479 |Validation err: 0.3475, Validation loss: 0.6285116523504257
Epoch 185: Train err: 0.335, Train loss: 0.6161641366779804 |Validation err: 0.3515, Validation loss: 0.6281201988458633
Epoch 186: Train err: 0.33525, Train loss: 0.61563765630126 |Validation err: 0.345, Validation loss: 0.62840236723423
Epoch 187: Train err: 0.33375, Train loss: 0.6157813258469105 |Validation err: 0.347, Validation loss: 0.6284310966730118
Epoch 188: Train err: 0.33475, Train loss: 0.6153341196477413 |Validation err: 0.35, Validation loss: 0.6279737949371338
Epoch 189: Train err: 0.33425, Train loss: 0.6153622344136238 |Validation err: 0.3505, Validation loss: 0.6279012560844421
Epoch 190: Train err: 0.33575, Train loss: 0.6146344132721424 |Validation err: 0.342, Validation loss: 0.6280615478754044
Epoch 191: Train err: 0.334375, Train loss: 0.6140148006379604 |Validation err: 0.349, Validation loss: 0.6278650164604187
Epoch 192: Train err: 0.334125, Train loss: 0.6146249026060104 |Validation err: 0.344, Validation loss: 0.6274440586566925
Epoch 193: Train err: 0.334, Train loss: 0.6146381422877312 |Validation err: 0.3455, Validation loss: 0.6274329870939255
Epoch 194: Train err: 0.334375, Train loss: 0.6138033159077168 |Validation err: 0.3465, Validation loss: 0.6273475736379623
Epoch 195: Train err: 0.333375, Train loss: 0.6140344031155109 |Validation err: 0.3445, Validation loss: 0.6275072544813156
Epoch 196: Train err: 0.334125, Train loss: 0.614194069057703 |Validation err: 0.343, Validation loss: 0.6275416910648346
Epoch 197: Train err: 0.334125, Train loss: 0.6130005829036236 |Validation err: 0.3395, Validation loss: 0.6273566484451294
Epoch 198: Train err: 0.333125, Train loss: 0.613382313400507 |Validation err: 0.3425, Validation loss: 0.6269955039024353
Epoch 199: Train err: 0.332625, Train loss: 0.6131939217448235 |Validation err: 0.341, Validation loss: 0.626531645655632
Epoch 200: Train err: 0.3325, Train loss: 0.6125909797847271 |Validation err: 0.3415, Validation loss: 0.6272182017564774
Epoch 201: Train err: 0.33325, Train loss: 0.6131086610257626 |Validation err: 0.34, Validation loss: 0.6275225728750229
Epoch 202: Train err: 0.332125, Train loss: 0.6132305264472961 |Validation err: 0.341, Validation loss: 0.6262383759021759
Epoch 203: Train err: 0.33175, Train loss: 0.6128402464091778 |Validation err: 0.342, Validation loss: 0.6268710494041443
Epoch 204: Train err: 0.331, Train loss: 0.6129305586218834 |Validation err: 0.34, Validation loss: 0.6270936727523804
Epoch 205: Train err: 0.330875, Train loss: 0.6119750663638115 |Validation err: 0.3415, Validation loss: 0.6269080936908722
Epoch 206: Train err: 0.33325, Train loss: 0.6123532056808472 |Validation err: 0.3415, Validation loss: 0.6270882785320282
Epoch 207: Train err: 0.332, Train loss: 0.611754335463047 |Validation err: 0.3415, Validation loss: 0.6263571679592133
Epoch 208: Train err: 0.33175, Train loss: 0.6115053296089172 |Validation err: 0.3415, Validation loss: 0.6255656331777573
Epoch 209: Train err: 0.330375, Train loss: 0.6116035282611847 |Validation err: 0.34, Validation loss: 0.6259562820196152
Epoch 210: Train err: 0.3305, Train loss: 0.6119225323200226 |Validation err: 0.34, Validation loss: 0.6261148750782013
Epoch 211: Train err: 0.33125, Train loss: 0.610858615487814 |Validation err: 0.338, Validation loss: 0.6263421475887299
Epoch 212: Train err: 0.329375, Train loss: 0.6111992336809635 |Validation err: 0.34, Validation loss: 0.6257790476083755
Epoch 213: Train err: 0.32925, Train loss: 0.6102056317031384 |Validation err: 0.34, Validation loss: 0.6253479719161987
Epoch 214: Train err: 0.3315, Train loss: 0.6112767942249775 |Validation err: 0.337, Validation loss: 0.6261299252510071
Epoch 215: Train err: 0.330125, Train loss: 0.6103851944208145 |Validation err: 0.3375, Validation loss: 0.625588059425354
Epoch 216: Train err: 0.3295, Train loss: 0.6108263283967972 |Validation err: 0.339, Validation loss: 0.625440388917923
Epoch 217: Train err: 0.3295, Train loss: 0.6108123697340488 |Validation err: 0.3385, Validation loss: 0.6247231364250183
Epoch 218: Train err: 0.330625, Train loss: 0.6105120815336704 |Validation err: 0.3385, Validation loss: 0.6243307292461395
Epoch 219: Train err: 0.328375, Train loss: 0.6095845066010952 |Validation err: 0.34, Validation loss: 0.6254759877920151
Epoch 220: Train err: 0.32925, Train loss: 0.6104028411209583 |Validation err: 0.3425, Validation loss: 0.6249479651451111
Epoch 221: Train err: 0.32975, Train loss: 0.6086757071316242 |Validation err: 0.339, Validation loss: 0.6249470412731171
Epoch 222: Train err: 0.32875, Train loss: 0.6092469803988934 |Validation err: 0.3435, Validation loss: 0.6247849017381668
Epoch 223: Train err: 0.329125, Train loss: 0.6084737330675125 |Validation err: 0.344, Validation loss: 0.624570831656456
Epoch 224: Train err: 0.327625, Train loss: 0.6094430647790432 |Validation err: 0.3385, Validation loss: 0.6248327493667603
Epoch 225: Train err: 0.32825, Train loss: 0.6091358251869678 |Validation err: 0.3445, Validation loss: 0.6247092932462692
Epoch 226: Train err: 0.328625, Train loss: 0.6094259545207024 |Validation err: 0.3455, Validation loss: 0.6240073293447495
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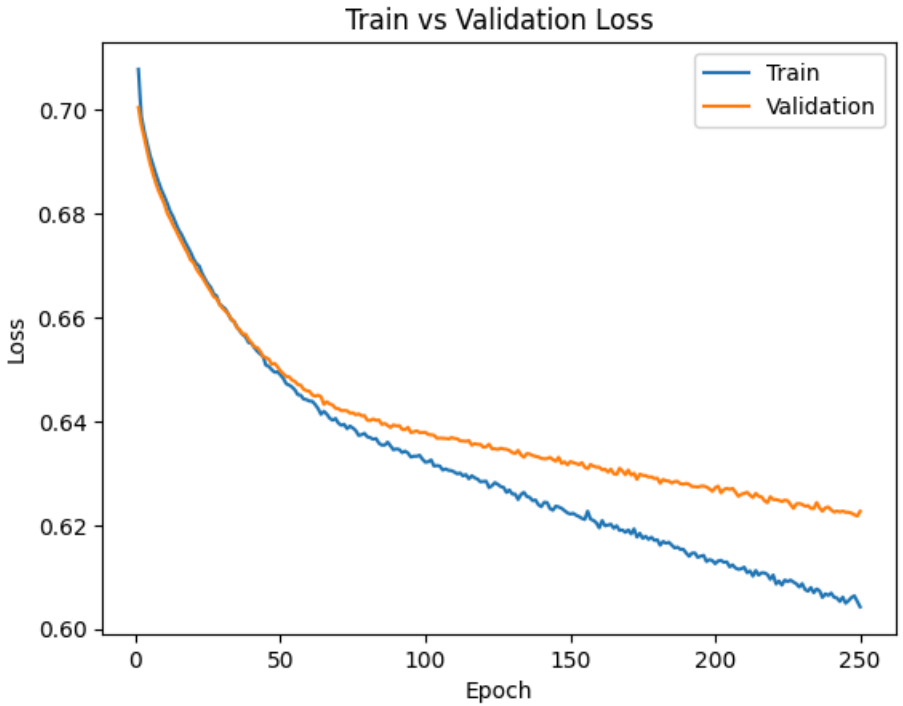
Epoch 227: Train err: 0.326375, Train loss: 0.6090475581586361 |Validation err: 0.3395, Validation loss: 0.6232572346925735
Epoch 228: Train err: 0.327625, Train loss: 0.6087151244282722 |Validation err: 0.344, Validation loss: 0.6241108626127243
Epoch 229: Train err: 0.328625, Train loss: 0.608096044510603 |Validation err: 0.346, Validation loss: 0.6241813451051712
Epoch 230: Train err: 0.327, Train loss: 0.6087336912751198 |Validation err: 0.3425, Validation loss: 0.6239994764328003
Epoch 231: Train err: 0.32825, Train loss: 0.6076220870018005 |Validation err: 0.3455, Validation loss: 0.6236598342657089
Epoch 232: Train err: 0.3285, Train loss: 0.60728370398283 |Validation err: 0.3435, Validation loss: 0.6237752884626389
Epoch 233: Train err: 0.326625, Train loss: 0.6079992726445198 |Validation err: 0.343, Validation loss: 0.623253270983696
Epoch 234: Train err: 0.327125, Train loss: 0.607006199657917 |Validation err: 0.3435, Validation loss: 0.6232121884822845
Epoch 235: Train err: 0.328375, Train loss: 0.6077112816274166 |Validation err: 0.344, Validation loss: 0.6243588328361511
Epoch 236: Train err: 0.325625, Train loss: 0.6073770858347416 |Validation err: 0.3435, Validation loss: 0.6233194768428802
Epoch 237: Train err: 0.3265, Train loss: 0.6060909740626812 |Validation err: 0.343, Validation loss: 0.6227014660835266
Epoch 238: Train err: 0.327625, Train loss: 0.6067788749933243 |Validation err: 0.3435, Validation loss: 0.6233496516942978
Epoch 239: Train err: 0.326125, Train loss: 0.6064778491854668 |Validation err: 0.343, Validation loss: 0.6235049813985825
Epoch 240: Train err: 0.328625, Train loss: 0.6069264933466911 |Validation err: 0.3425, Validation loss: 0.6229536235332489
Epoch 241: Train err: 0.32725, Train loss: 0.6061325706541538 |Validation err: 0.3445, Validation loss: 0.6225339621305466
Epoch 242: Train err: 0.32625, Train loss: 0.6059824638068676 |Validation err: 0.3445, Validation loss: 0.6227284222841263
Epoch 243: Train err: 0.32725, Train loss: 0.6053153984248638 |Validation err: 0.343, Validation loss: 0.6225527673959732
Epoch 244: Train err: 0.32625, Train loss: 0.6061468496918678 |Validation err: 0.3435, Validation loss: 0.6227276772260666
Epoch 245: Train err: 0.3255, Train loss: 0.6049693860113621 |Validation err: 0.3405, Validation loss: 0.6224883943796158
Epoch 246: Train err: 0.32775, Train loss: 0.6054592430591583 |Validation err: 0.3435, Validation loss: 0.622488722205162
Epoch 247: Train err: 0.327, Train loss: 0.6060619316995144 |Validation err: 0.341, Validation loss: 0.6223208159208298
Epoch 248: Train err: 0.324625, Train loss: 0.6064074523746967 |Validation err: 0.342, Validation loss: 0.6220047622919083
Epoch 249: Train err: 0.327625, Train loss: 0.6053499393165112 |Validation err: 0.3385, Validation loss: 0.6217648237943649
Epoch 250: Train err: 0.326625, Train loss: 0.6042712703347206 |Validation err: 0.342, Validation loss: 0.6226722151041031
Finished Training
Total time elapsed: 1117.10 seconds
SMALL  MODEL
```



Part(e) - that no one asked for

Seeing how the small model tends to diverge as the number of epoch increases, I would like to go back to the big model and increase the number of epoch with decreased learning rate and increased batch size. As decreasing the learning rate can help with less fluctuation and increased batch size helps reduce overfitting.

In [ ]:
```
# decrease learning rate, increase epoch, increase batch size
large_net = LargeNet()
train_net(large_net, batch_size=512, learning_rate=0.001, num_epochs=250)
model_path_large = get_model_name("large", batch_size=512, learning_rate=0.001, epoch=249)
print("LARGE  MODEL")
plot_training_curve(model_path_large)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.50225, Train loss: 0.6946656666696072 |Validation err: 0.491, Validation loss: 0.6939187347888947
Epoch 2: Train err: 0.50225, Train loss: 0.6945646665990353 |Validation err: 0.491, Validation loss: 0.6938043832778931
Epoch 3: Train err: 0.50225, Train loss: 0.6943127699196339 |Validation err: 0.491, Validation loss: 0.6936505287885666
Epoch 4: Train err: 0.50225, Train loss: 0.6941213682293892 |Validation err: 0.491, Validation loss: 0.69350565969944
Epoch 5: Train err: 0.50225, Train loss: 0.6940221525728703 |Validation err: 0.491, Validation loss: 0.6934881210327148
Epoch 6: Train err: 0.502125, Train loss: 0.6938703320920467 |Validation err: 0.491, Validation loss: 0.6934278756380081
Epoch 7: Train err: 0.50225, Train loss: 0.6938018389046192 |Validation err: 0.491, Validation loss: 0.6933837682008743
Epoch 8: Train err: 0.502, Train loss: 0.6936991885304451 |Validation err: 0.4905, Validation loss: 0.6933301687240601
Epoch 9: Train err: 0.502625, Train loss: 0.6936227530241013 |Validation err: 0.4915, Validation loss: 0.6932712942361832
Epoch 10: Train err: 0.502625, Train loss: 0.6935233399271965 |Validation err: 0.494, Validation loss: 0.6932681649923325
Epoch 11: Train err: 0.502, Train loss: 0.6934509500861168 |Validation err: 0.4945, Validation loss: 0.6931762546300888
Epoch 12: Train err: 0.502375, Train loss: 0.6933865249156952 |Validation err: 0.4965, Validation loss: 0.693166047334671
Epoch 13: Train err: 0.50125, Train loss: 0.6933329291641712 |Validation err: 0.4965, Validation loss: 0.6931363046169281
Epoch 14: Train err: 0.5, Train loss: 0.693255465477705 |Validation err: 0.501, Validation loss: 0.6931094974279404
Epoch 15: Train err: 0.498375, Train loss: 0.6932223998010159 |Validation err: 0.502, Validation loss: 0.6930967271327972
Epoch 16: Train err: 0.496875, Train loss: 0.693192332983017 |Validation err: 0.5005, Validation loss: 0.6930757015943527
Epoch 17: Train err: 0.497125, Train loss: 0.6931417137384415 |Validation err: 0.5025, Validation loss: 0.6930527091026306
Epoch 18: Train err: 0.495, Train loss: 0.6930913589894772 |Validation err: 0.5015, Validation loss: 0.6930250972509384
Epoch 19: Train err: 0.4935, Train loss: 0.6930611319839954 |Validation err: 0.505, Validation loss: 0.6930112391710281
Epoch 20: Train err: 0.49875, Train loss: 0.693008691072464 |Validation err: 0.492, Validation loss: 0.6929741501808167
Epoch 21: Train err: 0.498625, Train loss: 0.6929592862725258 |Validation err: 0.4835, Validation loss: 0.6929477155208588
Epoch 22: Train err: 0.492125, Train loss: 0.6929332315921783 |Validation err: 0.485, Validation loss: 0.6929442882537842
Epoch 23: Train err: 0.48775, Train loss: 0.6929034106433392 |Validation err: 0.481, Validation loss: 0.6929181069135666
Epoch 24: Train err: 0.48325, Train loss: 0.6928639225661755 |Validation err: 0.478, Validation loss: 0.6928846389055252
Epoch 25: Train err: 0.47825, Train loss: 0.6928178817033768 |Validation err: 0.4755, Validation loss: 0.6928640902042389
Epoch 26: Train err: 0.4755, Train loss: 0.6927873864769936 |Validation err: 0.4685, Validation loss: 0.6928312331438065
Epoch 27: Train err: 0.475, Train loss: 0.6927421391010284 |Validation err: 0.466, Validation loss: 0.6928148716688156
Epoch 28: Train err: 0.46675, Train loss: 0.6927144601941109 |Validation err: 0.4555, Validation loss: 0.6927801817655563
Epoch 29: Train err: 0.464625, Train loss: 0.6926762983202934 |Validation err: 0.4545, Validation loss: 0.6927497386932373
Epoch 30: Train err: 0.4595, Train loss: 0.6926236003637314 |Validation err: 0.456, Validation loss: 0.6927342712879181
Epoch 31: Train err: 0.458625, Train loss: 0.6926114037632942 |Validation err: 0.4565, Validation loss: 0.6926875710487366
Epoch 32: Train err: 0.459125, Train loss: 0.692581657320261 |Validation err: 0.461, Validation loss: 0.6926579922437668
Epoch 33: Train err: 0.45675, Train loss: 0.6925121322274208 |Validation err: 0.4605, Validation loss: 0.6926300227642059
Epoch 34: Train err: 0.455125, Train loss: 0.6924976147711277 |Validation err: 0.4615, Validation loss: 0.6925956755876541
Epoch 35: Train err: 0.4555, Train loss: 0.6924449503421783 |Validation err: 0.456, Validation loss: 0.6925519853830338
Epoch 36: Train err: 0.458375, Train loss: 0.6923805736005306 |Validation err: 0.4585, Validation loss: 0.6925291568040848
Epoch 37: Train err: 0.453375, Train loss: 0.6923540718853474 |Validation err: 0.4575, Validation loss: 0.6924693435430527
Epoch 38: Train err: 0.453625, Train loss: 0.692316398024559 |Validation err: 0.451, Validation loss: 0.6924460232257843
Epoch 39: Train err: 0.450375, Train loss: 0.6922618225216866 |Validation err: 0.451, Validation loss: 0.692383199930191
Epoch 40: Train err: 0.4505, Train loss: 0.6922209560871124 |Validation err: 0.448, Validation loss: 0.6923236548900604
Epoch 41: Train err: 0.448375, Train loss: 0.6921541020274162 |Validation err: 0.4485, Validation loss: 0.6922810673713684
Epoch 42: Train err: 0.448625, Train loss: 0.6921153664588928 |Validation err: 0.447, Validation loss: 0.6922516822814941
Epoch 43: Train err: 0.447625, Train loss: 0.6920526698231697 |Validation err: 0.446, Validation loss: 0.6921881139278412
Epoch 44: Train err: 0.44375, Train loss: 0.6919991448521614 |Validation err: 0.4415, Validation loss: 0.692125990986824
Epoch 45: Train err: 0.44425, Train loss: 0.6919257827103138 |Validation err: 0.438, Validation loss: 0.6920842975378036
Epoch 46: Train err: 0.441375, Train loss: 0.6918713413178921 |Validation err: 0.437, Validation loss: 0.6920250952243805
Epoch 47: Train err: 0.4375, Train loss: 0.6918222643435001 |Validation err: 0.433, Validation loss: 0.6919521689414978
Epoch 48: Train err: 0.438, Train loss: 0.6917693838477135 |Validation err: 0.4325, Validation loss: 0.6918986290693283
Epoch 49: Train err: 0.43725, Train loss: 0.6917297281324863 |Validation err: 0.4295, Validation loss: 0.6918486505746841
Epoch 50: Train err: 0.436625, Train loss: 0.6916605457663536 |Validation err: 0.4305, Validation loss: 0.691771924495697
Epoch 51: Train err: 0.43575, Train loss: 0.6916201710700989 |Validation err: 0.429, Validation loss: 0.6917062252759933
Epoch 52: Train err: 0.435375, Train loss: 0.691507775336504 |Validation err: 0.4265, Validation loss: 0.6916402876377106
Epoch 53: Train err: 0.432875, Train loss: 0.6914504244923592 |Validation err: 0.4275, Validation loss: 0.6915708184242249
Epoch 54: Train err: 0.432, Train loss: 0.6913831979036331 |Validation err: 0.429, Validation loss: 0.6914924532175064
Epoch 55: Train err: 0.431125, Train loss: 0.6913192011415958 |Validation err: 0.4265, Validation loss: 0.6914208382368088
```

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Epoch 56: Train err: 0.431875, Train loss: 0.6912351958453655 |Validation err: 0.4245, Validation loss: 0.6913564503192902
Epoch 57: Train err: 0.431375, Train loss: 0.6911774314939976 |Validation err: 0.4235, Validation loss: 0.6912534087896347
Epoch 58: Train err: 0.432125, Train loss: 0.6910880729556084 |Validation err: 0.4265, Validation loss: 0.6911721378564835
Epoch 59: Train err: 0.4325, Train loss: 0.6910297870635986 |Validation err: 0.427, Validation loss: 0.6910500526428223
Epoch 60: Train err: 0.431125, Train loss: 0.6909448467195034 |Validation err: 0.428, Validation loss: 0.6909986734390259
Epoch 61: Train err: 0.431, Train loss: 0.6908868290483952 |Validation err: 0.427, Validation loss: 0.6909023374319077
Epoch 62: Train err: 0.432125, Train loss: 0.6907891035079956 |Validation err: 0.4275, Validation loss: 0.6907922327518463
Epoch 63: Train err: 0.4325, Train loss: 0.6906571350991726 |Validation err: 0.427, Validation loss: 0.6907144486904144
Epoch 64: Train err: 0.432375, Train loss: 0.6905428692698479 |Validation err: 0.426, Validation loss: 0.6906267553567886
Epoch 65: Train err: 0.4325, Train loss: 0.6904796250164509 |Validation err: 0.424, Validation loss: 0.6904796659946442
Epoch 66: Train err: 0.432375, Train loss: 0.690385814756155 |Validation err: 0.4235, Validation loss: 0.6904041916131973
Epoch 67: Train err: 0.4315, Train loss: 0.6902611702680588 |Validation err: 0.4205, Validation loss: 0.6902721226215363
Epoch 68: Train err: 0.431125, Train loss: 0.6901572421193123 |Validation err: 0.42, Validation loss: 0.6901413947343826
Epoch 69: Train err: 0.43125, Train loss: 0.6900523006916046 |Validation err: 0.4195, Validation loss: 0.690010592341423
Epoch 70: Train err: 0.43125, Train loss: 0.6898405216634274 |Validation err: 0.418, Validation loss: 0.6898927092552185
Epoch 71: Train err: 0.43175, Train loss: 0.6898188404738903 |Validation err: 0.415, Validation loss: 0.6897212713956833
Epoch 72: Train err: 0.432, Train loss: 0.6896554455161095 |Validation err: 0.4165, Validation loss: 0.6895360797643661
Epoch 73: Train err: 0.4325, Train loss: 0.6895142495632172 |Validation err: 0.414, Validation loss: 0.6893967092037201
Epoch 74: Train err: 0.4325, Train loss: 0.689413495361805 |Validation err: 0.4145, Validation loss: 0.6892313808202744
Epoch 75: Train err: 0.43225, Train loss: 0.6892828159034252 |Validation err: 0.415, Validation loss: 0.6891141086816788
Epoch 76: Train err: 0.432375, Train loss: 0.6890616677701473 |Validation err: 0.4125, Validation loss: 0.6889253705739975
Epoch 77: Train err: 0.43225, Train loss: 0.6889022141695023 |Validation err: 0.4125, Validation loss: 0.688783586025238
Epoch 78: Train err: 0.433, Train loss: 0.6887520775198936 |Validation err: 0.4135, Validation loss: 0.6885491013526917
Epoch 79: Train err: 0.433125, Train loss: 0.6886077933013439 |Validation err: 0.412, Validation loss: 0.6883784979581833
Epoch 80: Train err: 0.43325, Train loss: 0.6883946061134338 |Validation err: 0.412, Validation loss: 0.6881255358457565
Epoch 81: Train err: 0.432375, Train loss: 0.688307698816061 |Validation err: 0.4125, Validation loss: 0.6878968924283981
Epoch 82: Train err: 0.432, Train loss: 0.6880334988236427 |Validation err: 0.4145, Validation loss: 0.6877035796642303
Epoch 83: Train err: 0.431625, Train loss: 0.687853716313839 |Validation err: 0.4135, Validation loss: 0.6875060945749283
Epoch 84: Train err: 0.431125, Train loss: 0.6877403780817986 |Validation err: 0.414, Validation loss: 0.6872715651988983
Epoch 85: Train err: 0.432875, Train loss: 0.6874730475246906 |Validation err: 0.414, Validation loss: 0.6869788467884064
Epoch 86: Train err: 0.430875, Train loss: 0.6872506327927113 |Validation err: 0.4135, Validation loss: 0.6867439597845078
Epoch 87: Train err: 0.430375, Train loss: 0.6870566047728062 |Validation err: 0.4135, Validation loss: 0.6865525543689728
Epoch 88: Train err: 0.429875, Train loss: 0.6868365965783596 |Validation err: 0.4145, Validation loss: 0.6861297339200974
Epoch 89: Train err: 0.43025, Train loss: 0.6865493804216385 |Validation err: 0.416, Validation loss: 0.6859079152345657
Epoch 90: Train err: 0.430125, Train loss: 0.6864043846726418 |Validation err: 0.4145, Validation loss: 0.685609981417656
Epoch 91: Train err: 0.429625, Train loss: 0.6861906796693802 |Validation err: 0.414, Validation loss: 0.6853555142879486
Epoch 92: Train err: 0.42975, Train loss: 0.6857514269649982 |Validation err: 0.413, Validation loss: 0.6851253509521484
Epoch 93: Train err: 0.4295, Train loss: 0.6856582537293434 |Validation err: 0.4125, Validation loss: 0.6846897006034851
Epoch 94: Train err: 0.43, Train loss: 0.6854818798601627 |Validation err: 0.414, Validation loss: 0.6844274997711182
Epoch 95: Train err: 0.429625, Train loss: 0.6849660500884056 |Validation err: 0.4135, Validation loss: 0.6840268671512604
Epoch 96: Train err: 0.4285, Train loss: 0.6847492903470993 |Validation err: 0.4135, Validation loss: 0.6838065087795258
Epoch 97: Train err: 0.4285, Train loss: 0.6844758726656437 |Validation err: 0.412, Validation loss: 0.6834784597158432
Epoch 98: Train err: 0.42775, Train loss: 0.6842847168445587 |Validation err: 0.413, Validation loss: 0.6831555068492889
Epoch 99: Train err: 0.42725, Train loss: 0.683942586183548 |Validation err: 0.4105, Validation loss: 0.6828420162200928
Epoch 100: Train err: 0.428625, Train loss: 0.6835609264671803 |Validation err: 0.41, Validation loss: 0.6824479848146439
Epoch 101: Train err: 0.42875, Train loss: 0.6834132559597492 |Validation err: 0.4095, Validation loss: 0.6821361482143402
Epoch 102: Train err: 0.427625, Train loss: 0.6831761784851551 |Validation err: 0.408, Validation loss: 0.6817921847105026
Epoch 103: Train err: 0.42725, Train loss: 0.6826210990548134 |Validation err: 0.4085, Validation loss: 0.6813653707504272
Epoch 104: Train err: 0.427, Train loss: 0.6824648194015026 |Validation err: 0.4105, Validation loss: 0.6808875203132629
Epoch 105: Train err: 0.426625, Train loss: 0.6821138747036457 |Validation err: 0.4095, Validation loss: 0.6805253624916077
Epoch 106: Train err: 0.426875, Train loss: 0.6816279590129852 |Validation err: 0.4085, Validation loss: 0.6800623536109924
Epoch 107: Train err: 0.426375, Train loss: 0.681294783949852 |Validation err: 0.4085, Validation loss: 0.6799519807100296
Epoch 108: Train err: 0.4265, Train loss: 0.6810732334852219 |Validation err: 0.4075, Validation loss: 0.6794981956481934
Epoch 109: Train err: 0.42575, Train loss: 0.6806905008852482 |Validation err: 0.407, Validation loss: 0.6792173385620117
Epoch 110: Train err: 0.425625, Train loss: 0.6805584356188774 |Validation err: 0.408, Validation loss: 0.6789938062429428
Epoch 111: Train err: 0.426, Train loss: 0.6801694296300411 |Validation err: 0.4085, Validation loss: 0.6787084192037582
Epoch 112: Train err: 0.425125, Train loss: 0.6799359247088432 |Validation err: 0.4085, Validation loss: 0.6780410259962082
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Epoch 113: Train err: 0.42475, Train loss: 0.6796525940299034 |Validation err: 0.409, Validation loss: 0.6777620166540146
Epoch 114: Train err: 0.424375, Train loss: 0.6793111823499203 |Validation err: 0.4085, Validation loss: 0.6774286329746246
Epoch 115: Train err: 0.423625, Train loss: 0.6789243929088116 |Validation err: 0.4075, Validation loss: 0.6772084981203079
Epoch 116: Train err: 0.423, Train loss: 0.678829301148653 |Validation err: 0.409, Validation loss: 0.6765513867139816
Epoch 117: Train err: 0.422625, Train loss: 0.6785277612507343 |Validation err: 0.407, Validation loss: 0.6765766888856888
Epoch 118: Train err: 0.4205, Train loss: 0.6777703426778316 |Validation err: 0.4095, Validation loss: 0.6761161684989929
Epoch 119: Train err: 0.4205, Train loss: 0.6776143461465836 |Validation err: 0.4135, Validation loss: 0.6757786124944687
Epoch 120: Train err: 0.42025, Train loss: 0.6774959936738014 |Validation err: 0.413, Validation loss: 0.6754007339477539
Epoch 121: Train err: 0.420125, Train loss: 0.6772118173539639 |Validation err: 0.412, Validation loss: 0.6749392002820969
Epoch 122: Train err: 0.42, Train loss: 0.6764765530824661 |Validation err: 0.411, Validation loss: 0.6747914403676987
Epoch 123: Train err: 0.41975, Train loss: 0.6762800849974155 |Validation err: 0.412, Validation loss: 0.674484446644783
Epoch 124: Train err: 0.41875, Train loss: 0.6760981604456902 |Validation err: 0.4115, Validation loss: 0.6742175966501236
Epoch 125: Train err: 0.418875, Train loss: 0.6760004870593548 |Validation err: 0.411, Validation loss: 0.6737333387136459
Epoch 126: Train err: 0.416875, Train loss: 0.6755211390554905 |Validation err: 0.4095, Validation loss: 0.673682764172554
Epoch 127: Train err: 0.4175, Train loss: 0.6750767976045609 |Validation err: 0.409, Validation loss: 0.6735025197267532
Epoch 128: Train err: 0.41675, Train loss: 0.6743520796298981 |Validation err: 0.408, Validation loss: 0.6730614453554153
Epoch 129: Train err: 0.416375, Train loss: 0.6746117472648621 |Validation err: 0.4065, Validation loss: 0.6727490574121475
Epoch 130: Train err: 0.41625, Train loss: 0.6739772893488407 |Validation err: 0.4065, Validation loss: 0.6722803264856339
Epoch 131: Train err: 0.4145, Train loss: 0.6736587770283222 |Validation err: 0.4075, Validation loss: 0.6720249652862549
Epoch 132: Train err: 0.413625, Train loss: 0.6728574074804783 |Validation err: 0.406, Validation loss: 0.6719972342252731
Epoch 133: Train err: 0.41325, Train loss: 0.6730046793818474 |Validation err: 0.404, Validation loss: 0.6711348444223404
Epoch 134: Train err: 0.41275, Train loss: 0.672863844782114 |Validation err: 0.405, Validation loss: 0.670825183391571
Epoch 135: Train err: 0.412625, Train loss: 0.6722486726939678 |Validation err: 0.4055, Validation loss: 0.6711439937353134
Epoch 136: Train err: 0.409875, Train loss: 0.6718971431255341 |Validation err: 0.4025, Validation loss: 0.6709491312503815
Epoch 137: Train err: 0.408375, Train loss: 0.6709647327661514 |Validation err: 0.4005, Validation loss: 0.6699699461460114
Epoch 138: Train err: 0.4065, Train loss: 0.6710431762039661 |Validation err: 0.4005, Validation loss: 0.6698475480079651
Epoch 139: Train err: 0.40525, Train loss: 0.6707974672317505 |Validation err: 0.401, Validation loss: 0.6695012748241425
Epoch 140: Train err: 0.40525, Train loss: 0.6701169535517693 |Validation err: 0.4, Validation loss: 0.6691978126764297
Epoch 141: Train err: 0.405625, Train loss: 0.6702574491500854 |Validation err: 0.4, Validation loss: 0.668927401304245
Epoch 142: Train err: 0.404375, Train loss: 0.6698707826435566 |Validation err: 0.402, Validation loss: 0.6685707718133926
Epoch 143: Train err: 0.40275, Train loss: 0.6692592352628708 |Validation err: 0.4025, Validation loss: 0.6683849543333054
Epoch 144: Train err: 0.401875, Train loss: 0.6688405759632587 |Validation err: 0.4005, Validation loss: 0.6677661240100861
Epoch 145: Train err: 0.402, Train loss: 0.6687541268765926 |Validation err: 0.3995, Validation loss: 0.6674753278493881
Epoch 146: Train err: 0.399375, Train loss: 0.6685492172837257 |Validation err: 0.398, Validation loss: 0.6674187332391739
Epoch 147: Train err: 0.3985, Train loss: 0.6677406951785088 |Validation err: 0.3985, Validation loss: 0.6666404604911804
Epoch 148: Train err: 0.398375, Train loss: 0.6676515191793442 |Validation err: 0.398, Validation loss: 0.6666103005409241
Epoch 149: Train err: 0.397, Train loss: 0.6670689508318901 |Validation err: 0.4, Validation loss: 0.6660355478525162
Epoch 150: Train err: 0.39825, Train loss: 0.666555855423212 |Validation err: 0.4005, Validation loss: 0.6658670753240585
Epoch 151: Train err: 0.396, Train loss: 0.6663856506347656 |Validation err: 0.3985, Validation loss: 0.6654952168464661
Epoch 152: Train err: 0.3965, Train loss: 0.6664487086236477 |Validation err: 0.399, Validation loss: 0.6650817692279816
Epoch 153: Train err: 0.394625, Train loss: 0.6653505265712738 |Validation err: 0.3985, Validation loss: 0.6646571755409241
Epoch 154: Train err: 0.392625, Train loss: 0.665391493588686 |Validation err: 0.399, Validation loss: 0.664530798792839
Epoch 155: Train err: 0.392375, Train loss: 0.664687741547823 |Validation err: 0.397, Validation loss: 0.6638845503330231
Epoch 156: Train err: 0.391625, Train loss: 0.6648348271846771 |Validation err: 0.3975, Validation loss: 0.6634024083614349
Epoch 157: Train err: 0.390375, Train loss: 0.6639791913330555 |Validation err: 0.396, Validation loss: 0.663625031709671
Epoch 158: Train err: 0.3885, Train loss: 0.6636824235320091 |Validation err: 0.3935, Validation loss: 0.6631114333868027
Epoch 159: Train err: 0.3865, Train loss: 0.6631218418478966 |Validation err: 0.3955, Validation loss: 0.6626551747322083
Epoch 160: Train err: 0.3875, Train loss: 0.6627303101122379 |Validation err: 0.394, Validation loss: 0.6621969789266586
Epoch 161: Train err: 0.386, Train loss: 0.6626723036170006 |Validation err: 0.393, Validation loss: 0.661425769329071
Epoch 162: Train err: 0.38525, Train loss: 0.6618916876614094 |Validation err: 0.395, Validation loss: 0.661316528916359
Epoch 163: Train err: 0.385125, Train loss: 0.6617562174797058 |Validation err: 0.3935, Validation loss: 0.6609383076429367
Epoch 164: Train err: 0.384875, Train loss: 0.6611166410148144 |Validation err: 0.393, Validation loss: 0.6610241234302521
Epoch 165: Train err: 0.382, Train loss: 0.6606350131332874 |Validation err: 0.3855, Validation loss: 0.6597632169723511
Epoch 166: Train err: 0.3825, Train loss: 0.6604376137256622 |Validation err: 0.3845, Validation loss: 0.6593876928091049
Epoch 167: Train err: 0.3825, Train loss: 0.6599841974675655 |Validation err: 0.3855, Validation loss: 0.6598221510648727
Epoch 168: Train err: 0.381, Train loss: 0.6594627425074577 |Validation err: 0.3825, Validation loss: 0.6591793745756149
Epoch 169: Train err: 0.380375, Train loss: 0.6589672565460205 |Validation err: 0.3805, Validation loss: 0.6584382355213165
```
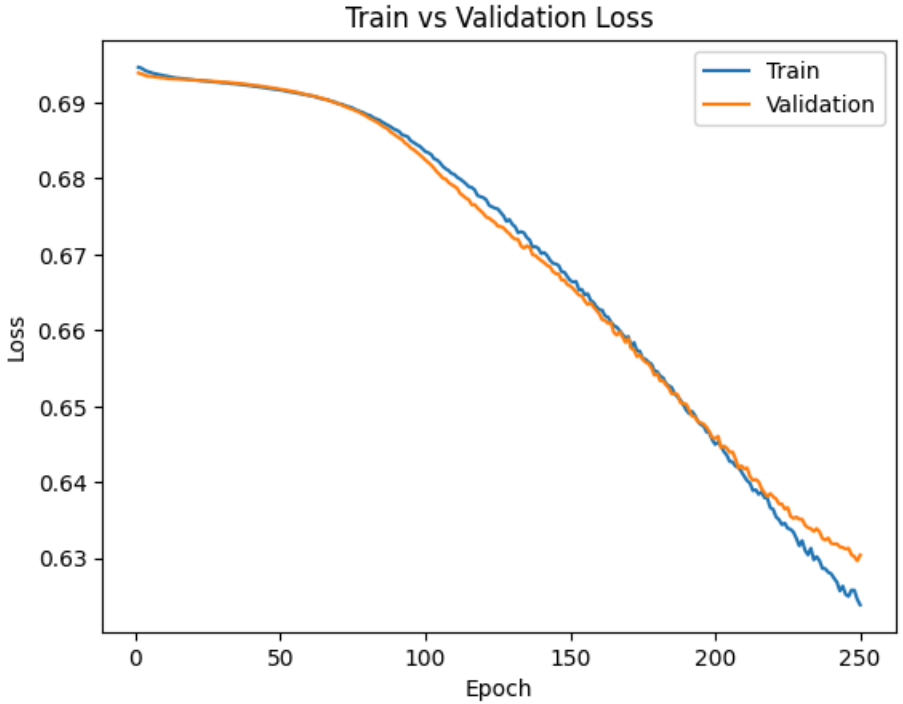

Epoch 170: Train err: 0.3775, Train loss: 0.6592022217810154 |Validation err: 0.3825, Validation loss: 0.6589421629905701
Epoch 171: Train err: 0.37825, Train loss: 0.6578175164759159 |Validation err: 0.3785, Validation loss: 0.6576595902442932
Epoch 172: Train err: 0.37725, Train loss: 0.6584004014730453 |Validation err: 0.3775, Validation loss: 0.6574203819036484
Epoch 173: Train err: 0.378875, Train loss: 0.6573068797588348 |Validation err: 0.3775, Validation loss: 0.6565466821193695
Epoch 174: Train err: 0.375875, Train loss: 0.6572541669011116 |Validation err: 0.3775, Validation loss: 0.6567869633436203
Epoch 175: Train err: 0.375, Train loss: 0.6562671139836311 |Validation err: 0.3785, Validation loss: 0.656185045838356
Epoch 176: Train err: 0.3765, Train loss: 0.6561914198100567 |Validation err: 0.3775, Validation loss: 0.6558070778846741
Epoch 177: Train err: 0.375125, Train loss: 0.6557968594133854 |Validation err: 0.3765, Validation loss: 0.655627578496933
Epoch 178: Train err: 0.37375, Train loss: 0.6555670909583569 |Validation err: 0.3765, Validation loss: 0.6550460904836655
Epoch 179: Train err: 0.373125, Train loss: 0.6546685881912708 |Validation err: 0.3765, Validation loss: 0.6541016548871994
Epoch 180: Train err: 0.373125, Train loss: 0.6545755937695503 |Validation err: 0.3775, Validation loss: 0.6542789340019226
Epoch 181: Train err: 0.3735, Train loss: 0.653965424746275 |Validation err: 0.375, Validation loss: 0.6533480137586594
Epoch 182: Train err: 0.37225, Train loss: 0.6537709683179855 |Validation err: 0.3745, Validation loss: 0.6533846110105515
Epoch 183: Train err: 0.37175, Train loss: 0.6529779471457005 |Validation err: 0.3765, Validation loss: 0.6528366804122925
Epoch 184: Train err: 0.372, Train loss: 0.6526968739926815 |Validation err: 0.3755, Validation loss: 0.6524147391319275
Epoch 185: Train err: 0.371, Train loss: 0.6524669378995895 |Validation err: 0.376, Validation loss: 0.6516474038362503
Epoch 186: Train err: 0.3715, Train loss: 0.651637252420187 |Validation err: 0.3735, Validation loss: 0.6517084985971451
Epoch 187: Train err: 0.369, Train loss: 0.6512525342404842 |Validation err: 0.3755, Validation loss: 0.651543453335762
Epoch 188: Train err: 0.3715, Train loss: 0.6508104614913464 |Validation err: 0.375, Validation loss: 0.6504813432693481
Epoch 189: Train err: 0.370375, Train loss: 0.6502097137272358 |Validation err: 0.373, Validation loss: 0.6503698527812958
Epoch 190: Train err: 0.36725, Train loss: 0.6495061591267586 |Validation err: 0.371, Validation loss: 0.6502932161092758
Epoch 191: Train err: 0.36825, Train loss: 0.6490390747785568 |Validation err: 0.3735, Validation loss: 0.6495047956705093
Epoch 192: Train err: 0.36925, Train loss: 0.6493314579129219 |Validation err: 0.375, Validation loss: 0.648711770772934
Epoch 193: Train err: 0.366125, Train loss: 0.648791003972292 |Validation err: 0.374, Validation loss: 0.6485956758260727
Epoch 194: Train err: 0.368375, Train loss: 0.6480263993144035 |Validation err: 0.3725, Validation loss: 0.6480036079883575
Epoch 195: Train err: 0.36725, Train loss: 0.647594578564167 |Validation err: 0.3695, Validation loss: 0.6478288024663925
Epoch 196: Train err: 0.365125, Train loss: 0.6474127843976021 |Validation err: 0.371, Validation loss: 0.64765265583992
Epoch 197: Train err: 0.36525, Train loss: 0.6466252729296684 |Validation err: 0.372, Validation loss: 0.647242471575737
Epoch 198: Train err: 0.362625, Train loss: 0.6465006768703461 |Validation err: 0.3715, Validation loss: 0.6466283202171326
Epoch 199: Train err: 0.362375, Train loss: 0.645562183111906 |Validation err: 0.371, Validation loss: 0.6458666771650314
Epoch 200: Train err: 0.362375, Train loss: 0.6449735648930073 |Validation err: 0.3695, Validation loss: 0.6457756459712982
Epoch 201: Train err: 0.362125, Train loss: 0.645277626812458 |Validation err: 0.367, Validation loss: 0.6460474878549576
Epoch 202: Train err: 0.361625, Train loss: 0.6447567194700241 |Validation err: 0.365, Validation loss: 0.6445518285036087
Epoch 203: Train err: 0.36075, Train loss: 0.6440349593758583 |Validation err: 0.3635, Validation loss: 0.6447558104991913
Epoch 204: Train err: 0.360375, Train loss: 0.6435615830123425 |Validation err: 0.3615, Validation loss: 0.6444883048534393
Epoch 205: Train err: 0.359625, Train loss: 0.6427263058722019 |Validation err: 0.3635, Validation loss: 0.6439489126205444
Epoch 206: Train err: 0.36, Train loss: 0.6426854394376278 |Validation err: 0.3585, Validation loss: 0.6439788937568665
Epoch 207: Train err: 0.3605, Train loss: 0.6421037055552006 |Validation err: 0.3585, Validation loss: 0.6430622786283493
Epoch 208: Train err: 0.35775, Train loss: 0.6419771388173103 |Validation err: 0.3575, Validation loss: 0.6418753117322922
Epoch 209: Train err: 0.36, Train loss: 0.6414141394197941 |Validation err: 0.3585, Validation loss: 0.642165020108223
Epoch 210: Train err: 0.359125, Train loss: 0.6407776176929474 |Validation err: 0.3595, Validation loss: 0.6417614966630936
Epoch 211: Train err: 0.358875, Train loss: 0.6402048878371716 |Validation err: 0.3605, Validation loss: 0.6418865621089935
Epoch 212: Train err: 0.359, Train loss: 0.6398744694888592 |Validation err: 0.356, Validation loss: 0.6407270133495331
Epoch 213: Train err: 0.357875, Train loss: 0.6388994678854942 |Validation err: 0.359, Validation loss: 0.6402442753314972
Epoch 214: Train err: 0.359625, Train loss: 0.6390045620501041 |Validation err: 0.3555, Validation loss: 0.6403610557317734
Epoch 215: Train err: 0.35925, Train loss: 0.6384034678339958 |Validation err: 0.355, Validation loss: 0.6400601416826248
Epoch 216: Train err: 0.357625, Train loss: 0.6387377828359604 |Validation err: 0.354, Validation loss: 0.6391418427228928
Epoch 217: Train err: 0.358875, Train loss: 0.637954343110323 |Validation err: 0.3545, Validation loss: 0.638592317700386
Epoch 218: Train err: 0.358, Train loss: 0.637869019061327 |Validation err: 0.3505, Validation loss: 0.6380994021892548
Epoch 219: Train err: 0.354375, Train loss: 0.636641588062048 |Validation err: 0.353, Validation loss: 0.6385094672441483
Epoch 220: Train err: 0.3565, Train loss: 0.6364182904362679 |Validation err: 0.3525, Validation loss: 0.6380852311849594
Epoch 221: Train err: 0.35525, Train loss: 0.6354278177022934 |Validation err: 0.3505, Validation loss: 0.6377973407506943
Epoch 222: Train err: 0.3525, Train loss: 0.6350692957639694 |Validation err: 0.3505, Validation loss: 0.6371492147445679
Epoch 223: Train err: 0.3565, Train loss: 0.6344163864850998 |Validation err: 0.3505, Validation loss: 0.637116327881813
Epoch 224: Train err: 0.3525, Train loss: 0.6345961913466454 |Validation err: 0.35, Validation loss: 0.6364645957946777
Epoch 225: Train err: 0.353375, Train loss: 0.6339190118014812 |Validation err: 0.3495, Validation loss: 0.6366552710533142
Epoch 226: Train err: 0.353625, Train loss: 0.6337974667549133 |Validation err: 0.349, Validation loss: 0.6355050206184387

```
Epoch 227: Train err: 0.35175, Train loss: 0.6334178484976292 |Validation err: 0.35, Validation loss: 0.635235607624054
Epoch 228: Train err: 0.351375, Train loss: 0.6326084062457085 |Validation err: 0.347, Validation loss: 0.6354153901338577
Epoch 229: Train err: 0.352125, Train loss: 0.6316296868026257 |Validation err: 0.348, Validation loss: 0.635128065943718
Epoch 230: Train err: 0.35175, Train loss: 0.6322974115610123 |Validation err: 0.347, Validation loss: 0.6351099014282227
Epoch 231: Train err: 0.349, Train loss: 0.6310222297906876 |Validation err: 0.3455, Validation loss: 0.6343351006507874
Epoch 232: Train err: 0.35, Train loss: 0.6304285526275635 |Validation err: 0.3445, Validation loss: 0.6340064853429794
Epoch 233: Train err: 0.348875, Train loss: 0.6312953606247902 |Validation err: 0.344, Validation loss: 0.63387231528759
Epoch 234: Train err: 0.3495, Train loss: 0.6297812238335609 |Validation err: 0.3425, Validation loss: 0.6335289031267166
Epoch 235: Train err: 0.348625, Train loss: 0.6301983445882797 |Validation err: 0.3455, Validation loss: 0.6338886469602585
Epoch 236: Train err: 0.348125, Train loss: 0.6296541579067707 |Validation err: 0.3415, Validation loss: 0.6334449499845505
Epoch 237: Train err: 0.348375, Train loss: 0.6286394074559212 |Validation err: 0.341, Validation loss: 0.6325752139091492
Epoch 238: Train err: 0.3475, Train loss: 0.6285956650972366 |Validation err: 0.345, Validation loss: 0.6323904395103455
Epoch 239: Train err: 0.346125, Train loss: 0.6281345672905445 |Validation err: 0.3425, Validation loss: 0.6326520889997482
Epoch 240: Train err: 0.34525, Train loss: 0.6279400251805782 |Validation err: 0.345, Validation loss: 0.6319319307804108
Epoch 241: Train err: 0.34575, Train loss: 0.6273497492074966 |Validation err: 0.3465, Validation loss: 0.6318477690219879
Epoch 242: Train err: 0.34475, Train loss: 0.6268279291689396 |Validation err: 0.3475, Validation loss: 0.6318741142749786
Epoch 243: Train err: 0.34525, Train loss: 0.6256814561784267 |Validation err: 0.345, Validation loss: 0.6314703822135925
Epoch 244: Train err: 0.344125, Train loss: 0.6263059712946415 |Validation err: 0.344, Validation loss: 0.6313956081867218
Epoch 245: Train err: 0.34275, Train loss: 0.6252145208418369 |Validation err: 0.349, Validation loss: 0.6312028616666794
Epoch 246: Train err: 0.344875, Train loss: 0.6249533109366894 |Validation err: 0.348, Validation loss: 0.631303608417511
Epoch 247: Train err: 0.3425, Train loss: 0.6257809363305569 |Validation err: 0.3435, Validation loss: 0.6304453760385513
Epoch 248: Train err: 0.343, Train loss: 0.6257619522511959 |Validation err: 0.3495, Validation loss: 0.6302028298377991
Epoch 249: Train err: 0.34025, Train loss: 0.6245686896145344 |Validation err: 0.3445, Validation loss: 0.6296440660953522
Epoch 250: Train err: 0.343875, Train loss: 0.6238382793962955 |Validation err: 0.3495, Validation loss: 0.6303893476724625
Finished Training
Total time elapsed: 1240.73 seconds
LARGE  MODEL
```

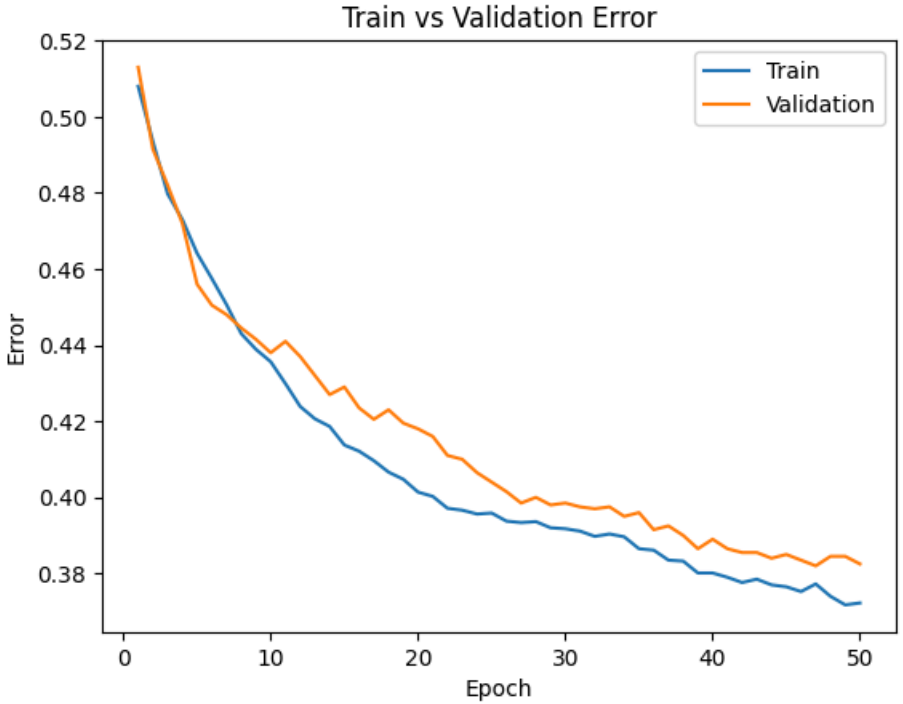


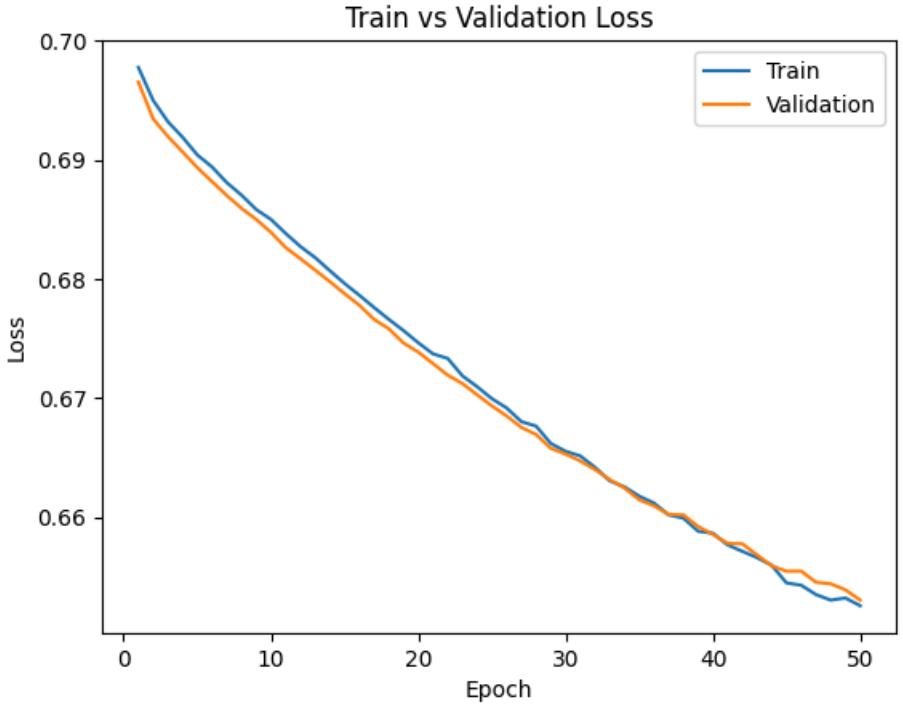
Part (f)

Decreasing # epoch in previous small model. For myself, do not mark.

In [ ]:
```
train_net(small_net, batch_size=512, learning_rate=0.001, num_epochs=50)
model_path_small = get_model_name("small", batch_size=512, learning_rate=0.001, epoch=49)
print("SMALL  MODEL")
plot_training_curve(model_path_small)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.508, Train loss: 0.6977777779102325 |Validation err: 0.513, Validation loss: 0.6965532004833221
Epoch 2: Train err: 0.4935, Train loss: 0.6950152777135372 |Validation err: 0.4915, Validation loss: 0.6934622675180435
Epoch 3: Train err: 0.47975, Train loss: 0.693225234746933 |Validation err: 0.482, Validation loss: 0.6919800788164139
Epoch 4: Train err: 0.473, Train loss: 0.6919130086898804 |Validation err: 0.472, Validation loss: 0.6906810849905014
Epoch 5: Train err: 0.464125, Train loss: 0.6904340833425522 |Validation err: 0.456, Validation loss: 0.6893652528524399
Epoch 6: Train err: 0.4575, Train loss: 0.6894184499979019 |Validation err: 0.4505, Validation loss: 0.6881870478391647
Epoch 7: Train err: 0.450625, Train loss: 0.6881065107882023 |Validation err: 0.448, Validation loss: 0.6870236098766327
Epoch 8: Train err: 0.443, Train loss: 0.687056191265583 |Validation err: 0.4445, Validation loss: 0.685946524143219
Epoch 9: Train err: 0.438875, Train loss: 0.6858464628458023 |Validation err: 0.4415, Validation loss: 0.6850134581327438
Epoch 10: Train err: 0.435625, Train loss: 0.6850165911018848 |Validation err: 0.438, Validation loss: 0.6839290112257004
Epoch 11: Train err: 0.429875, Train loss: 0.6838399581611156 |Validation err: 0.441, Validation loss: 0.682651937007904
Epoch 12: Train err: 0.423875, Train loss: 0.6827382631599903 |Validation err: 0.437, Validation loss: 0.6817187666893005
Epoch 13: Train err: 0.420625, Train loss: 0.6818085424602032 |Validation err: 0.432, Validation loss: 0.6807624697685242
Epoch 14: Train err: 0.418625, Train loss: 0.6807086244225502 |Validation err: 0.427, Validation loss: 0.6797897219657898
Epoch 15: Train err: 0.41375, Train loss: 0.6796332448720932 |Validation err: 0.429, Validation loss: 0.6787800192832947
Epoch 16: Train err: 0.412125, Train loss: 0.678648054599762 |Validation err: 0.4235, Validation loss: 0.6778114587068558
Epoch 17: Train err: 0.409625, Train loss: 0.6776198819279671 |Validation err: 0.4205, Validation loss: 0.6766199022531509
Epoch 18: Train err: 0.406625, Train loss: 0.6766246110200882 |Validation err: 0.423, Validation loss: 0.6758345663547516
Epoch 19: Train err: 0.40475, Train loss: 0.6756814494729042 |Validation err: 0.4195, Validation loss: 0.6746376007795334
Epoch 20: Train err: 0.401375, Train loss: 0.6746599301695824 |Validation err: 0.418, Validation loss: 0.6738754212856293
Epoch 21: Train err: 0.40025, Train loss: 0.6737297587096691 |Validation err: 0.416, Validation loss: 0.6729164868593216
Epoch 22: Train err: 0.397125, Train loss: 0.6733440347015858 |Validation err: 0.411, Validation loss: 0.6719383150339127
Epoch 23: Train err: 0.396625, Train loss: 0.6718782782554626 |Validation err: 0.41, Validation loss: 0.6712298840284348
Epoch 24: Train err: 0.395625, Train loss: 0.6709701158106327 |Validation err: 0.4065, Validation loss: 0.6702883839607239
Epoch 25: Train err: 0.395875, Train loss: 0.6699647158384323 |Validation err: 0.404, Validation loss: 0.669355496764183
Epoch 26: Train err: 0.39375, Train loss: 0.6691839434206486 |Validation err: 0.4015, Validation loss: 0.6685125231742859
Epoch 27: Train err: 0.393375, Train loss: 0.6680367849767208 |Validation err: 0.3985, Validation loss: 0.6675493866205215
Epoch 28: Train err: 0.393625, Train loss: 0.6676642782986164 |Validation err: 0.4, Validation loss: 0.6669595539569855
Epoch 29: Train err: 0.392, Train loss: 0.6662011817097664 |Validation err: 0.398, Validation loss: 0.6657919883728027
Epoch 30: Train err: 0.39175, Train loss: 0.6655476912856102 |Validation err: 0.3985, Validation loss: 0.6653169393539429
Epoch 31: Train err: 0.391125, Train loss: 0.6651573702692986 |Validation err: 0.3975, Validation loss: 0.6647298336029053
Epoch 32: Train err: 0.38975, Train loss: 0.6641959026455879 |Validation err: 0.397, Validation loss: 0.6640109866857529
Epoch 33: Train err: 0.390375, Train loss: 0.6630741134285927 |Validation err: 0.3975, Validation loss: 0.6631657928228378
Epoch 34: Train err: 0.389625, Train loss: 0.6625550761818886 |Validation err: 0.395, Validation loss: 0.6624559015035629
Epoch 35: Train err: 0.3865, Train loss: 0.6617827825248241 |Validation err: 0.396, Validation loss: 0.6614760458469391
Epoch 36: Train err: 0.386125, Train loss: 0.661202035844326 |Validation err: 0.3915, Validation loss: 0.6609670519828796
Epoch 37: Train err: 0.3835, Train loss: 0.6602045074105263 |Validation err: 0.3925, Validation loss: 0.6602411568164825
Epoch 38: Train err: 0.38325, Train loss: 0.6599360443651676 |Validation err: 0.39, Validation loss: 0.6602090746164322
Epoch 39: Train err: 0.380125, Train loss: 0.6588343419134617 |Validation err: 0.3865, Validation loss: 0.6592379212379456
Epoch 40: Train err: 0.380125, Train loss: 0.6586707942187786 |Validation err: 0.389, Validation loss: 0.6585734188556671
Epoch 41: Train err: 0.379, Train loss: 0.6576907187700272 |Validation err: 0.3865, Validation loss: 0.6578102707862854
Epoch 42: Train err: 0.377625, Train loss: 0.6571493931114674 |Validation err: 0.3855, Validation loss: 0.6577807813882828
Epoch 43: Train err: 0.3785, Train loss: 0.6566215008497238 |Validation err: 0.3855, Validation loss: 0.6568458378314972
Epoch 44: Train err: 0.377, Train loss: 0.6559706032276154 |Validation err: 0.384, Validation loss: 0.6559300571680069
Epoch 45: Train err: 0.3765, Train loss: 0.6544964797794819 |Validation err: 0.385, Validation loss: 0.6554763913154602
Epoch 46: Train err: 0.37525, Train loss: 0.6543016135692596 |Validation err: 0.3835, Validation loss: 0.6554866284132004
Epoch 47: Train err: 0.37725, Train loss: 0.6535196453332901 |Validation err: 0.382, Validation loss: 0.65455362200737
Epoch 48: Train err: 0.374, Train loss: 0.6530533879995346 |Validation err: 0.3845, Validation loss: 0.6544213443994522
Epoch 49: Train err: 0.37175, Train loss: 0.6532307118177414 |Validation err: 0.3845, Validation loss: 0.6539135128259659
Epoch 50: Train err: 0.37225, Train loss: 0.6525823883712292 |Validation err: 0.3825, Validation loss: 0.6530591696500778
Finished Training
Total time elapsed: 228.98 seconds
SMALL  MODEL
```





Part 5. 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`.

In [ ]:
```
net = LargeNet()
model_path = get_model_name(net.name, batch_size=512, learning_rate=0.001, epoch=249)
state = torch.load(model_path)
net.load_state_dict(state)
```

Out[ ]:
```
<All keys matched successfully>
```

Part (b) - 2pt

Justify your choice of model from part (a).

I chose to use the large model, batch size 512, learning rate of 0.001, and epoch number 250. Overall, The training curve and validation curve display a downward trend, with decreasing losses and errors as epoch continues. There isn't as much fluctuation with a faster learning rate, and increasing the batch size helps with overfitting. Overall, it's a more stable model and a more fitting validation curve.

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.

In [ ]:
```
# 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=64)

test_error, test_loss = evaluate(net, test_loader, nn.BCEWithLogitsLoss())
print("Test Error: ", test_error)
print("Test Loss: ", test_loss)
```

```
Files already downloaded and verified
Files already downloaded and verified
Test Error:  0.3415
Test Loss:  0.6211681421846151
```

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.

In [ ]:
```
val_error, val_loss = evaluate(net, val_loader, nn.BCEWithLogitsLoss())
print("Validation Error: ", val_error)
print("Validation Loss: ", val_loss)
```

```
Validation Error:  0.3495
Validation Loss:  0.6287204194813967
```

Unexpectedly my test classification error is lower than my validation error. Typically we should expect the test error to be higher because of the model's infamiliarity with the testing dataset. In my case it can be that the testing dataset happens to be easier to classify.

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?

The test dataset is used at the very end because we want the model to use new data and see its learning outcomes. If the model gets very good at reducing loss and error for one set of data, but shows no learning with a subset of the original dataset, it has low learning capabilities. This leads to bias, and it will only optimize for that specific dataset. The testing data is new and the model has never seen before, so it can be used to evaluate it's true performance.

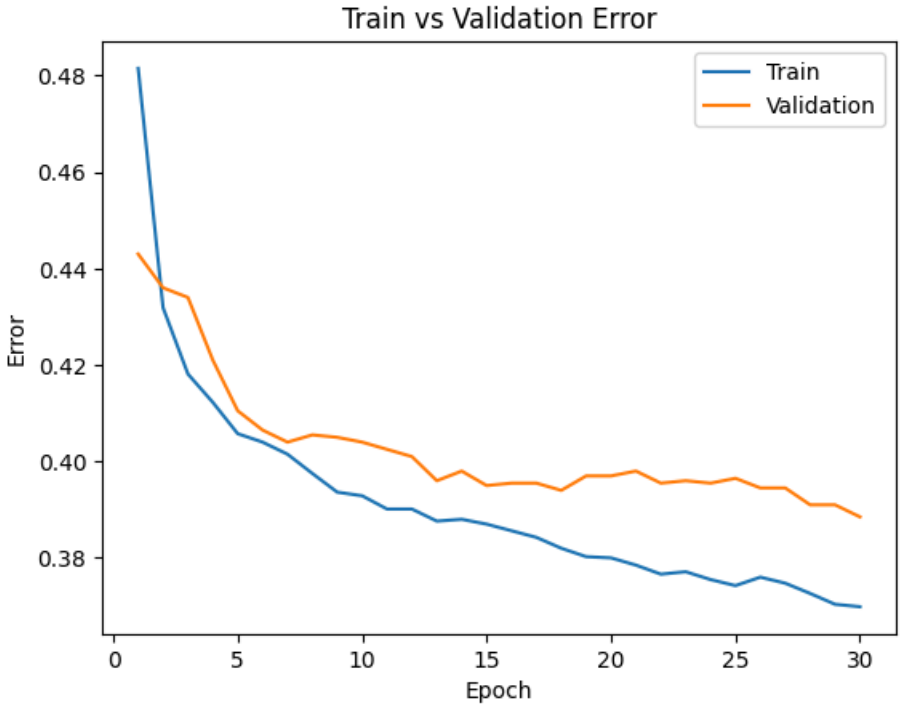
Part (f) - 5pt

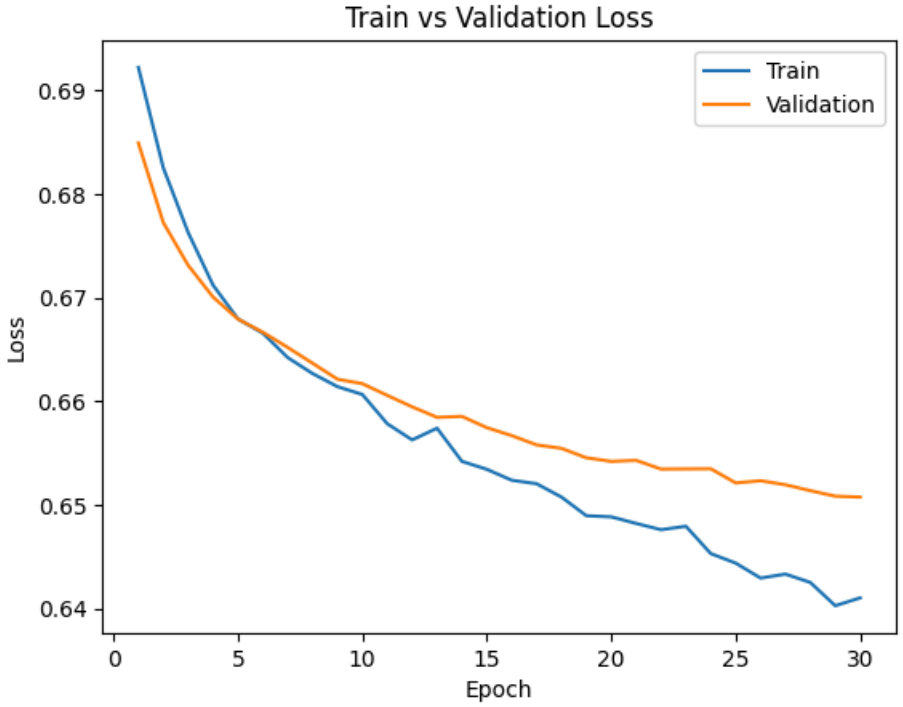
How does the your best CNN model compare with an 2-layer ANN model (no convolutional layers) on classifying cat and dog images. You can use a 2-layer ANN architecture similar to what you used in Lab 1. You should explore different hyperparameter settings to determine how well you can do on the validation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

In [ ]:
```python
torch.manual_seed(1) # set the random seed

# define a 2-layer artificial neural network
class CatDogNet(nn.Module):
    def __init__(self):

        super(CatDogNet, self).__init__()
        self.name = "cat_dog_ann"
        self.layer1 = nn.Linear(3* 32 * 32, 30) # used 300 and 3000 for second parameter for changing hidden values
        self.layer2 = nn.Linear(30, 1)
    def forward(self, img):
        flattened = img.view(-1, 3 * 32 * 32)
        activation1 = self.layer1(flattened)
        activation1 = F.relu(activation1) # used softplus and silu
        activation2 = self.layer2(activation1)
        activation2 = activation2.squeeze(1)
        return activation2

cat_dog_ann = CatDogNet()
train_net(cat_dog_ann, batch_size=256, learning_rate=0.0005, num_epochs=30)

model_cat_dog = get_model_name("cat_dog_ann", batch_size=256, learning_rate=0.0005, epoch=29)
print("CAT DOG ANN")
plot_training_curve(model_cat_dog)
```

```
Files already downloaded and verified
Files already downloaded and verified
Epoch 1: Train err: 0.4815, Train loss: 0.6921891421079636 |Validation err: 0.443, Validation loss: 0.6849011033773422
Epoch 2: Train err: 0.431875, Train loss: 0.6825137138366699 |Validation err: 0.436, Validation loss: 0.6772310733795166
Epoch 3: Train err: 0.418125, Train loss: 0.676270728930831 |Validation err: 0.434, Validation loss: 0.673106238245964
Epoch 4: Train err: 0.41225, Train loss: 0.6711958665400743 |Validation err: 0.421, Validation loss: 0.6700495108962059
Epoch 5: Train err: 0.40575, Train loss: 0.6679403390735388 |Validation err: 0.4105, Validation loss: 0.6679195240139961
Epoch 6: Train err: 0.404, Train loss: 0.6665613315999508 |Validation err: 0.4065, Validation loss: 0.6666593998670578
Epoch 7: Train err: 0.4015, Train loss: 0.6642101369798183 |Validation err: 0.404, Validation loss: 0.6651891320943832
Epoch 8: Train err: 0.3975, Train loss: 0.6626701727509499 |Validation err: 0.4055, Validation loss: 0.6636651232838631
Epoch 9: Train err: 0.393625, Train loss: 0.6614069417119026 |Validation err: 0.405, Validation loss: 0.6621246114373207
Epoch 10: Train err: 0.392875, Train loss: 0.6606532279402018 |Validation err: 0.404, Validation loss: 0.6616927161812782
Epoch 11: Train err: 0.390125, Train loss: 0.6578328739851713 |Validation err: 0.4025, Validation loss: 0.6605673804879189
Epoch 12: Train err: 0.390125, Train loss: 0.6562741529196501 |Validation err: 0.401, Validation loss: 0.659462183713913
Epoch 13: Train err: 0.387625, Train loss: 0.657402915880084 |Validation err: 0.396, Validation loss: 0.6584517732262611
Epoch 14: Train err: 0.388, Train loss: 0.6542058326303959 |Validation err: 0.398, Validation loss: 0.6585417687892914
Epoch 15: Train err: 0.387, Train loss: 0.6534393299371004 |Validation err: 0.395, Validation loss: 0.6574550643563271
Epoch 16: Train err: 0.385625, Train loss: 0.6523850597441196 |Validation err: 0.3955, Validation loss: 0.6566879898309708
Epoch 17: Train err: 0.38425, Train loss: 0.6520482916384935 |Validation err: 0.3955, Validation loss: 0.6557946503162384
Epoch 18: Train err: 0.382, Train loss: 0.6507632955908775 |Validation err: 0.394, Validation loss: 0.6554587483406067
Epoch 19: Train err: 0.38025, Train loss: 0.6489608623087406 |Validation err: 0.397, Validation loss: 0.6545503810048103
Epoch 20: Train err: 0.38, Train loss: 0.6488563641905785 |Validation err: 0.397, Validation loss: 0.654203474521637
Epoch 21: Train err: 0.3785, Train loss: 0.6482201404869556 |Validation err: 0.398, Validation loss: 0.6543024629354477
Epoch 22: Train err: 0.376625, Train loss: 0.6476174928247929 |Validation err: 0.3955, Validation loss: 0.653461143374443
Epoch 23: Train err: 0.377125, Train loss: 0.6479471176862717 |Validation err: 0.396, Validation loss: 0.6534792631864548
Epoch 24: Train err: 0.3755, Train loss: 0.6453119609504938 |Validation err: 0.3955, Validation loss: 0.6534907445311546
Epoch 25: Train err: 0.37425, Train loss: 0.6443953886628151 |Validation err: 0.3965, Validation loss: 0.6521253362298012
Epoch 26: Train err: 0.376, Train loss: 0.642954146489501 |Validation err: 0.3945, Validation loss: 0.6523378044366837
Epoch 27: Train err: 0.37475, Train loss: 0.6433354634791613 |Validation err: 0.3945, Validation loss: 0.6519473865628242
Epoch 28: Train err: 0.372625, Train loss: 0.6425302252173424 |Validation err: 0.391, Validation loss: 0.65138029307127
Epoch 29: Train err: 0.370375, Train loss: 0.6402877662330866 |Validation err: 0.391, Validation loss: 0.6508482918143272
Epoch 30: Train err: 0.369875, Train loss: 0.6410424076020718 |Validation err: 0.3885, Validation loss: 0.6507641449570656
Finished Training
Total time elapsed: 120.45 seconds
CAT DOG ANN
```





In [ ]:
```
val_error, val_loss = evaluate(cat_dog_ann, val_loader, nn.BCEWithLogitsLoss())
print("Validation Error: ", val_error)
```

```
print("Validation Loss: ", val_loss)

test_error, test_loss = evaluate(cat_dog_ann, test_loader, nn.BCEWithLogitsLoss())
print("Test Error: ", test_error)
print("Test Loss: ", test_loss)
```

```
Validation Error:  0.3885
Validation Loss:  0.6528794206678867
Test Error:  0.368
Test Loss:  0.6471942327916622
```

Overall, the CNN outperforms the ANN at classifying cats and dogs. The CNN is able to take in more inputs and can work with higher dimensions.