

RNN_Assignment3

October 31, 2023

Assignment 3: Recurrent Neural Networks

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1 Importing Libraries, data, and setup

```
[1]: import random
import math
import os
import time
import numpy as np
import seaborn as sns
import cv2
import matplotlib.pyplot as plt
import sklearn
import torch
import torch.nn as nn
import torch.nn.functional as F
from torch.autograd import Variable
import torch.optim as optim
from torch.utils.data import DataLoader, Subset
import torchvision
import torchvision.transforms as transforms
from torchsummary import summary
from sklearn.model_selection import train_test_split
from sklearn.metrics import accuracy_score, classification_report, \
    confusion_matrix, ConfusionMatrixDisplay
```

```
[2]: device = torch.device('cuda' if torch.cuda.is_available() else 'cpu')
```

```
[ ]: from google.colab import drive
drive.mount('/content/drive')
```

Mounted at /content/drive

```
[3]: torch.manual_seed(42)
np.random.seed(42)
random.seed(42)
```

```
if torch.cuda.is_available():
    torch.cuda.manual_seed_all(42)
```

```
[ ]: transform = transforms.Compose([transforms.ToTensor()])
train_dataset = torchvision.datasets.MNIST(root='./data', train=True,
    ↳transform=transform, download=True)
test_dataset = torchvision.datasets.MNIST(root='./data', train=False,
    ↳transform=transform)

train_dataset, val_dataset = torch.utils.data.random_split(train_dataset,
    ↳[50000, 10000])
train_loader = torch.utils.data.DataLoader(train_dataset, batch_size=64,
    ↳shuffle=True)
val_loader = torch.utils.data.DataLoader(val_dataset, batch_size=64,
    ↳shuffle=False)
test_loader = torch.utils.data.DataLoader(test_dataset, batch_size=64,
    ↳shuffle=False)
```

```
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/train-images-idx3-ubyte.gz to
./data/MNIST/raw/train-images-idx3-ubyte.gz
```

```
100%|          | 9912422/9912422 [00:00<00:00, 44069563.79it/s]
```

```
Extracting ./data/MNIST/raw/train-images-idx3-ubyte.gz to ./data/MNIST/raw
```

```
Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/train-labels-idx1-ubyte.gz to
./data/MNIST/raw/train-labels-idx1-ubyte.gz
```

```
100%|          | 28881/28881 [00:00<00:00, 86773419.64it/s]
```

```
Extracting ./data/MNIST/raw/train-labels-idx1-ubyte.gz to ./data/MNIST/raw
```

```
Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-images-idx3-ubyte.gz to
./data/MNIST/raw/t10k-images-idx3-ubyte.gz
```

```
100%|          | 1648877/1648877 [00:00<00:00, 28499513.31it/s]
```

```
Extracting ./data/MNIST/raw/t10k-images-idx3-ubyte.gz to ./data/MNIST/raw
```

```
Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz
Downloading http://yann.lecun.com/exdb/mnist/t10k-labels-idx1-ubyte.gz to
./data/MNIST/raw/t10k-labels-idx1-ubyte.gz
```

```
100%|          | 4542/4542 [00:00<00:00, 3884691.84it/s]
```

```
Extracting ./data/MNIST/raw/t10k-labels-idx1-ubyte.gz to ./data/MNIST/raw
```

2 The RNN Class

```
[ ]: class RNN(nn.Module):
    def __init__(self, input_size, hidden_size, output_size, layers = 1,
        ↪ rnn_cell_type = 'vanilla', bidirectional = False):
        super(RNN, self).__init__()
        self.hidden_size = hidden_size
        self.num_layers = layers
        self.bidirectional = bidirectional

        if rnn_cell_type == 'vanilla':
            self.rnn = nn.RNN(input_size, hidden_size, num_layers = layers,
        ↪ batch_first = True, bidirectional = bidirectional)
        elif rnn_cell_type == 'lstm':
            self.rnn = nn.LSTM(input_size, hidden_size, num_layers = layers,
        ↪ batch_first = True, bidirectional = bidirectional)
        elif rnn_cell_type == 'gru':
            self.rnn = nn.GRU(input_size, hidden_size, num_layers = layers,
        ↪ batch_first = True, bidirectional = bidirectional)

        linear_input_size = hidden_size * 2 if bidirectional else hidden_size
        self.fc = nn.Linear(linear_input_size, output_size)

    def forward(self, x):
        x = x.view(-1, 28, 28)
        num_dirs = 2 if self.bidirectional else 1
        h0 = torch.zeros(self.num_layers*num_dirs, x.size(0), self.hidden_size).
        ↪ to(device)
        if isinstance(self.rnn, nn.LSTM):
            c0 = torch.zeros(self.num_layers*num_dirs, x.size(0), self.
        ↪ hidden_size).to(device)
            out, _ = self.rnn(x, (h0, c0))
        else:
            out, _ = self.rnn(x, h0)

        if self.bidirectional:
            out = torch.cat((out[:, -1, :self.hidden_size], out[:, 0, self.
        ↪ hidden_size:]), 1)
        else:
            out = out[:, -1, :]

        return self.fc(out)
```

3 Some useful functions

3.1 Function to train and test the model

```
[ ]: def train_and_evaluate(input_dim, hidden_dim, output_dim, train_loader,
    ↪ val_loader, test_loader, layers, rnn_cell_type, bidirectional):
    net = RNN(input_dim, hidden_dim, output_dim, layers, rnn_cell_type,
    ↪ bidirectional).to(device)
    criterion = nn.CrossEntropyLoss().to(device)
    optimizer = optim.Adam(net.parameters())

    num_epochs = 5
    train_losses, val_losses, accuracies = [], [], []

    start_time = time.time()
    for epoch in range(num_epochs):
        # Training
        net.train()
        train_loss = 0.0
        for inputs, labels in train_loader:
            inputs, labels = inputs.to(device), labels.to(device)
            optimizer.zero_grad()
            outputs = net(inputs)
            loss = criterion(outputs, labels)
            loss.backward()
            optimizer.step()
            train_loss += loss.item()

        # Validation
        net.eval()
        val_loss, correct, total = 0.0, 0, 0
        with torch.no_grad():
            for inputs, labels in val_loader:
                inputs, labels = inputs.to(device), labels.to(device)
                outputs = net(inputs)
                val_loss += criterion(outputs, labels).item()
                _, predicted = outputs.max(1)
                total += labels.size(0)
                correct += predicted.eq(labels).sum().item()

        epoch_train_loss = train_loss / len(train_loader)
        epoch_val_loss = val_loss / len(val_loader)
        epoch_val_accuracy = 100. * correct / total

        print(f'Epoch: {epoch+1}/{num_epochs}, Train Loss: {epoch_train_loss:.
    ↪ 4f}, Validation Loss: {epoch_val_loss:.4f}, Validation Accuracy:
    ↪ {epoch_val_accuracy:.2f}%')
```

```

        train_losses.append(epoch_train_loss)
        val_losses.append(epoch_val_loss)
        accuracies.append(epoch_val_accuracy)
    end_time = time.time()

    elapsed_time = end_time - start_time
    print(f"Training using {rnn_cell_type.upper()} took {elapsed_time:.2f}␣
↪seconds.")

    # Plotting
    plt.figure(figsize=(12, 4))

    plt.subplot(1, 3, 1)
    plt.plot(train_losses, label='Train Loss')
    plt.plot(val_losses, label='Validation Loss')
    plt.legend()
    plt.title(f'{rnn_cell_type.upper()} - Train and Validation Losses')

    plt.subplot(1, 3, 2)
    plt.plot(accuracies, label='Validation Accuracy')
    plt.legend()
    plt.title(f'{rnn_cell_type.upper()} - Validation Accuracy')

    plt.tight_layout()
    plt.show()

    test_preds, test_true = [], []
    with torch.no_grad():
        for inputs, labels in test_loader:
            inputs, labels = inputs.to(device), labels.to(device)
            outputs = net(inputs)
            _, predicted = outputs.max(1)
            test_true.extend(labels.cpu().numpy())
            test_preds.extend(predicted.cpu().numpy())

    acc = 100. * sum(np.array(test_true) == np.array(test_preds)) /␣
↪len(test_true)

    return epoch_val_accuracy, acc, classification_report(test_true,␣
↪test_preds), confusion_matrix(test_true, test_preds), net

```

3.2 Function to plot results

```

[ ]: def display_results(rnn_cell_type, results):
    print(f"\nResults for {rnn_cell_type.upper()} RNN:")
    print(f"Accuracy: {results[1]:.2f}%")

```

```

print(f"\nClassification Report:\n{results[2]}")

# Plot confusion matrix as heatmap
plt.figure(figsize=(8, 6))
sns.heatmap(results[3], annot=True, fmt="d", cmap="Blues")
plt.title(f"Confusion Matrix for {rnn_cell_type.upper()} RNN")
plt.xlabel("Predicted Label")
plt.ylabel("True Label")
plt.show()

```

3.3 Function to plot predictions

```

[ ]: def plot_predictions(model, loader, num_samples=12):
    all_images, all_labels = [], []
    for images, labels in loader:
        all_images.append(images)
        all_labels.append(labels)
    all_images = torch.cat(all_images)
    all_labels = torch.cat(all_labels)

    random_indices = random.sample(range(len(all_images)), num_samples)
    images = all_images[random_indices]
    labels = all_labels[random_indices]

    outputs = model(images.to(device))
    _, predictions = outputs.max(1)

    grid_size = int(math.ceil(math.sqrt(num_samples)))

    plt.figure(figsize=(15, 15))
    for i, (img, label, pred) in enumerate(zip(images, labels, predictions)):
        plt.subplot(grid_size, grid_size, i+1)
        plt.imshow(img[0].numpy(), cmap='gray')
        plt.title(f"True: {label.item()}, Pred: {pred.item()}", fontsize=10)
        plt.axis('off')
    plt.tight_layout()
    plt.show()

```

4 Tuning the hyperparameters with vanilla RNN using a grid-search approach

```

[ ]: hidden_layer_list = [64, 128]
    num_layers_list = [1, 2, 3, 4, 5]

    best_val_acc = 0.0

```

```

best_model = None
best_hidden_size = None
best_num_layers = None

```

```

[ ]: for hidden_size in hidden_layer_list:
    for num_layers in num_layers_list:
        print(f'Training with hidden size: {hidden_size}, num layers: {num_layers}')
        val_acc, acc, _, _, net = train_and_evaluate(
            input_dim=28,
            hidden_dim=hidden_size,
            output_dim=10,
            train_loader=train_loader,
            val_loader=val_loader,
            test_loader=test_loader,
            layers=num_layers,
            rnn_cell_type='vanilla',
            bidirectional=False
        )

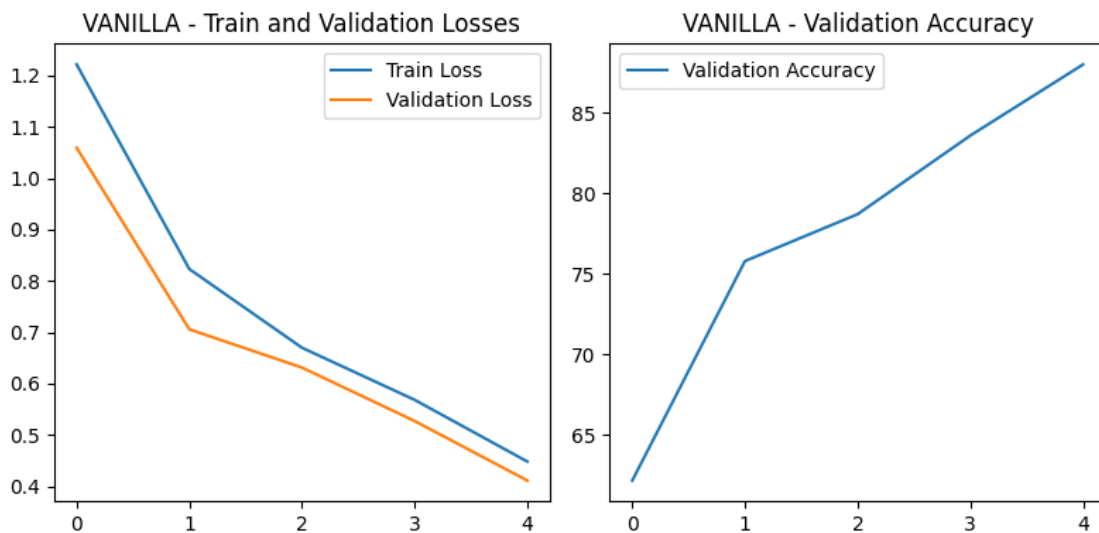
        if val_acc > best_val_acc: # check the validation accuracy to update the best model
            best_val_acc = val_acc
            best_model = net
            best_hidden_size = hidden_size
            best_num_layers = num_layers
            print(f'New best model found with validation accuracy: {best_val_acc:.2f}%')

```

```

Training with hidden size: 64, num layers: 1
Epoch: 1/5, Train Loss: 1.2213, Validation Loss: 1.0592, Validation Accuracy: 62.17%
Epoch: 2/5, Train Loss: 0.8230, Validation Loss: 0.7057, Validation Accuracy: 75.79%
Epoch: 3/5, Train Loss: 0.6698, Validation Loss: 0.6312, Validation Accuracy: 78.70%
Epoch: 4/5, Train Loss: 0.5682, Validation Loss: 0.5271, Validation Accuracy: 83.58%
Epoch: 5/5, Train Loss: 0.4481, Validation Loss: 0.4112, Validation Accuracy: 87.99%
Training using VANILLA took 47.14 seconds.

```



New best model found with validation accuracy: 87.99%

Training with hidden size: 64, num layers: 2

Epoch: 1/5, Train Loss: 0.8001, Validation Loss: 0.4300, Validation Accuracy: 87.24%

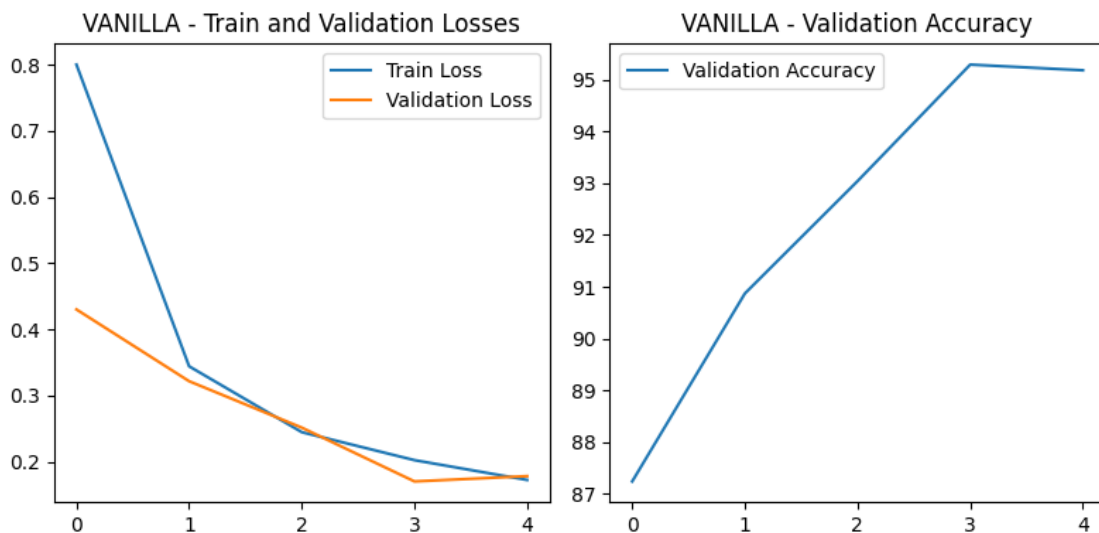
Epoch: 2/5, Train Loss: 0.3441, Validation Loss: 0.3216, Validation Accuracy: 90.87%

Epoch: 3/5, Train Loss: 0.2445, Validation Loss: 0.2514, Validation Accuracy: 93.04%

Epoch: 4/5, Train Loss: 0.2022, Validation Loss: 0.1701, Validation Accuracy: 95.29%

Epoch: 5/5, Train Loss: 0.1723, Validation Loss: 0.1780, Validation Accuracy: 95.18%

Training using VANILLA took 45.35 seconds.



New best model found with validation accuracy: 95.18%

Training with hidden size: 64, num layers: 3

Epoch: 1/5, Train Loss: 0.7711, Validation Loss: 0.3705, Validation Accuracy: 89.24%

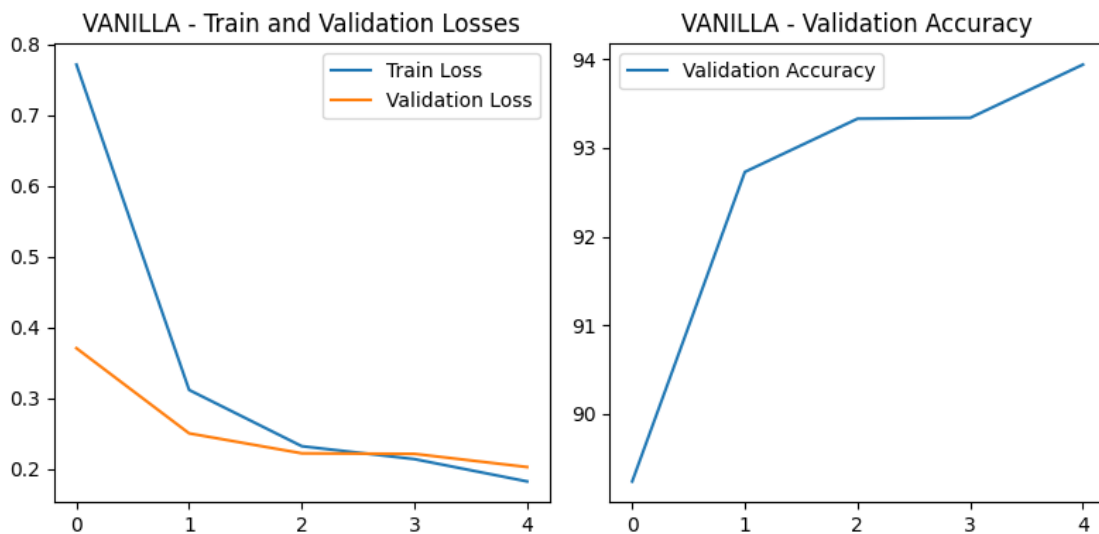
Epoch: 2/5, Train Loss: 0.3116, Validation Loss: 0.2503, Validation Accuracy: 92.73%

Epoch: 3/5, Train Loss: 0.2321, Validation Loss: 0.2221, Validation Accuracy: 93.33%

Epoch: 4/5, Train Loss: 0.2139, Validation Loss: 0.2213, Validation Accuracy: 93.34%

Epoch: 5/5, Train Loss: 0.1824, Validation Loss: 0.2027, Validation Accuracy: 93.94%

Training using VANILLA took 47.76 seconds.



Training with hidden size: 64, num layers: 4

Epoch: 1/5, Train Loss: 0.7350, Validation Loss: 0.3502, Validation Accuracy: 89.80%

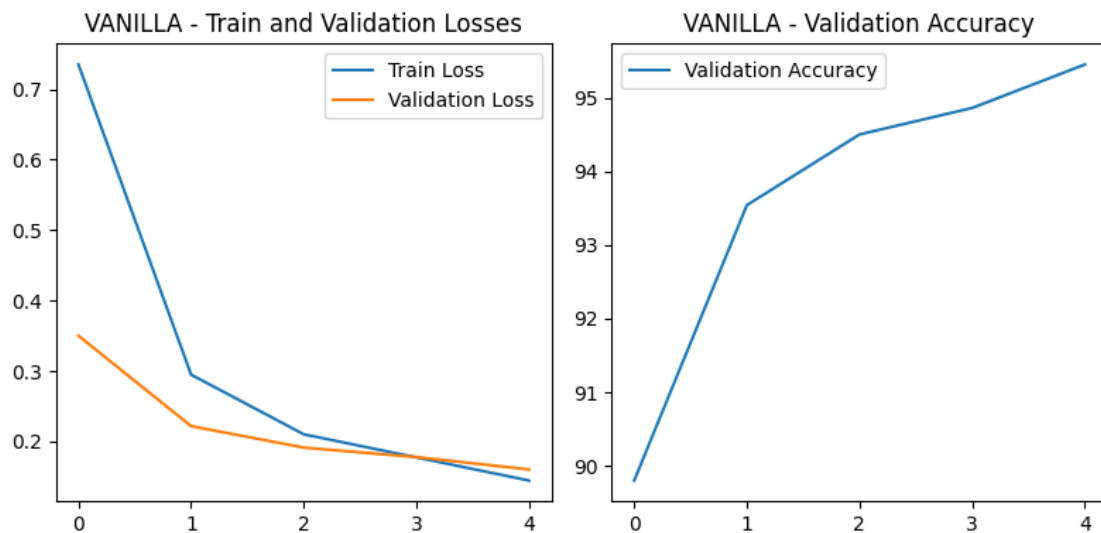
Epoch: 2/5, Train Loss: 0.2950, Validation Loss: 0.2220, Validation Accuracy: 93.54%

Epoch: 3/5, Train Loss: 0.2103, Validation Loss: 0.1915, Validation Accuracy: 94.50%

Epoch: 4/5, Train Loss: 0.1775, Validation Loss: 0.1781, Validation Accuracy: 94.86%

Epoch: 5/5, Train Loss: 0.1447, Validation Loss: 0.1604, Validation Accuracy: 95.45%

Training using VANILLA took 58.77 seconds.



New best model found with validation accuracy: 95.45%

Training with hidden size: 64, num layers: 5

Epoch: 1/5, Train Loss: 0.6420, Validation Loss: 0.3978, Validation Accuracy: 87.94%

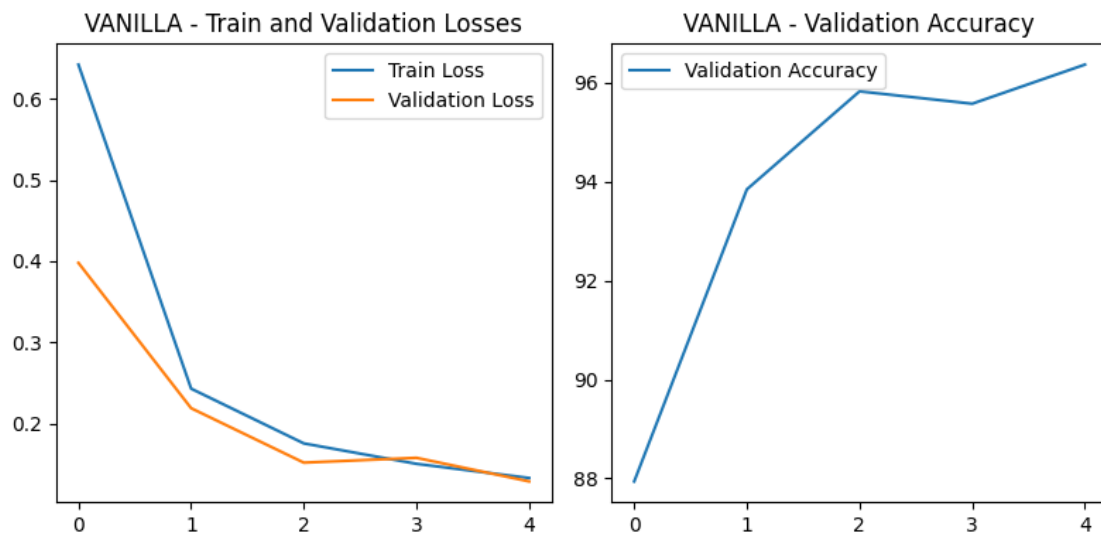
Epoch: 2/5, Train Loss: 0.2429, Validation Loss: 0.2188, Validation Accuracy: 93.84%

Epoch: 3/5, Train Loss: 0.1755, Validation Loss: 0.1517, Validation Accuracy: 95.82%

Epoch: 4/5, Train Loss: 0.1503, Validation Loss: 0.1577, Validation Accuracy: 95.57%

Epoch: 5/5, Train Loss: 0.1328, Validation Loss: 0.1286, Validation Accuracy: 96.36%

Training using VANILLA took 49.15 seconds.



New best model found with validation accuracy: 96.36%

Training with hidden size: 128, num layers: 1

Epoch: 1/5, Train Loss: 0.9751, Validation Loss: 0.7643, Validation Accuracy: 76.06%

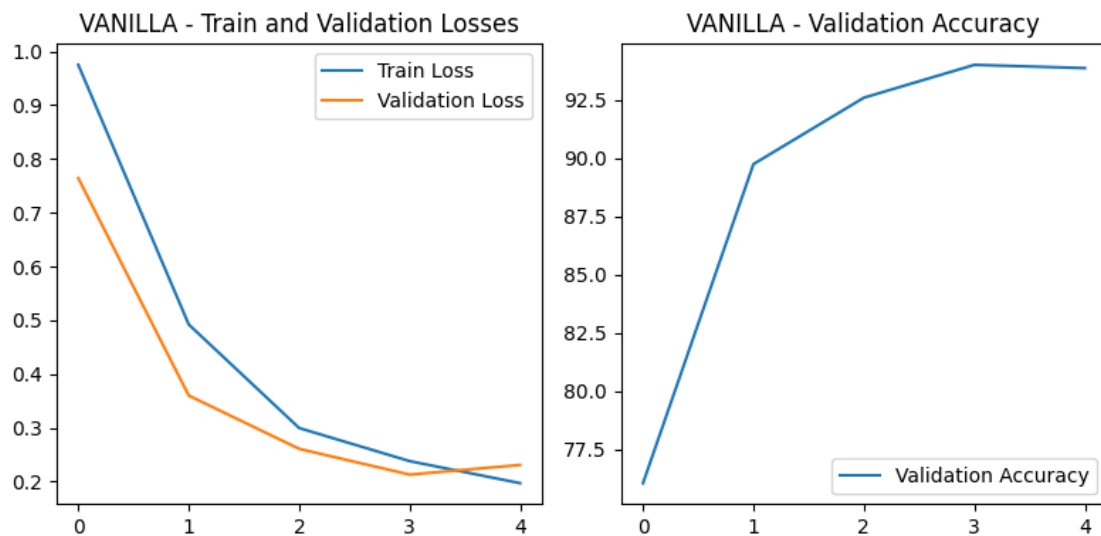
Epoch: 2/5, Train Loss: 0.4922, Validation Loss: 0.3600, Validation Accuracy: 89.75%

Epoch: 3/5, Train Loss: 0.2995, Validation Loss: 0.2609, Validation Accuracy: 92.60%

Epoch: 4/5, Train Loss: 0.2381, Validation Loss: 0.2129, Validation Accuracy: 94.01%

Epoch: 5/5, Train Loss: 0.1970, Validation Loss: 0.2309, Validation Accuracy: 93.87%

Training using VANILLA took 48.32 seconds.



Training with hidden size: 128, num layers: 2

Epoch: 1/5, Train Loss: 0.6611, Validation Loss: 0.3406, Validation Accuracy: 89.23%

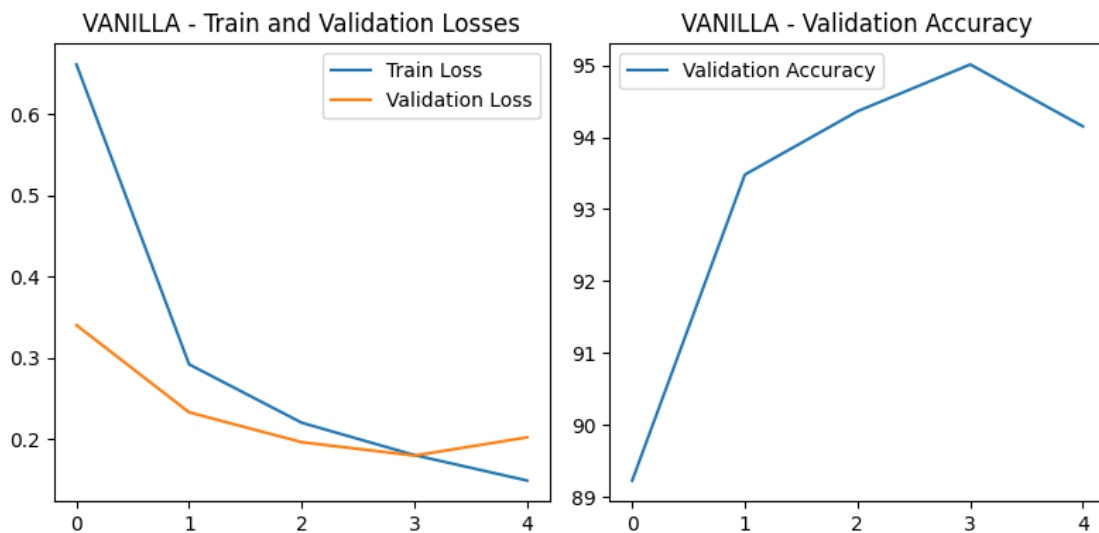
Epoch: 2/5, Train Loss: 0.2923, Validation Loss: 0.2333, Validation Accuracy: 93.48%

Epoch: 3/5, Train Loss: 0.2205, Validation Loss: 0.1966, Validation Accuracy: 94.36%

Epoch: 4/5, Train Loss: 0.1807, Validation Loss: 0.1801, Validation Accuracy: 95.01%

Epoch: 5/5, Train Loss: 0.1494, Validation Loss: 0.2026, Validation Accuracy: 94.15%

Training using VANILLA took 45.65 seconds.



Training with hidden size: 128, num layers: 3

Epoch: 1/5, Train Loss: 0.5694, Validation Loss: 0.3802, Validation Accuracy: 88.76%

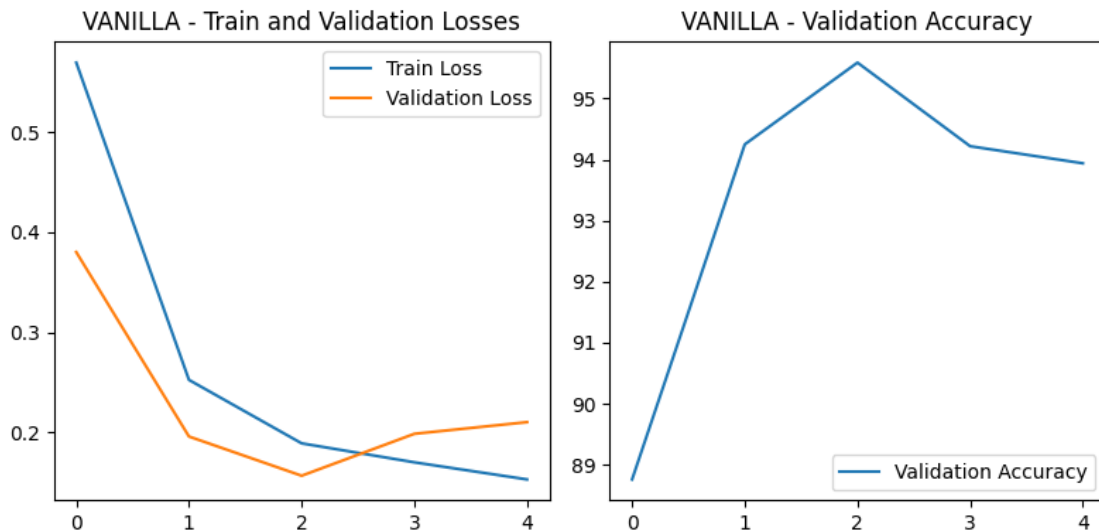
Epoch: 2/5, Train Loss: 0.2527, Validation Loss: 0.1961, Validation Accuracy: 94.25%

Epoch: 3/5, Train Loss: 0.1893, Validation Loss: 0.1570, Validation Accuracy: 95.59%

Epoch: 4/5, Train Loss: 0.1704, Validation Loss: 0.1988, Validation Accuracy: 94.22%

Epoch: 5/5, Train Loss: 0.1533, Validation Loss: 0.2105, Validation Accuracy: 93.94%

Training using VANILLA took 46.91 seconds.



Training with hidden size: 128, num layers: 4

Epoch: 1/5, Train Loss: 0.7114, Validation Loss: 0.4073, Validation Accuracy: 87.53%

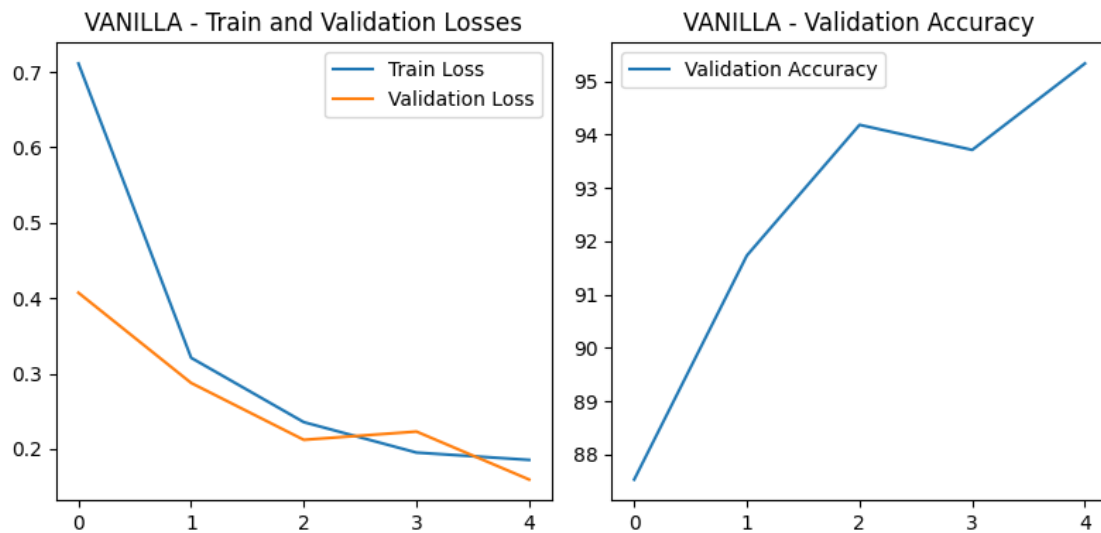
Epoch: 2/5, Train Loss: 0.3211, Validation Loss: 0.2877, Validation Accuracy: 91.73%

Epoch: 3/5, Train Loss: 0.2357, Validation Loss: 0.2123, Validation Accuracy: 94.18%

Epoch: 4/5, Train Loss: 0.1954, Validation Loss: 0.2232, Validation Accuracy: 93.71%

Epoch: 5/5, Train Loss: 0.1857, Validation Loss: 0.1596, Validation Accuracy: 95.33%

Training using VANILLA took 47.98 seconds.



Training with hidden size: 128, num layers: 5

Epoch: 1/5, Train Loss: 0.6193, Validation Loss: 0.3309, Validation Accuracy: 90.40%

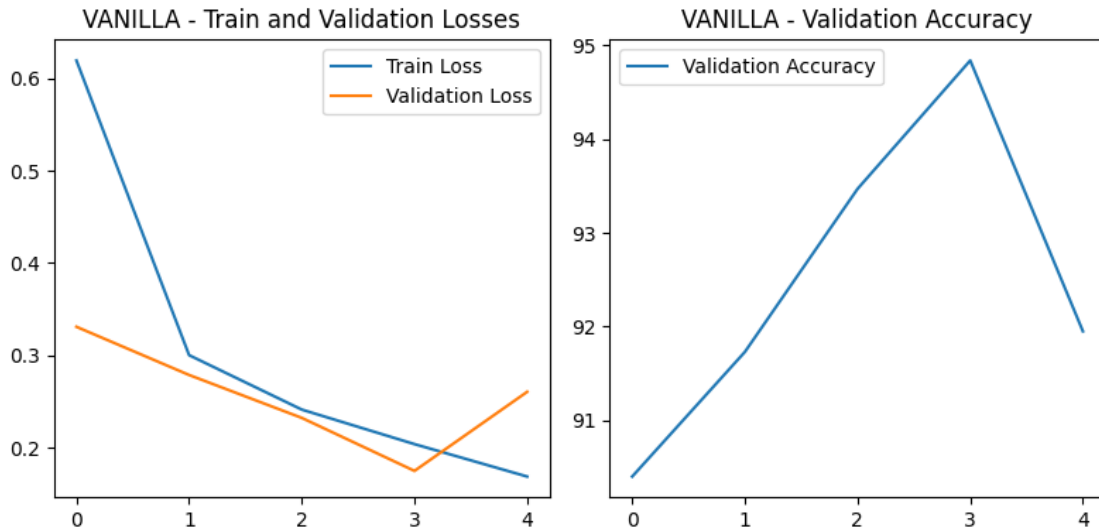
Epoch: 2/5, Train Loss: 0.3002, Validation Loss: 0.2787, Validation Accuracy: 91.73%

Epoch: 3/5, Train Loss: 0.2412, Validation Loss: 0.2322, Validation Accuracy: 93.47%

Epoch: 4/5, Train Loss: 0.2038, Validation Loss: 0.1748, Validation Accuracy: 94.84%

Epoch: 5/5, Train Loss: 0.1687, Validation Loss: 0.2604, Validation Accuracy: 91.95%

Training using VANILLA took 50.55 seconds.



```
[ ]: save_path = f'/content/drive/MyDrive/EE5179 DLI/Assignment3/best_model/
      ↪best_model_hidden_{best_hidden_size}_layers_{best_num_layers}.pt'
torch.save(best_model.state_dict(), save_path)
print(f'Best model saved to {save_path} with accuracy: {best_val_acc:.2f}%')
```

Best model saved to /content/drive/MyDrive/EE5179
DLI/Assignment3/best_model/best_model_hidden_64_layers_5.pt with accuracy:
96.36%

We get the best performance with hidden state size of 64 and 5 layers. We'll stick with this configuration for all the further experiments.

5 Performance with uni-directional models

```
[ ]: in_dim = 28
hidden_dim = 64
out_dim = 10
num_layers = 5
bidir = False

[ ]: rnn_type = 'vanilla'
rnn_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader,
      ↪val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.7325, Validation Loss: 0.4398, Validation Accuracy: 87.32%

Epoch: 2/5, Train Loss: 0.2664, Validation Loss: 0.2095, Validation Accuracy: 94.29%

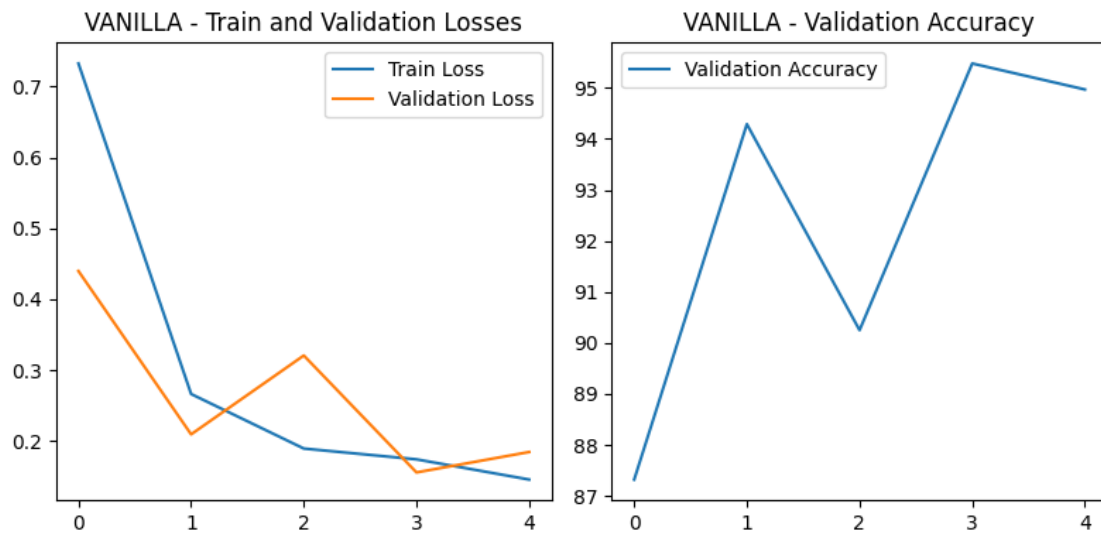
Epoch: 3/5, Train Loss: 0.1895, Validation Loss: 0.3207, Validation Accuracy:

90.25%

Epoch: 4/5, Train Loss: 0.1742, Validation Loss: 0.1558, Validation Accuracy: 95.48%

Epoch: 5/5, Train Loss: 0.1457, Validation Loss: 0.1846, Validation Accuracy: 94.97%

Training using VANILLA took 57.67 seconds.



```
[ ]: display_results(rnn_type, rnn_res)
```

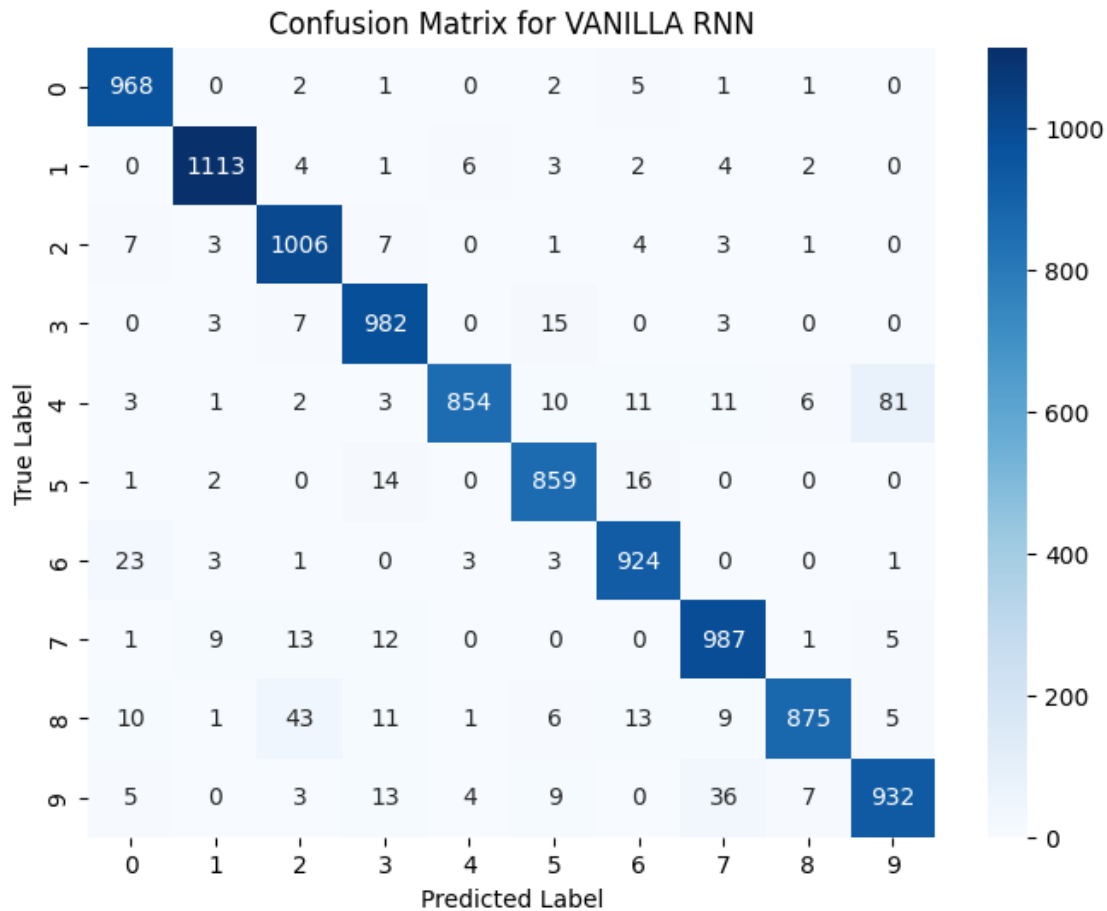
Results for VANILLA RNN:

Accuracy: 95.00%

Classification Report:

| | precision | recall | f1-score | support |
|-----------|-----------|--------|----------|---------|
| 0 | 0.95 | 0.99 | 0.97 | 980 |
| 1 | 0.98 | 0.98 | 0.98 | 1135 |
| 2 | 0.93 | 0.97 | 0.95 | 1032 |
| 3 | 0.94 | 0.97 | 0.96 | 1010 |
| 4 | 0.98 | 0.87 | 0.92 | 982 |
| 5 | 0.95 | 0.96 | 0.95 | 892 |
| 6 | 0.95 | 0.96 | 0.96 | 958 |
| 7 | 0.94 | 0.96 | 0.95 | 1028 |
| 8 | 0.98 | 0.90 | 0.94 | 974 |
| 9 | 0.91 | 0.92 | 0.92 | 1009 |
| accuracy | | | 0.95 | 10000 |
| macro avg | 0.95 | 0.95 | 0.95 | 10000 |

weighted avg 0.95 0.95 0.95 10000



```
[ ]: rnn_type = 'gru'
gru_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader,
                             val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.5521, Validation Loss: 0.2212, Validation Accuracy: 93.35%

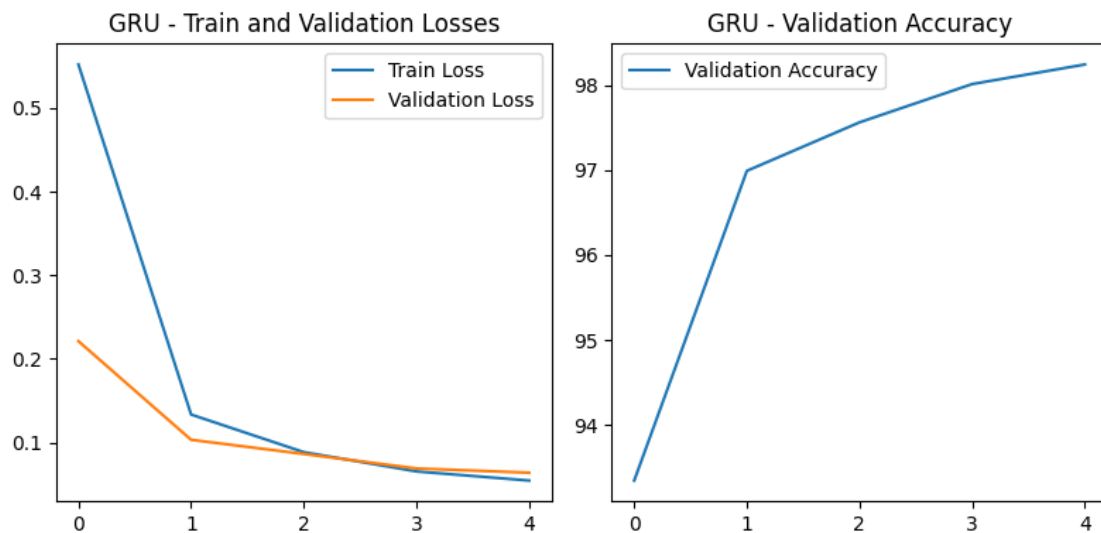
Epoch: 2/5, Train Loss: 0.1335, Validation Loss: 0.1032, Validation Accuracy: 96.99%

Epoch: 3/5, Train Loss: 0.0884, Validation Loss: 0.0863, Validation Accuracy: 97.56%

Epoch: 4/5, Train Loss: 0.0654, Validation Loss: 0.0689, Validation Accuracy: 98.01%

Epoch: 5/5, Train Loss: 0.0545, Validation Loss: 0.0639, Validation Accuracy: 98.24%

Training using GRU took 49.94 seconds.



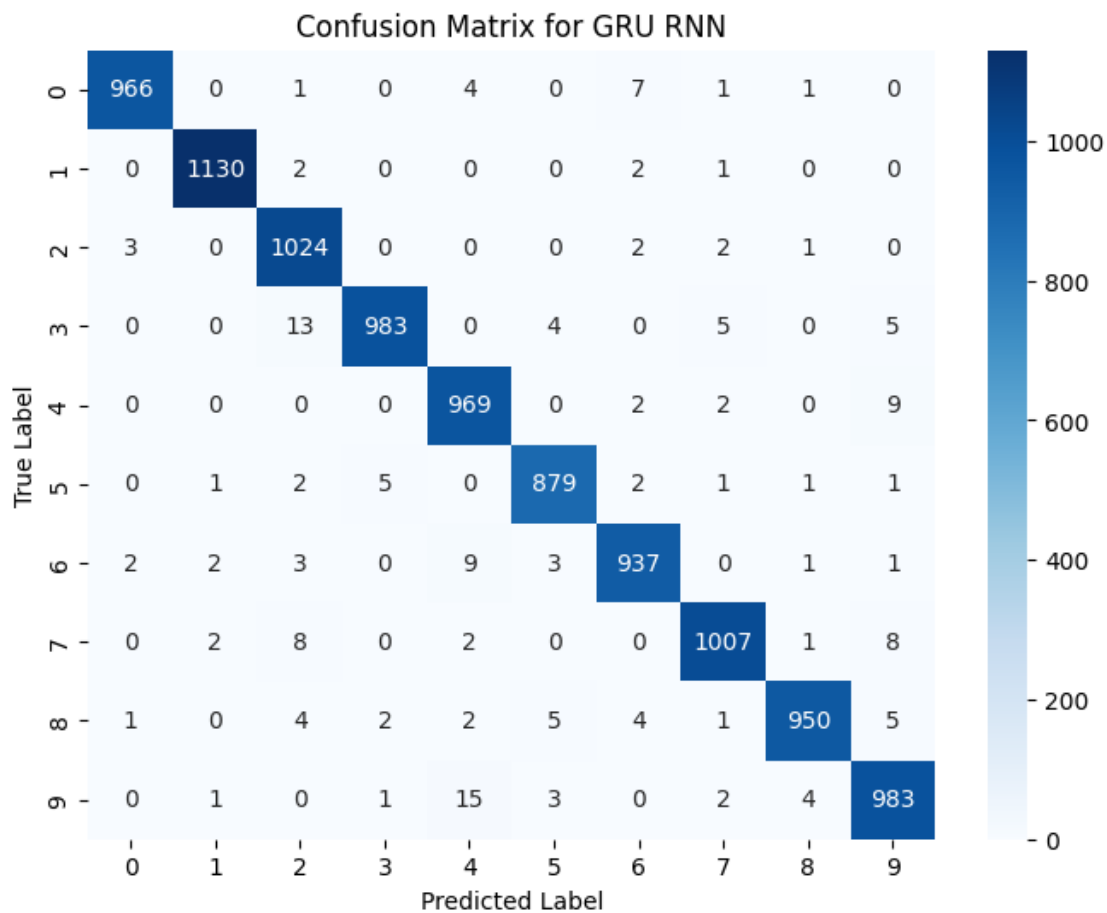
```
[ ]: display_results(rnn_type, gru_res)
```

Results for GRU RNN:

Accuracy: 98.28%

Classification Report:

| | precision | recall | f1-score | support |
|--------------|-----------|--------|----------|---------|
| 0 | 0.99 | 0.99 | 0.99 | 980 |
| 1 | 0.99 | 1.00 | 1.00 | 1135 |
| 2 | 0.97 | 0.99 | 0.98 | 1032 |
| 3 | 0.99 | 0.97 | 0.98 | 1010 |
| 4 | 0.97 | 0.99 | 0.98 | 982 |
| 5 | 0.98 | 0.99 | 0.98 | 892 |
| 6 | 0.98 | 0.98 | 0.98 | 958 |
| 7 | 0.99 | 0.98 | 0.98 | 1028 |
| 8 | 0.99 | 0.98 | 0.98 | 974 |
| 9 | 0.97 | 0.97 | 0.97 | 1009 |
| accuracy | | | 0.98 | 10000 |
| macro avg | 0.98 | 0.98 | 0.98 | 10000 |
| weighted avg | 0.98 | 0.98 | 0.98 | 10000 |



```
[ ]: rnn_type = 'lstm'
lstm_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader,
                               val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.7443, Validation Loss: 0.2628, Validation Accuracy: 92.42%

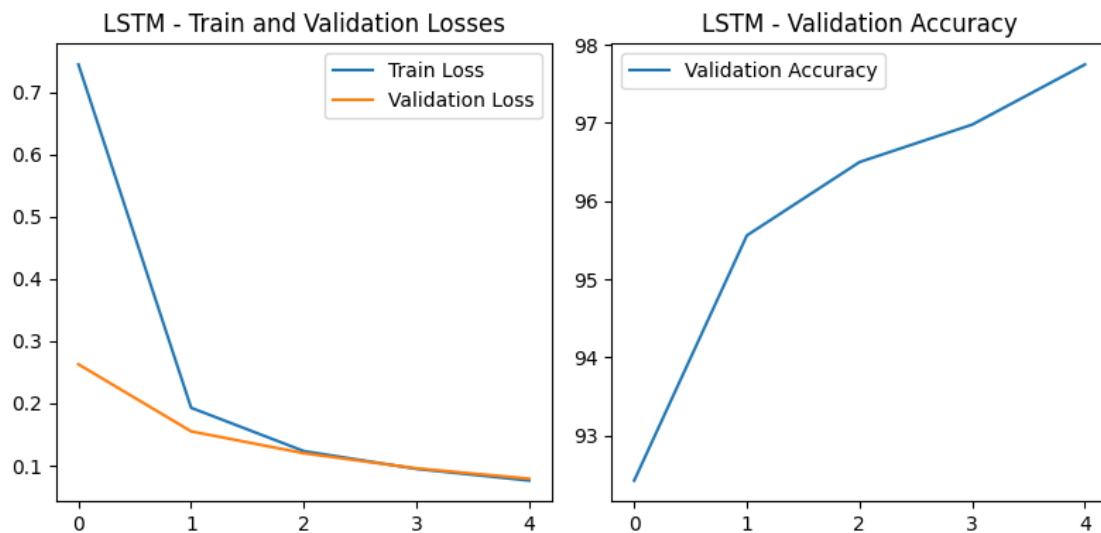
Epoch: 2/5, Train Loss: 0.1930, Validation Loss: 0.1552, Validation Accuracy: 95.56%

Epoch: 3/5, Train Loss: 0.1235, Validation Loss: 0.1200, Validation Accuracy: 96.50%

Epoch: 4/5, Train Loss: 0.0949, Validation Loss: 0.0957, Validation Accuracy: 96.98%

Epoch: 5/5, Train Loss: 0.0762, Validation Loss: 0.0792, Validation Accuracy: 97.75%

Training using LSTM took 51.67 seconds.



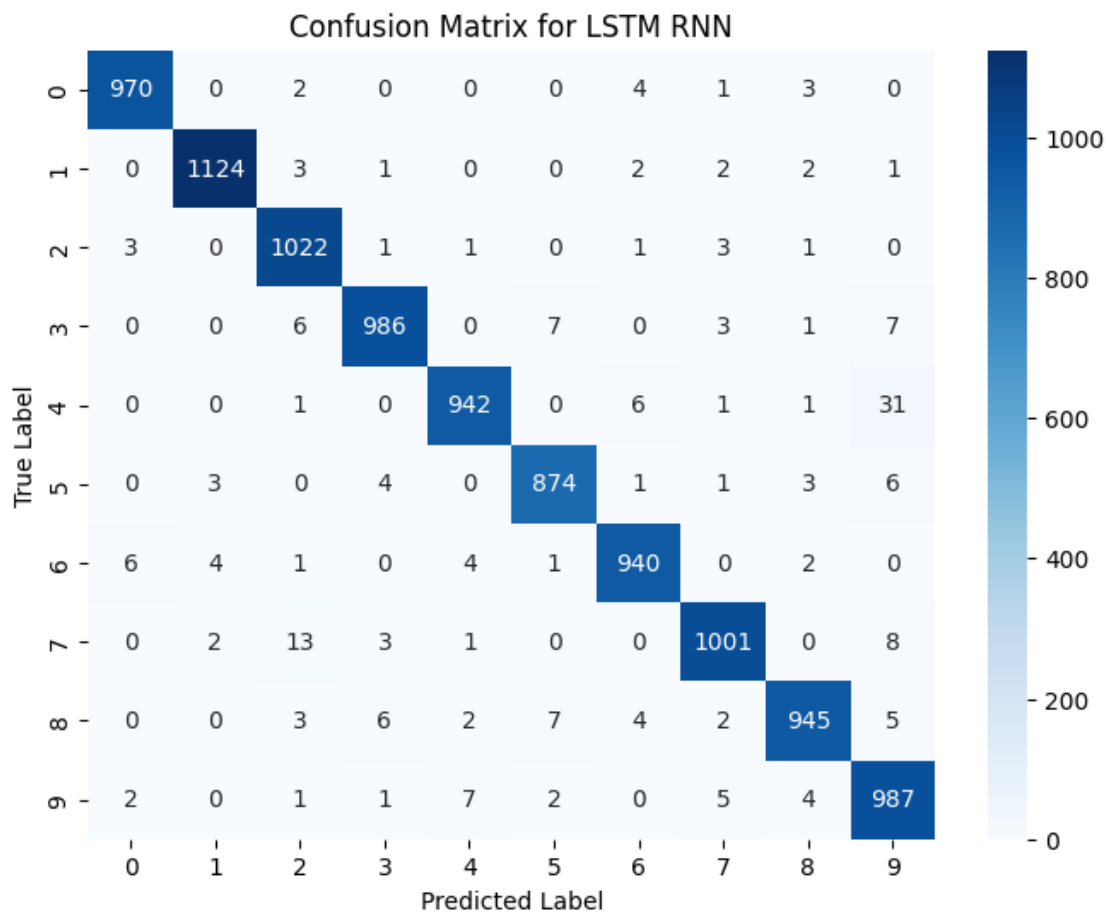
```
[ ]: display_results(rnn_type, lstm_res)
```

Results for LSTM RNN:

Accuracy: 97.91%

Classification Report:

| | precision | recall | f1-score | support |
|--------------|-----------|--------|----------|---------|
| 0 | 0.99 | 0.99 | 0.99 | 980 |
| 1 | 0.99 | 0.99 | 0.99 | 1135 |
| 2 | 0.97 | 0.99 | 0.98 | 1032 |
| 3 | 0.98 | 0.98 | 0.98 | 1010 |
| 4 | 0.98 | 0.96 | 0.97 | 982 |
| 5 | 0.98 | 0.98 | 0.98 | 892 |
| 6 | 0.98 | 0.98 | 0.98 | 958 |
| 7 | 0.98 | 0.97 | 0.98 | 1028 |
| 8 | 0.98 | 0.97 | 0.98 | 974 |
| 9 | 0.94 | 0.98 | 0.96 | 1009 |
| accuracy | | | 0.98 | 10000 |
| macro avg | 0.98 | 0.98 | 0.98 | 10000 |
| weighted avg | 0.98 | 0.98 | 0.98 | 10000 |



The GRU has the best performance and is the least time consuming.

6 Performance with bi-directional models

Ideally one should also tune hyperparameters for a bi-directional setup separately because the number of layers double, but for this simple dataset, we'll just stick with the best hyperparams from the uni-directional tuning experiment.

```
[ ]: bidir = True
```

```
[ ]: rnn_type = 'vanilla'  

bi_rnn_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader, val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.4914, Validation Loss: 0.2568, Validation Accuracy: 92.11%

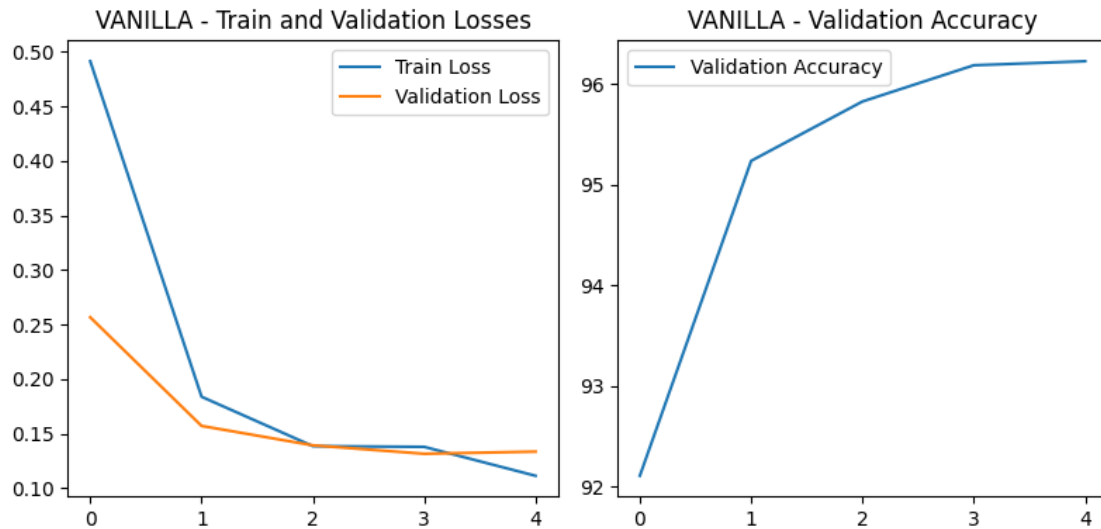
Epoch: 2/5, Train Loss: 0.1840, Validation Loss: 0.1572, Validation Accuracy: 95.24%

Epoch: 3/5, Train Loss: 0.1387, Validation Loss: 0.1394, Validation Accuracy: 95.83%

Epoch: 4/5, Train Loss: 0.1380, Validation Loss: 0.1317, Validation Accuracy: 96.19%

Epoch: 5/5, Train Loss: 0.1115, Validation Loss: 0.1337, Validation Accuracy: 96.23%

Training using VANILLA took 62.32 seconds.



```
[ ]: display_results(rnn_type, bi_rnn_res)
```

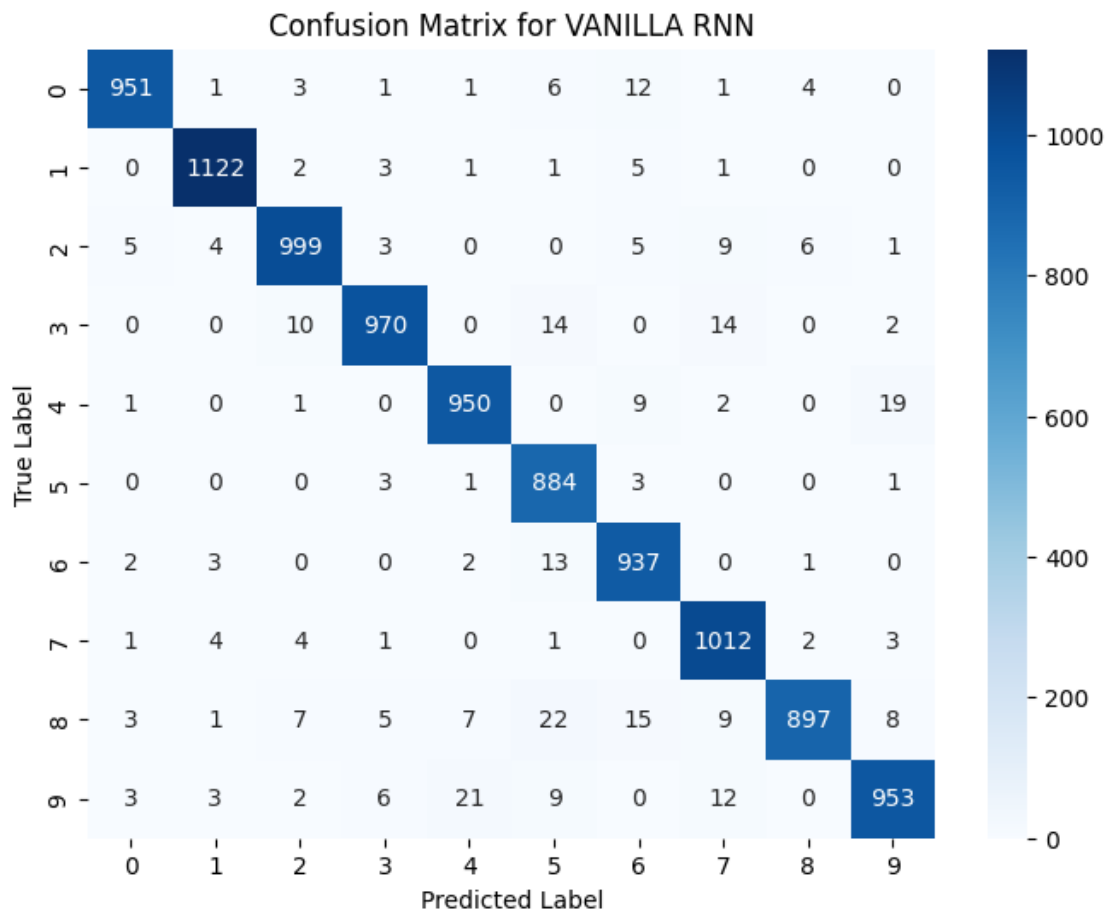
Results for VANILLA RNN:

Accuracy: 96.75%

Classification Report:

| | precision | recall | f1-score | support |
|----------|-----------|--------|----------|---------|
| 0 | 0.98 | 0.97 | 0.98 | 980 |
| 1 | 0.99 | 0.99 | 0.99 | 1135 |
| 2 | 0.97 | 0.97 | 0.97 | 1032 |
| 3 | 0.98 | 0.96 | 0.97 | 1010 |
| 4 | 0.97 | 0.97 | 0.97 | 982 |
| 5 | 0.93 | 0.99 | 0.96 | 892 |
| 6 | 0.95 | 0.98 | 0.96 | 958 |
| 7 | 0.95 | 0.98 | 0.97 | 1028 |
| 8 | 0.99 | 0.92 | 0.95 | 974 |
| 9 | 0.97 | 0.94 | 0.95 | 1009 |
| accuracy | | | 0.97 | 10000 |

| | | | | |
|--------------|------|------|------|-------|
| macro avg | 0.97 | 0.97 | 0.97 | 10000 |
| weighted avg | 0.97 | 0.97 | 0.97 | 10000 |



```
[ ]: rnn_type = 'gru'
bi_gru_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader,
    val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.3484, Validation Loss: 0.1105, Validation Accuracy: 96.52%

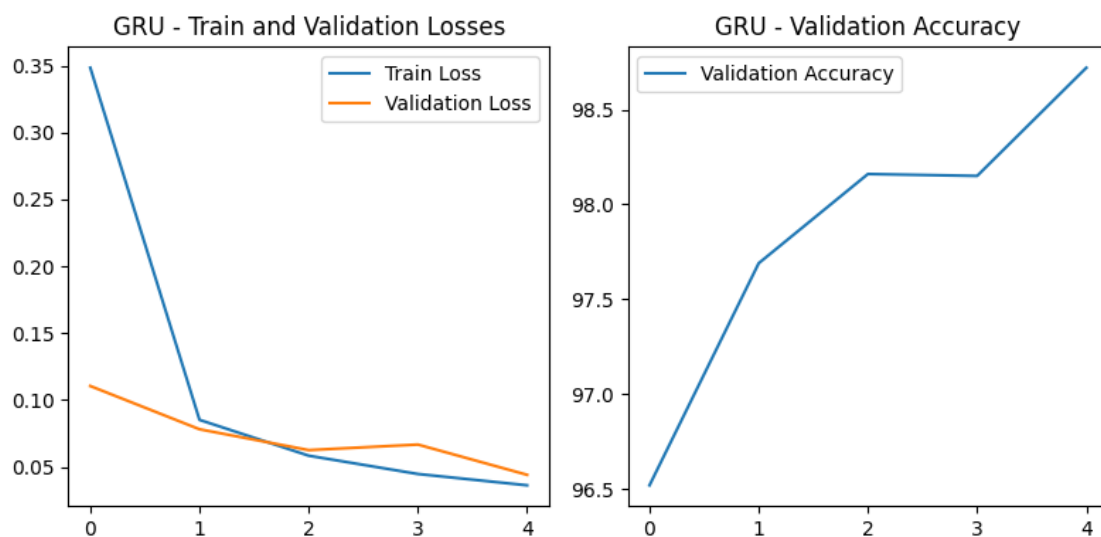
Epoch: 2/5, Train Loss: 0.0852, Validation Loss: 0.0782, Validation Accuracy: 97.69%

Epoch: 3/5, Train Loss: 0.0584, Validation Loss: 0.0626, Validation Accuracy: 98.16%

Epoch: 4/5, Train Loss: 0.0448, Validation Loss: 0.0667, Validation Accuracy: 98.15%

Epoch: 5/5, Train Loss: 0.0363, Validation Loss: 0.0441, Validation Accuracy: 98.72%

Training using GRU took 62.74 seconds.



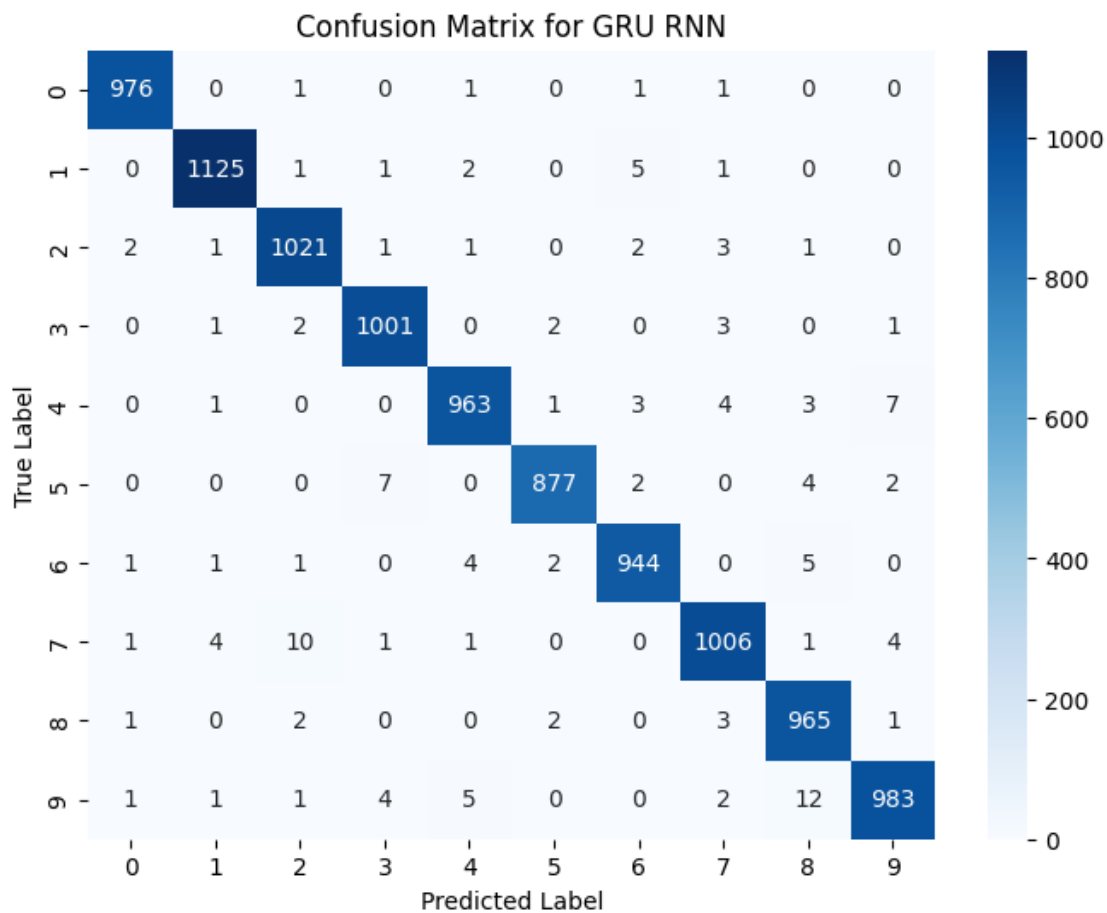
```
[ ]: display_results(rnn_type, bi_gru_res)
```

Results for GRU RNN:

Accuracy: 98.61%

Classification Report:

| | precision | recall | f1-score | support |
|--------------|-----------|--------|----------|---------|
| 0 | 0.99 | 1.00 | 0.99 | 980 |
| 1 | 0.99 | 0.99 | 0.99 | 1135 |
| 2 | 0.98 | 0.99 | 0.99 | 1032 |
| 3 | 0.99 | 0.99 | 0.99 | 1010 |
| 4 | 0.99 | 0.98 | 0.98 | 982 |
| 5 | 0.99 | 0.98 | 0.99 | 892 |
| 6 | 0.99 | 0.99 | 0.99 | 958 |
| 7 | 0.98 | 0.98 | 0.98 | 1028 |
| 8 | 0.97 | 0.99 | 0.98 | 974 |
| 9 | 0.98 | 0.97 | 0.98 | 1009 |
| accuracy | | | 0.99 | 10000 |
| macro avg | 0.99 | 0.99 | 0.99 | 10000 |
| weighted avg | 0.99 | 0.99 | 0.99 | 10000 |



```
[ ]: rnn_type = 'lstm'
bi_lstm_res = train_and_evaluate(in_dim, hidden_dim, out_dim, train_loader,
    val_loader, test_loader, num_layers, rnn_type, bidir)
```

Epoch: 1/5, Train Loss: 0.5315, Validation Loss: 0.1800, Validation Accuracy: 94.70%

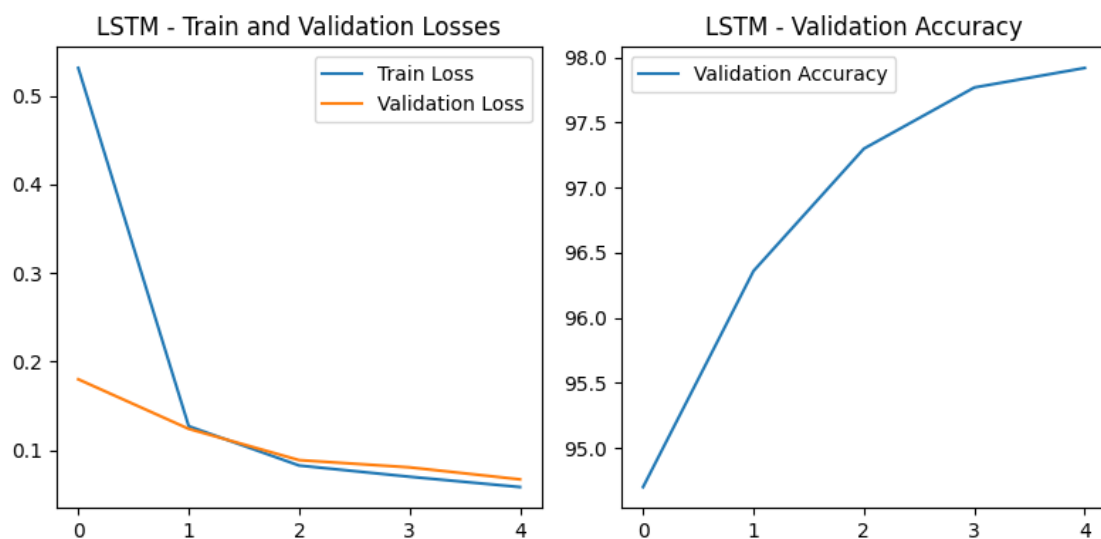
Epoch: 2/5, Train Loss: 0.1271, Validation Loss: 0.1241, Validation Accuracy: 96.36%

Epoch: 3/5, Train Loss: 0.0827, Validation Loss: 0.0888, Validation Accuracy: 97.30%

Epoch: 4/5, Train Loss: 0.0700, Validation Loss: 0.0806, Validation Accuracy: 97.77%

Epoch: 5/5, Train Loss: 0.0584, Validation Loss: 0.0670, Validation Accuracy: 97.92%

Training using LSTM took 61.25 seconds.



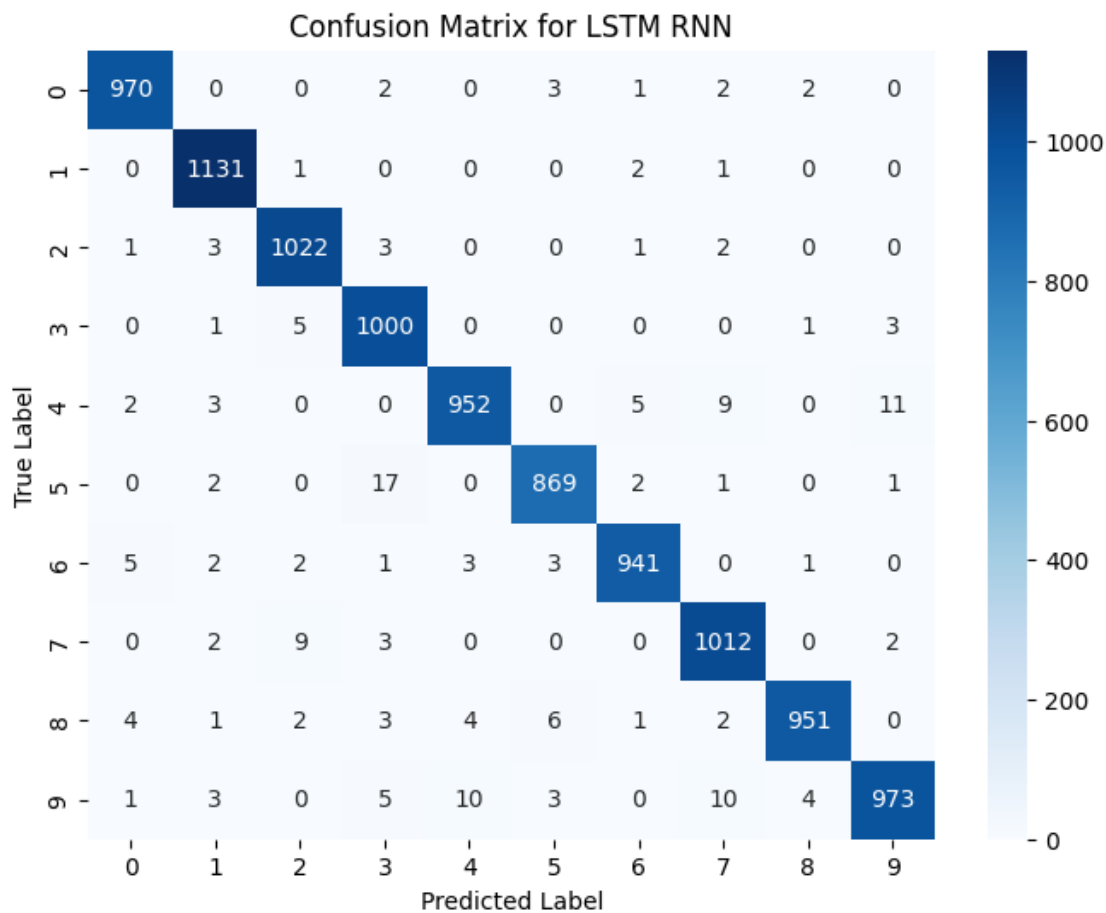
```
[ ]: display_results(rnn_type, bi_lstm_res)
```

Results for LSTM RNN:

Accuracy: 98.21%

Classification Report:

| | precision | recall | f1-score | support |
|--------------|-----------|--------|----------|---------|
| 0 | 0.99 | 0.99 | 0.99 | 980 |
| 1 | 0.99 | 1.00 | 0.99 | 1135 |
| 2 | 0.98 | 0.99 | 0.99 | 1032 |
| 3 | 0.97 | 0.99 | 0.98 | 1010 |
| 4 | 0.98 | 0.97 | 0.98 | 982 |
| 5 | 0.98 | 0.97 | 0.98 | 892 |
| 6 | 0.99 | 0.98 | 0.98 | 958 |
| 7 | 0.97 | 0.98 | 0.98 | 1028 |
| 8 | 0.99 | 0.98 | 0.98 | 974 |
| 9 | 0.98 | 0.96 | 0.97 | 1009 |
| accuracy | | | 0.98 | 10000 |
| macro avg | 0.98 | 0.98 | 0.98 | 10000 |
| weighted avg | 0.98 | 0.98 | 0.98 | 10000 |



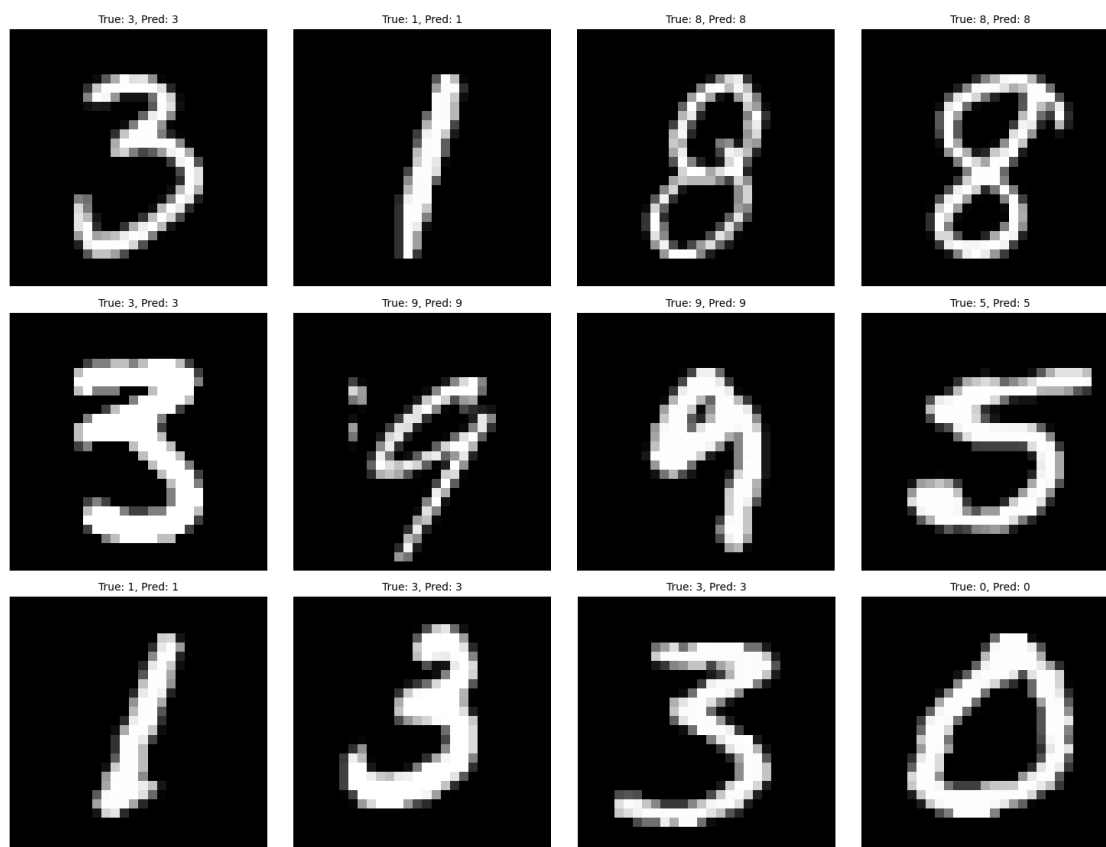
Once again, the GRU performs the best and takes the least amount to be trained.

We see that the performance of a bi-directional setup is definitely better than a uni-directional one. This is expected because of improved context captured and higher complexity.

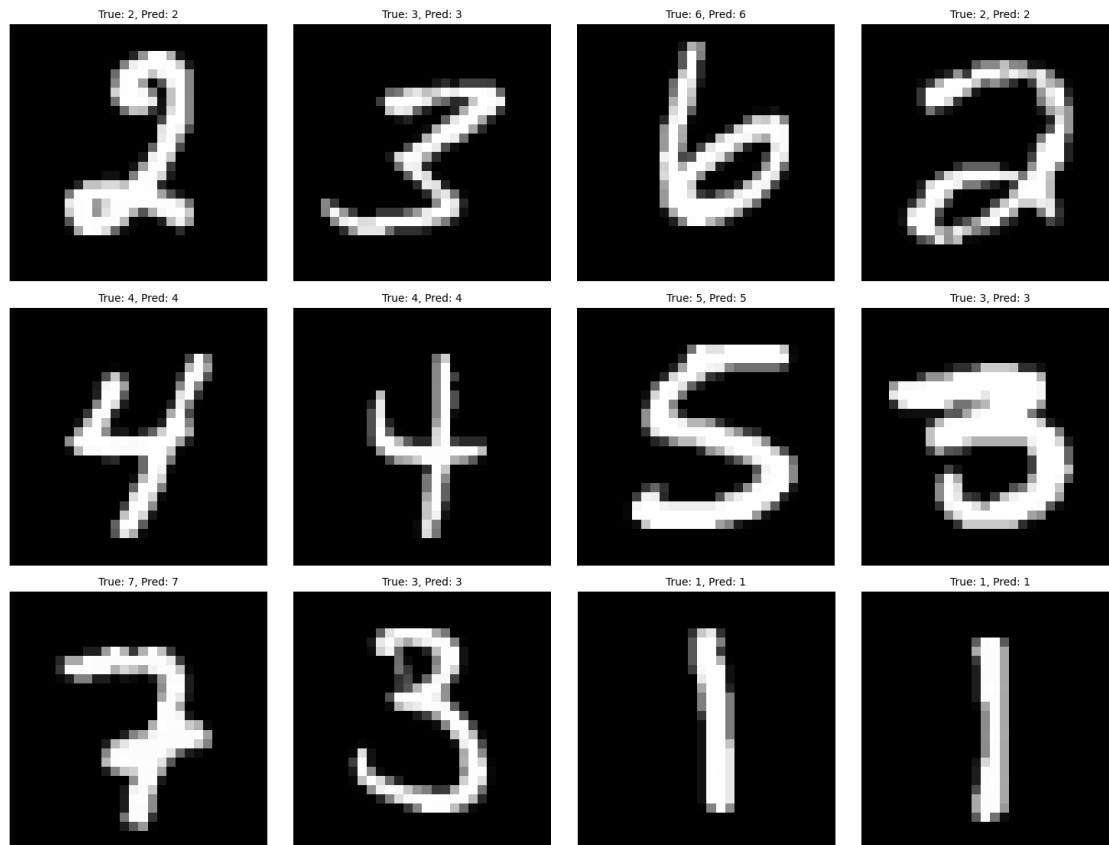
The slightly better performance of GRUs over LSTMs might hint that exposing all the hidden state information without any control is beneficial for the MNIST dataset.

7 Plotting predictions

```
[ ]: top_uni_model = gru_res[-1]
top_uni_model = top_uni_model.to(device)
plot_predictions(top_uni_model, test_loader)
```



```
[ ]: top_bi_model = bi_gru_res[-1]
      top_bi_model = top_bi_model.to(device)
      plot_predictions(top_bi_model, test_loader)
```



8 Predicitons on custom handwritten digits

```
[ ]: def plot_custom_images(model, images, labels, device):
    images_tensor = torch.stack([torch.Tensor(img) for img in X]).unsqueeze(1)
    labels_tensor = torch.Tensor(labels).long()
    #print(labels)

    outputs = model(images_tensor.to(device))
    #print(outputs)
    _, predictions = outputs.max(1)

    num_samples = len(images)
    grid_size = int(math.ceil(math.sqrt(num_samples)))

    plt.figure(figsize=(15, 15))
    for i, (img, label, pred) in enumerate(zip(images_tensor, labels_tensor,
    ↪ predictions)):
        plt.subplot(grid_size, grid_size, i + 1)
        plt.imshow(img[0].cpu().numpy(), cmap='gray')
```

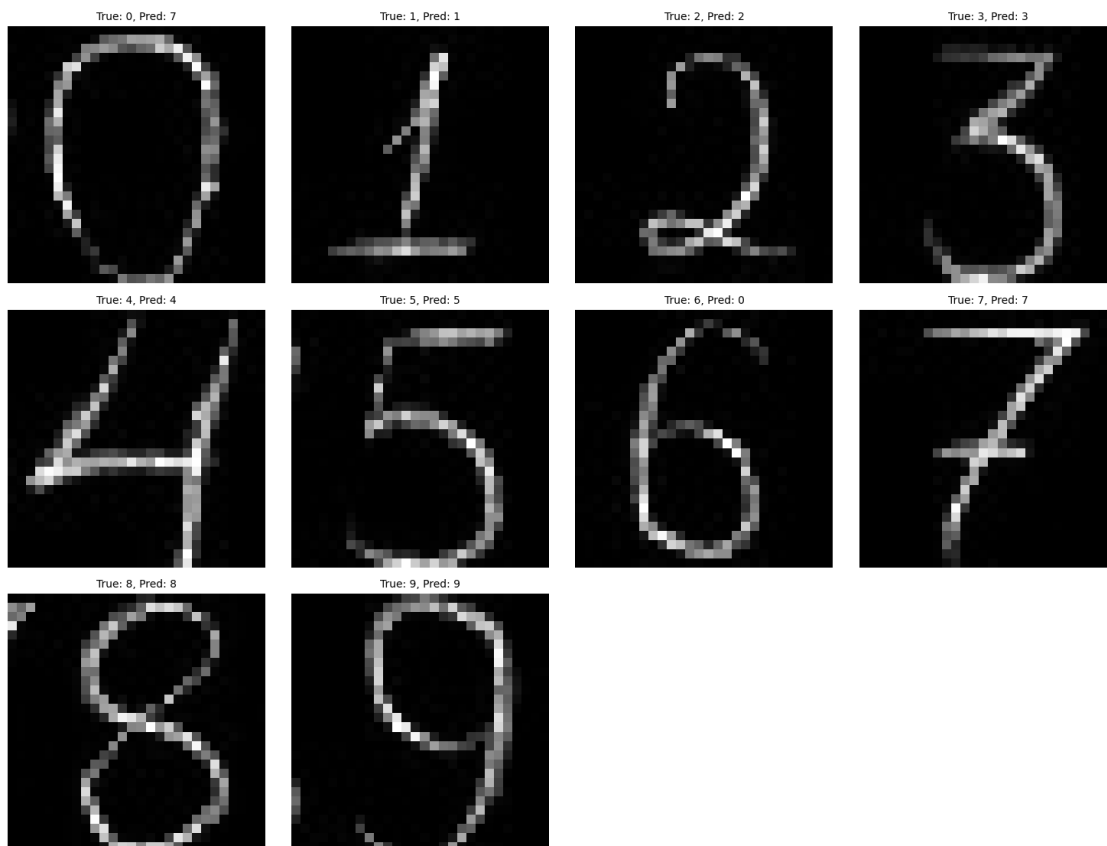
```
plt.title(f"True: {label.item()}, Pred: {pred.item()}", fontsize=10)
plt.axis('off')
plt.tight_layout()
plt.show()
```

```
[ ]: def preprocess_image(img_path):
    img = cv2.imread(img_path)
    img_gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)
    img_resized = cv2.resize(img_gray, (28, 28))
    img_normalized = img_resized / 255.0
    # Inverted the colors to match the MNIST format
    img_normalized = 1.0 - img_normalized
    return img_normalized
```

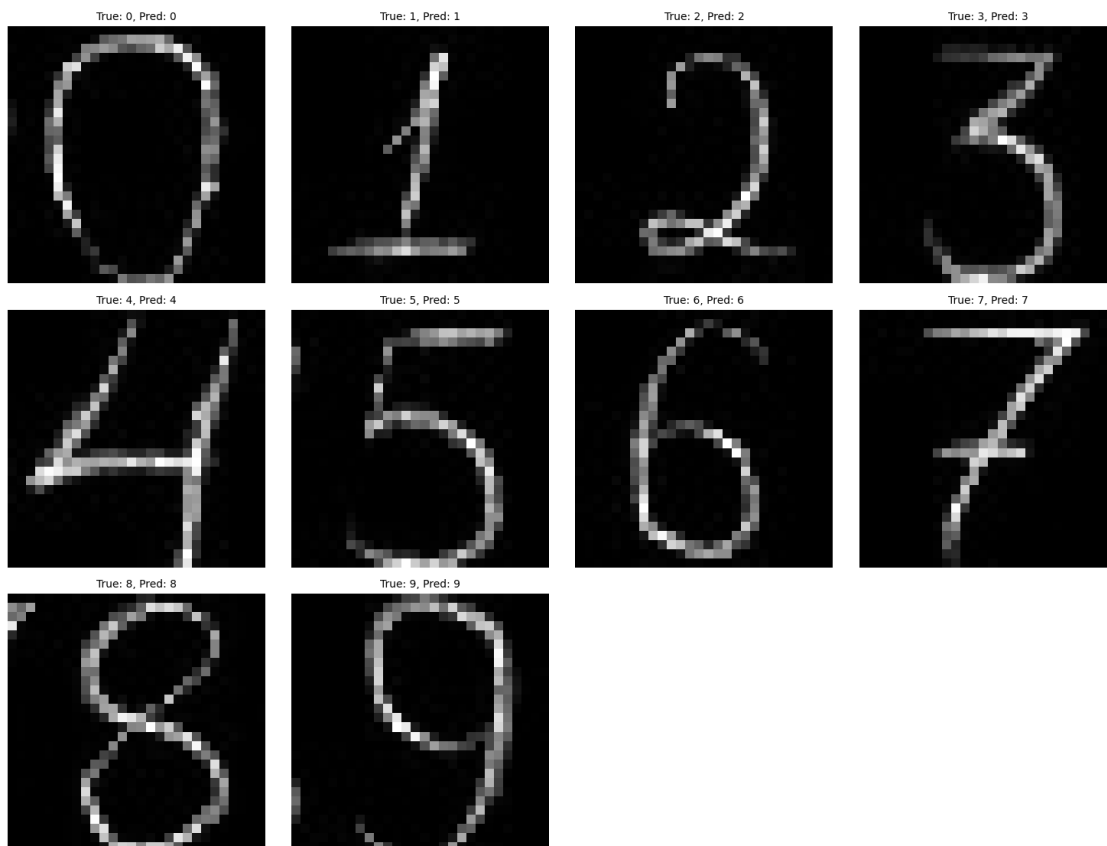
```
[ ]: # Load and preprocess your images
X = [preprocess_image(f"/content/drive/MyDrive/EE5179 DLI/Assignment3/
↳ custom_images/{i}.jpg") for i in range(10)]
y = [i for i in range(10)]
```

8.1 Prediciton with GRU

```
[ ]: plot_custom_images(top_uni_model, X, y, device)
```



```
[ ]: plot_custom_images(top_bi_model, X, y, device)
```



This experiment shows the robustness of the bi-directional model, as it works well even with the custom images, which clearly have a thinner stroke than the images from the MNIST dataset.

9 Teaching an RNN to learn binary addition

We'll have 5 layers in our LSTM architecture for this task and train for 5000 epochs with each hidden state size. We'll use a sequence of length 5 for each experiment as specified in the assignment.

9.1 Function to generate data

```
[4]: def get_batch(K, L):
    max_num = (2 ** L) - 1
    X = np.zeros((K, L + 1, 2))
    y = np.zeros((K, L + 1, 1))

    for i in range(K):
```

```

a, b = random.sample(range(max_num + 1), 2)
c = a + b

# Convert to padded binary strings
a_bin = format(a, f'0{L + 1}b')
b_bin = format(b, f'0{L + 1}b')
c_bin = format(c, f'0{L + 1}b')

for j in range(L + 1):
    X[i, j, 0] = int(a_bin[j])
    X[i, j, 1] = int(b_bin[j])
    y[i, j, 0] = int(c_bin[j])

return torch.tensor(X).float(), torch.tensor(y).long()

```

9.2 The LSTM Architecture

```

[5]: class BinaryAdder(nn.Module):
    def __init__(self, input_dim, hidden_dim, output_dim, layers = 1):
        super().__init__()
        self.layers = layers
        self.hidden_dim = hidden_dim
        self.rnn = nn.LSTM(input_dim, hidden_dim, num_layers = layers,
↪ batch_first = True)
        self.fc = nn.Linear(hidden_dim, output_dim)

    def forward(self, text):
        output, (hidden, cell) = self.rnn(text)
        return self.fc(output)

```

9.3 Functions to train, evaluate and plot

```

[6]: def evaluate(model, criterion, K, L):
    inputs, labels = get_batch(K, L)
    labels = labels.flatten()
    inputs, labels = inputs.to(device), labels.to(device)
    with torch.no_grad():
        outputs = model(inputs)
        if criterion:
            loss = criterion(outputs.view(-1, 2), labels)
            correct = (torch.argmax(outputs, dim=-1).flatten() == labels).sum().
↪ item()
            accuracy = 100 * correct / len(labels)

    if criterion:
        return loss.item(), accuracy

```

```

else:
    return None, accuracy

```

```

[7]: def train_model(model, criterion, optimizer, K, L, epochs=1000):
    train_costs = []
    val_costs = []
    train_acc = []
    val_acc = []

    for epoch in range(epochs):
        inputs, labels = get_batch(K, L)
        labels = labels.flatten()
        inputs, labels = inputs.to(device), labels.to(device)

        optimizer.zero_grad()

        outputs = model(inputs)
        loss = criterion(outputs.view(-1, 2), labels)
        loss.backward()
        optimizer.step()

        train_costs.append(loss.item())

        correct = (torch.argmax(outputs, dim=-1).flatten() == labels).sum().
↪item()
        accuracy = 100 * correct / len(labels)
        train_acc.append(accuracy)

        val_cost, val_accuracy = evaluate(model, criterion, K, L)
        val_costs.append(val_cost)
        val_acc.append(val_accuracy)

        print(f'Epoch: {epoch}. Train Loss: {loss.item()}. Validation Accuracy:
↪{val_accuracy}')
    return train_costs, train_acc, val_costs, val_acc

```

```

[8]: def plot_curves(train_costs, train_acc, val_costs, val_acc):
    plt.plot(train_costs)
    plt.plot(val_costs)
    plt.ylabel('Cost')
    plt.xlabel('epochs')
    plt.legend(['Train loss', 'Test loss'])
    plt.show()
    print(f'Train loss value after 1000 epochs: {train_costs[-1]}')
    print(f'Vaildation loss value after 1000 epochs: {val_costs[-1]}')

    plt.plot(train_acc)

```



```

plt.plot(val_acc)
plt.ylabel('Accuracy')
plt.xlabel('epochs')
plt.legend(['Train acc', 'Test acc'])
plt.show()
print(f'Best Test Accuracy: {max(val_acc)}%')

```

```

[9]: def plot_accuracy_vs_length(model):
    acc = []
    for L in range(1, 21):
        _, accuracy = evaluate(model, None, 100, L)
        acc.append(accuracy)

    plt.plot(range(1, 21), acc)
    plt.ylabel('Accuracy')
    plt.xlabel('Sequence length - L')
    plt.title('Accuracy vs L plot')
    plt.show()

```

9.4 Hyperparameter tuning

```

[33]: INPUT_DIM = 2
      OUTPUT_DIM = 2
      LR = 0.001
      K = 64
      num_layers = [1, 3, 5]
      hidden_state_sizes = [2, 5, 10]
      lengths_of_input = [3, 5, 10]

      best_accuracy = 0
      best_model = None
      best_params = None

      for num_layer in num_layers:
          for hidden_state_size in hidden_state_sizes:
              for length_of_input in lengths_of_input:

                  model = BinaryAdder(INPUT_DIM, hidden_state_size, OUTPUT_DIM,
                  ↪ num_layer).to(device)
                  criterion = nn.CrossEntropyLoss()
                  optimizer = optim.Adam(model.parameters(), lr=LR)

                  _, _, _, val_acc = train_model(model, criterion, optimizer, K,
                  ↪ length_of_input)

                  avg_val_acc = sum(val_acc[-10:]) / 10

```

```
if avg_val_acc > best_accuracy:
    best_accuracy = avg_val_acc
    best_model = model
    best_params = (num_layer, hidden_state_size, length_of_input)
```

Streaming output truncated to the last 5000 lines.

```
Epoch: 0. Train Loss: 0.7377268671989441. Validation Accuracy:
49.739583333333336
Epoch: 1. Train Loss: 0.7205824851989746. Validation Accuracy:
49.739583333333336
Epoch: 2. Train Loss: 0.7004799246788025. Validation Accuracy: 48.4375
Epoch: 3. Train Loss: 0.7569630742073059. Validation Accuracy:
47.395833333333336
Epoch: 4. Train Loss: 0.7294548153877258. Validation Accuracy: 50.78125
Epoch: 5. Train Loss: 0.7245316505432129. Validation Accuracy: 53.125
Epoch: 6. Train Loss: 0.7213378548622131. Validation Accuracy:
50.260416666666664
Epoch: 7. Train Loss: 0.7266207337379456. Validation Accuracy:
47.916666666666664
Epoch: 8. Train Loss: 0.7419173717498779. Validation Accuracy: 48.4375
Epoch: 9. Train Loss: 0.7342092990875244. Validation Accuracy: 47.65625
Epoch: 10. Train Loss: 0.7421014308929443. Validation Accuracy:
48.958333333333336
Epoch: 11. Train Loss: 0.7387790679931641. Validation Accuracy:
51.302083333333336
Epoch: 12. Train Loss: 0.738209068775177. Validation Accuracy:
48.697916666666664
Epoch: 13. Train Loss: 0.7320931553840637. Validation Accuracy:
51.302083333333336
Epoch: 14. Train Loss: 0.7301454544067383. Validation Accuracy: 50.78125
Epoch: 15. Train Loss: 0.7432265281677246. Validation Accuracy:
46.354166666666664
Epoch: 16. Train Loss: 0.7290828227996826. Validation Accuracy:
51.822916666666664
Epoch: 17. Train Loss: 0.7138242721557617. Validation Accuracy:
53.385416666666664
Epoch: 18. Train Loss: 0.7253994941711426. Validation Accuracy: 48.4375
Epoch: 19. Train Loss: 0.7157167792320251. Validation Accuracy:
48.697916666666664
Epoch: 20. Train Loss: 0.7453582286834717. Validation Accuracy:
48.697916666666664
Epoch: 21. Train Loss: 0.7201817035675049. Validation Accuracy:
48.958333333333336
Epoch: 22. Train Loss: 0.7260520458221436. Validation Accuracy:
52.083333333333336
Epoch: 23. Train Loss: 0.7178637981414795. Validation Accuracy:
```

52.864583333333336
Epoch: 24. Train Loss: 0.7327322959899902. Validation Accuracy: 48.4375
Epoch: 25. Train Loss: 0.7308409214019775. Validation Accuracy: 45.3125
Epoch: 26. Train Loss: 0.741461455821991. Validation Accuracy: 50.0
Epoch: 27. Train Loss: 0.7210667133331299. Validation Accuracy:
48.697916666666664
Epoch: 28. Train Loss: 0.7402495741844177. Validation Accuracy:
51.302083333333336
Epoch: 29. Train Loss: 0.7118515372276306. Validation Accuracy: 53.125
Epoch: 30. Train Loss: 0.7242457270622253. Validation Accuracy:
48.958333333333336
Epoch: 31. Train Loss: 0.7059382796287537. Validation Accuracy:
51.302083333333336
Epoch: 32. Train Loss: 0.720845639705658. Validation Accuracy:
48.958333333333336
Epoch: 33. Train Loss: 0.7195854187011719. Validation Accuracy:
51.041666666666664
Epoch: 34. Train Loss: 0.7175690531730652. Validation Accuracy:
49.479166666666664
Epoch: 35. Train Loss: 0.721138060092926. Validation Accuracy:
51.302083333333336
Epoch: 36. Train Loss: 0.7217392921447754. Validation Accuracy:
52.083333333333336
Epoch: 37. Train Loss: 0.7196409702301025. Validation Accuracy:
50.520833333333336
Epoch: 38. Train Loss: 0.7279248833656311. Validation Accuracy:
45.833333333333336
Epoch: 39. Train Loss: 0.7264270186424255. Validation Accuracy:
48.177083333333336
Epoch: 40. Train Loss: 0.7097496390342712. Validation Accuracy:
51.302083333333336
Epoch: 41. Train Loss: 0.7146470546722412. Validation Accuracy:
50.260416666666664
Epoch: 42. Train Loss: 0.7266681790351868. Validation Accuracy:
48.958333333333336
Epoch: 43. Train Loss: 0.7094681262969971. Validation Accuracy: 49.21875
Epoch: 44. Train Loss: 0.7207953929901123. Validation Accuracy: 48.4375
Epoch: 45. Train Loss: 0.7081453204154968. Validation Accuracy: 52.34375
Epoch: 46. Train Loss: 0.708087146282196. Validation Accuracy: 50.0
Epoch: 47. Train Loss: 0.709437906742096. Validation Accuracy:
48.177083333333336
Epoch: 48. Train Loss: 0.710386335849762. Validation Accuracy:
51.041666666666664
Epoch: 49. Train Loss: 0.7193045020103455. Validation Accuracy:
48.958333333333336
Epoch: 50. Train Loss: 0.7107743620872498. Validation Accuracy: 52.34375
Epoch: 51. Train Loss: 0.7100104689598083. Validation Accuracy:
48.697916666666664

Epoch: 52. Train Loss: 0.7102157473564148. Validation Accuracy: 47.135416666666664
Epoch: 53. Train Loss: 0.7113792896270752. Validation Accuracy: 49.739583333333336
Epoch: 54. Train Loss: 0.7036616206169128. Validation Accuracy: 51.302083333333336
Epoch: 55. Train Loss: 0.7060722708702087. Validation Accuracy: 49.479166666666664
Epoch: 56. Train Loss: 0.7114098072052002. Validation Accuracy: 50.0
Epoch: 57. Train Loss: 0.7129186987876892. Validation Accuracy: 52.864583333333336
Epoch: 58. Train Loss: 0.7082735896110535. Validation Accuracy: 52.604166666666664
Epoch: 59. Train Loss: 0.6994739174842834. Validation Accuracy: 49.21875
Epoch: 60. Train Loss: 0.6986456513404846. Validation Accuracy: 50.0
Epoch: 61. Train Loss: 0.707631528377533. Validation Accuracy: 51.302083333333336
Epoch: 62. Train Loss: 0.7027420401573181. Validation Accuracy: 51.041666666666664
Epoch: 63. Train Loss: 0.708347737789154. Validation Accuracy: 51.822916666666664
Epoch: 64. Train Loss: 0.7036609649658203. Validation Accuracy: 44.53125
Epoch: 65. Train Loss: 0.7096236348152161. Validation Accuracy: 48.697916666666664
Epoch: 66. Train Loss: 0.708792507648468. Validation Accuracy: 48.4375
Epoch: 67. Train Loss: 0.7088227272033691. Validation Accuracy: 50.520833333333336
Epoch: 68. Train Loss: 0.7130387425422668. Validation Accuracy: 48.697916666666664
Epoch: 69. Train Loss: 0.7024415135383606. Validation Accuracy: 48.958333333333336
Epoch: 70. Train Loss: 0.7134690284729004. Validation Accuracy: 50.0
Epoch: 71. Train Loss: 0.696833610534668. Validation Accuracy: 50.520833333333336
Epoch: 72. Train Loss: 0.6920778751373291. Validation Accuracy: 47.916666666666664
Epoch: 73. Train Loss: 0.7106249928474426. Validation Accuracy: 50.520833333333336
Epoch: 74. Train Loss: 0.6975871920585632. Validation Accuracy: 48.4375
Epoch: 75. Train Loss: 0.7041546702384949. Validation Accuracy: 52.083333333333336
Epoch: 76. Train Loss: 0.7021271586418152. Validation Accuracy: 48.958333333333336
Epoch: 77. Train Loss: 0.6994876861572266. Validation Accuracy: 50.520833333333336
Epoch: 78. Train Loss: 0.6950555443763733. Validation Accuracy: 50.0
Epoch: 79. Train Loss: 0.6986653208732605. Validation Accuracy: 48.958333333333336

Epoch: 80. Train Loss: 0.6985300183296204. Validation Accuracy: 55.46875
Epoch: 81. Train Loss: 0.6958487033843994. Validation Accuracy:
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Epoch: 82. Train Loss: 0.701943576335907. Validation Accuracy:
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Epoch: 83. Train Loss: 0.6998034119606018. Validation Accuracy: 50.78125
Epoch: 84. Train Loss: 0.7008748054504395. Validation Accuracy: 50.78125
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Epoch: 86. Train Loss: 0.6938181519508362. Validation Accuracy:
52.864583333333336
Epoch: 87. Train Loss: 0.6990917325019836. Validation Accuracy: 53.125
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Epoch: 92. Train Loss: 0.6949069499969482. Validation Accuracy: 52.34375
Epoch: 93. Train Loss: 0.6958864331245422. Validation Accuracy:
49.739583333333336
Epoch: 94. Train Loss: 0.6967394948005676. Validation Accuracy: 50.78125
Epoch: 95. Train Loss: 0.6926924586296082. Validation Accuracy: 47.65625
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Epoch: 110. Train Loss: 0.6954963803291321. Validation Accuracy: 53.125

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Epoch: 121. Train Loss: 0.6953163743019104. Validation Accuracy:
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Epoch: 122. Train Loss: 0.700361967086792. Validation Accuracy:
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Epoch: 123. Train Loss: 0.6949238181114197. Validation Accuracy:
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Epoch: 125. Train Loss: 0.6880524754524231. Validation Accuracy: 53.125
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Epoch: 132. Train Loss: 0.6983001232147217. Validation Accuracy:
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Epoch: 135. Train Loss: 0.6929656863212585. Validation Accuracy:
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51.822916666666664
Epoch: 137. Train Loss: 0.6928155422210693. Validation Accuracy:
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51.822916666666664
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Epoch: 144. Train Loss: 0.6981067061424255. Validation Accuracy:
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Epoch: 145. Train Loss: 0.6937136650085449. Validation Accuracy:
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Epoch: 159. Train Loss: 0.6960201859474182. Validation Accuracy: 46.09375
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50.520833333333336

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Epoch: 197. Train Loss: 0.6971733570098877. Validation Accuracy: 50.260416666666664

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Epoch: 214. Train Loss: 0.6953055262565613. Validation Accuracy: 49.739583333333336

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Epoch: 293. Train Loss: 0.6910286545753479. Validation Accuracy: 50.78125
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56.770833333333336

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Epoch: 330. Train Loss: 0.6918714642524719. Validation Accuracy: 53.125
Epoch: 331. Train Loss: 0.6932701468467712. Validation Accuracy:
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Epoch: 584. Train Loss: 0.6960334181785583. Validation Accuracy: 50.260416666666664
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Epoch: 587. Train Loss: 0.6905524730682373. Validation Accuracy: 50.260416666666664
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Epoch: 5. Train Loss: 0.7641711831092834. Validation Accuracy: 51.27840909090909

Epoch: 6. Train Loss: 0.7805152535438538. Validation Accuracy: 52.27272727272727

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51.13636363636363
Epoch: 102. Train Loss: 0.6974632740020752. Validation Accuracy:
52.41477272727273
Epoch: 103. Train Loss: 0.7015212774276733. Validation Accuracy:
49.28977272727273
Epoch: 104. Train Loss: 0.7012115716934204. Validation Accuracy:
46.59090909090909
Epoch: 105. Train Loss: 0.6994815468788147. Validation Accuracy:
48.29545454545455
Epoch: 106. Train Loss: 0.7006832361221313. Validation Accuracy:

51.70454545454545
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Epoch: 110. Train Loss: 0.6997820138931274. Validation Accuracy: 51.42045454545455
Epoch: 111. Train Loss: 0.6937780976295471. Validation Accuracy: 49.28977272727273
Epoch: 112. Train Loss: 0.6946254372596741. Validation Accuracy: 49.71590909090909
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Epoch: 608. Train Loss: 0.6926811933517456. Validation Accuracy: 50.0

Epoch: 609. Train Loss: 0.6930792331695557. Validation Accuracy: 51.42045454545455

Epoch: 610. Train Loss: 0.6937698125839233. Validation Accuracy: 48.86363636363637

Epoch: 611. Train Loss: 0.691800057888031. Validation Accuracy:

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Epoch: 612. Train Loss: 0.6942204833030701. Validation Accuracy: 50.0

Epoch: 613. Train Loss: 0.6925076246261597. Validation Accuracy: 49.85795454545455

Epoch: 614. Train Loss: 0.6927917003631592. Validation Accuracy: 48.01136363636363

Epoch: 615. Train Loss: 0.6915349364280701. Validation Accuracy: 50.56818181818182

Epoch: 616. Train Loss: 0.6942788362503052. Validation Accuracy: 54.26136363636363

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Epoch: 625. Train Loss: 0.6931922435760498. Validation Accuracy: 50.0

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Epoch: 122. Train Loss: 0.6926579475402832. Validation Accuracy: 51.171875
Epoch: 123. Train Loss: 0.6905508041381836. Validation Accuracy: 53.125
Epoch: 124. Train Loss: 0.6938311457633972. Validation Accuracy: 50.0
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Epoch: 408. Train Loss: 0.6914803385734558. Validation Accuracy: 56.25
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Epoch: 410. Train Loss: 0.6837229132652283. Validation Accuracy: 52.734375
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Epoch: 412. Train Loss: 0.6957346796989441. Validation Accuracy: 51.5625
Epoch: 413. Train Loss: 0.6843662261962891. Validation Accuracy: 53.515625

Epoch: 414. Train Loss: 0.6890854835510254. Validation Accuracy: 48.828125
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 Epoch: 695. Train Loss: 0.6835216879844666. Validation Accuracy: 51.171875
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 Epoch: 697. Train Loss: 0.6863301396369934. Validation Accuracy: 53.90625
 Epoch: 698. Train Loss: 0.6919813752174377. Validation Accuracy: 53.515625
 Epoch: 699. Train Loss: 0.6830273270606995. Validation Accuracy: 53.125
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 Epoch: 701. Train Loss: 0.6991662383079529. Validation Accuracy: 52.34375

Epoch: 702. Train Loss: 0.6868879795074463. Validation Accuracy: 51.171875
Epoch: 703. Train Loss: 0.6908113956451416. Validation Accuracy: 56.640625
Epoch: 704. Train Loss: 0.6950451731681824. Validation Accuracy: 52.34375
Epoch: 705. Train Loss: 0.6932086944580078. Validation Accuracy: 54.6875
Epoch: 706. Train Loss: 0.6925234198570251. Validation Accuracy: 52.34375
Epoch: 707. Train Loss: 0.6936022043228149. Validation Accuracy: 50.0
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Epoch: 709. Train Loss: 0.6906089782714844. Validation Accuracy: 48.828125
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Epoch: 717. Train Loss: 0.684216320514679. Validation Accuracy: 50.78125
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Epoch: 749. Train Loss: 0.6904631853103638. Validation Accuracy: 50.0

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Epoch: 797. Train Loss: 0.6981648802757263. Validation Accuracy: 53.125

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Epoch: 975. Train Loss: 0.691095769405365. Validation Accuracy: 55.859375
Epoch: 976. Train Loss: 0.6775232553482056. Validation Accuracy: 51.953125
Epoch: 977. Train Loss: 0.667954683303833. Validation Accuracy: 55.46875
Epoch: 978. Train Loss: 0.6727506518363953. Validation Accuracy: 57.421875
Epoch: 979. Train Loss: 0.6667513251304626. Validation Accuracy: 54.6875
Epoch: 980. Train Loss: 0.6707004904747009. Validation Accuracy: 62.890625
Epoch: 981. Train Loss: 0.669970691204071. Validation Accuracy: 54.6875
Epoch: 982. Train Loss: 0.6699057221412659. Validation Accuracy: 56.25
Epoch: 983. Train Loss: 0.6732928156852722. Validation Accuracy: 58.59375
Epoch: 984. Train Loss: 0.6643874049186707. Validation Accuracy: 55.859375
Epoch: 985. Train Loss: 0.653533399105072. Validation Accuracy: 52.34375
Epoch: 986. Train Loss: 0.6713194847106934. Validation Accuracy: 55.078125
Epoch: 987. Train Loss: 0.6667420864105225. Validation Accuracy: 61.328125
Epoch: 988. Train Loss: 0.6617143750190735. Validation Accuracy: 66.015625
Epoch: 989. Train Loss: 0.6529558300971985. Validation Accuracy: 64.84375

Epoch: 990. Train Loss: 0.6596722602844238. Validation Accuracy: 59.765625
 Epoch: 991. Train Loss: 0.6690569519996643. Validation Accuracy: 62.109375
 Epoch: 992. Train Loss: 0.6456115245819092. Validation Accuracy: 62.5
 Epoch: 993. Train Loss: 0.6463494896888733. Validation Accuracy: 60.9375
 Epoch: 994. Train Loss: 0.6474302411079407. Validation Accuracy: 66.40625
 Epoch: 995. Train Loss: 0.6556908488273621. Validation Accuracy: 63.671875
 Epoch: 996. Train Loss: 0.6347458958625793. Validation Accuracy: 64.0625
 Epoch: 997. Train Loss: 0.6283671259880066. Validation Accuracy: 58.984375
 Epoch: 998. Train Loss: 0.6375563144683838. Validation Accuracy: 59.375
 Epoch: 999. Train Loss: 0.6274358630180359. Validation Accuracy: 61.328125
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 Epoch: 1. Train Loss: 0.7011897563934326. Validation Accuracy: 48.4375
 Epoch: 2. Train Loss: 0.6890587210655212. Validation Accuracy:
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 Epoch: 3. Train Loss: 0.6939333081245422. Validation Accuracy: 50.0
 Epoch: 4. Train Loss: 0.6940292716026306. Validation Accuracy:
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 Epoch: 5. Train Loss: 0.6920952796936035. Validation Accuracy:
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 Epoch: 6. Train Loss: 0.6972795128822327. Validation Accuracy:
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 Epoch: 7. Train Loss: 0.6937164664268494. Validation Accuracy:
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 Epoch: 8. Train Loss: 0.6964437365531921. Validation Accuracy:
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 Epoch: 9. Train Loss: 0.696477472782135. Validation Accuracy: 53.125
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 Epoch: 11. Train Loss: 0.6933035254478455. Validation Accuracy: 49.21875
 Epoch: 12. Train Loss: 0.6927101612091064. Validation Accuracy:
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 Epoch: 13. Train Loss: 0.6933630108833313. Validation Accuracy: 48.4375
 Epoch: 14. Train Loss: 0.6950945854187012. Validation Accuracy:
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 Epoch: 15. Train Loss: 0.6952666640281677. Validation Accuracy:
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 Epoch: 16. Train Loss: 0.6937205791473389. Validation Accuracy:
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 Epoch: 17. Train Loss: 0.6962401270866394. Validation Accuracy:
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 Epoch: 18. Train Loss: 0.6922280192375183. Validation Accuracy:
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 Epoch: 21. Train Loss: 0.6935405731201172. Validation Accuracy:
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 Epoch: 22. Train Loss: 0.6935554146766663. Validation Accuracy: 44.53125

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Epoch: 36. Train Loss: 0.6926531791687012. Validation Accuracy: 50.0
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Epoch: 40. Train Loss: 0.6938059329986572. Validation Accuracy: 53.645833333333336
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Epoch: 43. Train Loss: 0.6929399967193604. Validation Accuracy: 47.916666666666664
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Epoch: 50. Train Loss: 0.6914694905281067. Validation Accuracy:

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Epoch: 54. Train Loss: 0.6938003897666931. Validation Accuracy: 50.0
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Epoch: 60. Train Loss: 0.6915169358253479. Validation Accuracy: 55.208333333333336
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Epoch: 75. Train Loss: 0.6936743259429932. Validation Accuracy: 48.177083333333336
Epoch: 76. Train Loss: 0.6928150057792664. Validation Accuracy: 48.697916666666664
Epoch: 77. Train Loss: 0.6914262771606445. Validation Accuracy: 51.5625

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Epoch: 105. Train Loss: 0.6934581398963928. Validation Accuracy: 53.385416666666664

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Epoch: 246. Train Loss: 0.6930031180381775. Validation Accuracy: 51.041666666666664
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Epoch: 249. Train Loss: 0.6923525333404541. Validation Accuracy: 53.125
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Epoch: 508. Train Loss: 0.6950197815895081. Validation Accuracy:
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Epoch: 510. Train Loss: 0.6945138573646545. Validation Accuracy:
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Epoch: 595. Train Loss: 0.6949098706245422. Validation Accuracy: 51.302083333333336
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Epoch: 769. Train Loss: 0.692396879196167. Validation Accuracy: 50.0
Epoch: 770. Train Loss: 0.6937246918678284. Validation Accuracy: 51.5625

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Epoch: 776. Train Loss: 0.6927050948143005. Validation Accuracy: 51.041666666666664
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Epoch: 787. Train Loss: 0.692702054977417. Validation Accuracy: 52.083333333333336
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Epoch: 789. Train Loss: 0.6921322345733643. Validation Accuracy: 44.53125
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Epoch: 794. Train Loss: 0.6937779784202576. Validation Accuracy: 52.083333333333336
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Epoch: 802. Train Loss: 0.6937152743339539. Validation Accuracy: 50.78125
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Epoch: 3. Train Loss: 0.6936200261116028. Validation Accuracy: 49.14772727272727
Epoch: 4. Train Loss: 0.6928936839103699. Validation Accuracy: 48.4375
Epoch: 5. Train Loss: 0.693376362323761. Validation Accuracy: 49.85795454545455
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Epoch: 27. Train Loss: 0.6934416890144348. Validation Accuracy:
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Epoch: 28. Train Loss: 0.6930121779441833. Validation Accuracy:
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Epoch: 29. Train Loss: 0.6937627196311951. Validation Accuracy: 51.5625
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Epoch: 775. Train Loss: 0.6927779912948608. Validation Accuracy: 49.85795454545455
Epoch: 776. Train Loss: 0.6930844783782959. Validation Accuracy: 46.16477272727273
Epoch: 777. Train Loss: 0.6932744383811951. Validation Accuracy: 48.57954545454545
Epoch: 778. Train Loss: 0.6933789849281311. Validation Accuracy: 50.99431818181818
Epoch: 779. Train Loss: 0.69277024269104. Validation Accuracy: 49.57386363636363
Epoch: 780. Train Loss: 0.6919878125190735. Validation Accuracy: 50.85227272727273
Epoch: 781. Train Loss: 0.6931257843971252. Validation Accuracy: 49.85795454545455
Epoch: 782. Train Loss: 0.693211555480957. Validation Accuracy: 52.98295454545455
Epoch: 783. Train Loss: 0.6940950155258179. Validation Accuracy: 47.58522727272727
Epoch: 784. Train Loss: 0.6930409669876099. Validation Accuracy: 53.26704545454545
Epoch: 785. Train Loss: 0.6929945945739746. Validation Accuracy: 47.72727272727273
Epoch: 786. Train Loss: 0.6921745538711548. Validation Accuracy: 46.73295454545455
Epoch: 787. Train Loss: 0.6940277814865112. Validation Accuracy: 52.84090909090909
Epoch: 788. Train Loss: 0.6936436295509338. Validation Accuracy: 48.15340909090909

Epoch: 789. Train Loss: 0.6934627890586853. Validation Accuracy: 47.72727272727273
Epoch: 790. Train Loss: 0.6930146813392639. Validation Accuracy: 50.56818181818182
Epoch: 791. Train Loss: 0.693344235420227. Validation Accuracy: 48.86363636363637
Epoch: 792. Train Loss: 0.6929087042808533. Validation Accuracy: 48.57954545454545
Epoch: 793. Train Loss: 0.693930447101593. Validation Accuracy: 47.01704545454545
Epoch: 794. Train Loss: 0.6928665637969971. Validation Accuracy: 51.27840909090909
Epoch: 795. Train Loss: 0.6927022337913513. Validation Accuracy: 49.00568181818182
Epoch: 796. Train Loss: 0.693510890007019. Validation Accuracy: 49.28977272727273
Epoch: 797. Train Loss: 0.6930848956108093. Validation Accuracy: 49.28977272727273
Epoch: 798. Train Loss: 0.692436158657074. Validation Accuracy: 51.98863636363637
Epoch: 799. Train Loss: 0.6932596564292908. Validation Accuracy: 49.14772727272727
Epoch: 800. Train Loss: 0.6926916837692261. Validation Accuracy: 51.13636363636363
Epoch: 801. Train Loss: 0.6935529708862305. Validation Accuracy: 51.70454545454545
Epoch: 802. Train Loss: 0.6927953362464905. Validation Accuracy: 50.28409090909091
Epoch: 803. Train Loss: 0.6930420398712158. Validation Accuracy: 48.86363636363637
Epoch: 804. Train Loss: 0.6935978531837463. Validation Accuracy: 50.0
Epoch: 805. Train Loss: 0.6935014724731445. Validation Accuracy: 50.28409090909091
Epoch: 806. Train Loss: 0.6933241486549377. Validation Accuracy: 50.42613636363637
Epoch: 807. Train Loss: 0.693295419216156. Validation Accuracy: 47.44318181818182
Epoch: 808. Train Loss: 0.6930376887321472. Validation Accuracy: 49.57386363636363
Epoch: 809. Train Loss: 0.693098783493042. Validation Accuracy: 51.13636363636363
Epoch: 810. Train Loss: 0.6933413147926331. Validation Accuracy: 50.42613636363637
Epoch: 811. Train Loss: 0.6934669017791748. Validation Accuracy: 49.14772727272727
Epoch: 812. Train Loss: 0.6928936839103699. Validation Accuracy: 47.44318181818182
Epoch: 813. Train Loss: 0.6932160258293152. Validation Accuracy:

47.72727272727273

Epoch: 814. Train Loss: 0.6933521032333374. Validation Accuracy:
51.13636363636363

Epoch: 815. Train Loss: 0.693250298500061. Validation Accuracy:
48.15340909090909

Epoch: 816. Train Loss: 0.6930217146873474. Validation Accuracy:
47.30113636363637

Epoch: 817. Train Loss: 0.6930657029151917. Validation Accuracy:
47.86931818181818

Epoch: 818. Train Loss: 0.6931040287017822. Validation Accuracy:
48.57954545454545

Epoch: 819. Train Loss: 0.692995548248291. Validation Accuracy:
49.57386363636363

Epoch: 820. Train Loss: 0.6933450102806091. Validation Accuracy:
49.28977272727273

Epoch: 821. Train Loss: 0.693303644657135. Validation Accuracy:
49.43181818181818

Epoch: 822. Train Loss: 0.6931973695755005. Validation Accuracy:
48.01136363636363

Epoch: 823. Train Loss: 0.6931712031364441. Validation Accuracy:
49.14772727272727

Epoch: 824. Train Loss: 0.6930646896362305. Validation Accuracy:
51.27840909090909

Epoch: 825. Train Loss: 0.6928517818450928. Validation Accuracy:
49.71590909090909

Epoch: 826. Train Loss: 0.693369448184967. Validation Accuracy:
52.41477272727273

Epoch: 827. Train Loss: 0.6932311654090881. Validation Accuracy:
49.14772727272727

Epoch: 828. Train Loss: 0.6929043531417847. Validation Accuracy:
51.27840909090909

Epoch: 829. Train Loss: 0.6923782229423523. Validation Accuracy:
49.71590909090909

Epoch: 830. Train Loss: 0.6940664649009705. Validation Accuracy:
49.71590909090909

Epoch: 831. Train Loss: 0.6930088996887207. Validation Accuracy:
49.14772727272727

Epoch: 832. Train Loss: 0.6928538680076599. Validation Accuracy:
49.43181818181818

Epoch: 833. Train Loss: 0.6932114958763123. Validation Accuracy:
49.57386363636363

Epoch: 834. Train Loss: 0.6936152577400208. Validation Accuracy:
51.84659090909091

Epoch: 835. Train Loss: 0.6932927966117859. Validation Accuracy:
49.57386363636363

Epoch: 836. Train Loss: 0.6936673521995544. Validation Accuracy:
47.44318181818182

Epoch: 837. Train Loss: 0.6926032304763794. Validation Accuracy:

53.40909090909091
Epoch: 838. Train Loss: 0.6930197477340698. Validation Accuracy: 50.71022727272727
Epoch: 839. Train Loss: 0.693953275680542. Validation Accuracy: 53.26704545454545
Epoch: 840. Train Loss: 0.692941427230835. Validation Accuracy: 51.5625
Epoch: 841. Train Loss: 0.6929755806922913. Validation Accuracy: 51.27840909090909
Epoch: 842. Train Loss: 0.6934085488319397. Validation Accuracy: 48.72159090909091
Epoch: 843. Train Loss: 0.6935771107673645. Validation Accuracy: 50.56818181818182
Epoch: 844. Train Loss: 0.6929312348365784. Validation Accuracy: 50.71022727272727
Epoch: 845. Train Loss: 0.6930320262908936. Validation Accuracy: 45.59659090909091
Epoch: 846. Train Loss: 0.6931843757629395. Validation Accuracy: 47.58522727272727
Epoch: 847. Train Loss: 0.6928807497024536. Validation Accuracy: 48.01136363636363
Epoch: 848. Train Loss: 0.6931825876235962. Validation Accuracy: 46.875
Epoch: 849. Train Loss: 0.6932353377342224. Validation Accuracy: 51.42045454545455
Epoch: 850. Train Loss: 0.6933059096336365. Validation Accuracy: 50.56818181818182
Epoch: 851. Train Loss: 0.6933389902114868. Validation Accuracy: 48.15340909090909
Epoch: 852. Train Loss: 0.6930415630340576. Validation Accuracy: 48.29545454545455
Epoch: 853. Train Loss: 0.6932395100593567. Validation Accuracy: 49.00568181818182
Epoch: 854. Train Loss: 0.6931218504905701. Validation Accuracy: 50.56818181818182
Epoch: 855. Train Loss: 0.693120539188385. Validation Accuracy: 50.85227272727273
Epoch: 856. Train Loss: 0.6930814981460571. Validation Accuracy: 50.99431818181818
Epoch: 857. Train Loss: 0.6928088068962097. Validation Accuracy: 52.98295454545455
Epoch: 858. Train Loss: 0.6931350231170654. Validation Accuracy: 50.85227272727273
Epoch: 859. Train Loss: 0.6930021047592163. Validation Accuracy: 48.29545454545455
Epoch: 860. Train Loss: 0.6932839155197144. Validation Accuracy: 51.13636363636363
Epoch: 861. Train Loss: 0.69284987449646. Validation Accuracy: 52.41477272727273
Epoch: 862. Train Loss: 0.69355708360672. Validation Accuracy: 48.29545454545455
Epoch: 863. Train Loss: 0.693240761756897. Validation Accuracy:

47.58522727272727
Epoch: 864. Train Loss: 0.6926368474960327. Validation Accuracy: 47.86931818181818
Epoch: 865. Train Loss: 0.692846417427063. Validation Accuracy: 49.14772727272727
Epoch: 866. Train Loss: 0.6931463479995728. Validation Accuracy: 48.72159090909091
Epoch: 867. Train Loss: 0.6939566135406494. Validation Accuracy: 50.56818181818182
Epoch: 868. Train Loss: 0.6938871741294861. Validation Accuracy: 49.57386363636363
Epoch: 869. Train Loss: 0.6932664513587952. Validation Accuracy: 50.85227272727273
Epoch: 870. Train Loss: 0.6937984824180603. Validation Accuracy: 48.29545454545455
Epoch: 871. Train Loss: 0.6936629414558411. Validation Accuracy: 49.43181818181818
Epoch: 872. Train Loss: 0.6933302879333496. Validation Accuracy: 49.57386363636363
Epoch: 873. Train Loss: 0.6934759616851807. Validation Accuracy: 50.14204545454545
Epoch: 874. Train Loss: 0.6939024925231934. Validation Accuracy: 51.42045454545455
Epoch: 875. Train Loss: 0.6930040717124939. Validation Accuracy: 50.42613636363637
Epoch: 876. Train Loss: 0.6934163570404053. Validation Accuracy: 51.70454545454545
Epoch: 877. Train Loss: 0.6932245492935181. Validation Accuracy: 49.57386363636363
Epoch: 878. Train Loss: 0.6929905414581299. Validation Accuracy: 50.85227272727273
Epoch: 879. Train Loss: 0.6931774616241455. Validation Accuracy: 50.42613636363637
Epoch: 880. Train Loss: 0.6929823756217957. Validation Accuracy: 47.30113636363637
Epoch: 881. Train Loss: 0.6931262016296387. Validation Accuracy: 51.27840909090909
Epoch: 882. Train Loss: 0.6933135986328125. Validation Accuracy: 51.70454545454545
Epoch: 883. Train Loss: 0.6934059262275696. Validation Accuracy: 52.98295454545455
Epoch: 884. Train Loss: 0.6935452818870544. Validation Accuracy: 48.15340909090909
Epoch: 885. Train Loss: 0.6932544112205505. Validation Accuracy: 48.4375
Epoch: 886. Train Loss: 0.6930409669876099. Validation Accuracy: 48.72159090909091
Epoch: 887. Train Loss: 0.6931518316268921. Validation Accuracy: 52.13068181818182

Epoch: 888. Train Loss: 0.6930708289146423. Validation Accuracy: 50.85227272727273
Epoch: 889. Train Loss: 0.6939163208007812. Validation Accuracy: 53.69318181818182
Epoch: 890. Train Loss: 0.6931116580963135. Validation Accuracy: 49.85795454545455
Epoch: 891. Train Loss: 0.6930604577064514. Validation Accuracy: 53.69318181818182
Epoch: 892. Train Loss: 0.69272381067276. Validation Accuracy: 50.0
Epoch: 893. Train Loss: 0.6934436559677124. Validation Accuracy: 51.5625
Epoch: 894. Train Loss: 0.6941356062889099. Validation Accuracy: 51.13636363636363
Epoch: 895. Train Loss: 0.6938591599464417. Validation Accuracy: 50.0
Epoch: 896. Train Loss: 0.6931604743003845. Validation Accuracy: 49.57386363636363
Epoch: 897. Train Loss: 0.6933431029319763. Validation Accuracy: 52.13068181818182
Epoch: 898. Train Loss: 0.6933817863464355. Validation Accuracy: 48.86363636363637
Epoch: 899. Train Loss: 0.6927934885025024. Validation Accuracy: 47.72727272727273
Epoch: 900. Train Loss: 0.6931488513946533. Validation Accuracy: 50.14204545454545
Epoch: 901. Train Loss: 0.6933971047401428. Validation Accuracy: 45.88068181818182
Epoch: 902. Train Loss: 0.69347083568573. Validation Accuracy: 52.69886363636363
Epoch: 903. Train Loss: 0.6932019591331482. Validation Accuracy: 49.00568181818182
Epoch: 904. Train Loss: 0.6929383873939514. Validation Accuracy: 51.42045454545455
Epoch: 905. Train Loss: 0.6928814053535461. Validation Accuracy: 50.99431818181818
Epoch: 906. Train Loss: 0.6929992437362671. Validation Accuracy: 50.99431818181818
Epoch: 907. Train Loss: 0.6929284334182739. Validation Accuracy: 49.57386363636363
Epoch: 908. Train Loss: 0.693375825881958. Validation Accuracy: 47.30113636363637
Epoch: 909. Train Loss: 0.6931552290916443. Validation Accuracy: 50.28409090909091
Epoch: 910. Train Loss: 0.6931690573692322. Validation Accuracy: 49.85795454545455
Epoch: 911. Train Loss: 0.6932463049888611. Validation Accuracy: 49.71590909090909
Epoch: 912. Train Loss: 0.6933594346046448. Validation Accuracy: 48.01136363636363
Epoch: 913. Train Loss: 0.6931260228157043. Validation Accuracy: 50.56818181818182

Epoch: 914. Train Loss: 0.693271815776825. Validation Accuracy: 50.42613636363637
Epoch: 915. Train Loss: 0.6930465698242188. Validation Accuracy: 54.54545454545455
Epoch: 916. Train Loss: 0.6929214596748352. Validation Accuracy: 46.30681818181818
Epoch: 917. Train Loss: 0.6932889223098755. Validation Accuracy: 48.72159090909091
Epoch: 918. Train Loss: 0.6930692195892334. Validation Accuracy: 50.14204545454545
Epoch: 919. Train Loss: 0.6929658055305481. Validation Accuracy: 48.4375
Epoch: 920. Train Loss: 0.6931834816932678. Validation Accuracy: 51.13636363636363
Epoch: 921. Train Loss: 0.6929469704627991. Validation Accuracy: 53.125
Epoch: 922. Train Loss: 0.6932426691055298. Validation Accuracy: 50.14204545454545
Epoch: 923. Train Loss: 0.6930375695228577. Validation Accuracy: 50.71022727272727
Epoch: 924. Train Loss: 0.6932604312896729. Validation Accuracy: 50.0
Epoch: 925. Train Loss: 0.6930381059646606. Validation Accuracy: 47.01704545454545
Epoch: 926. Train Loss: 0.693165123462677. Validation Accuracy: 51.84659090909091
Epoch: 927. Train Loss: 0.6932465434074402. Validation Accuracy: 50.85227272727273
Epoch: 928. Train Loss: 0.6932314038276672. Validation Accuracy: 48.4375
Epoch: 929. Train Loss: 0.693061888217926. Validation Accuracy: 46.16477272727273
Epoch: 930. Train Loss: 0.6930813193321228. Validation Accuracy: 53.125
Epoch: 931. Train Loss: 0.693170964717865. Validation Accuracy: 47.01704545454545
Epoch: 932. Train Loss: 0.6932847499847412. Validation Accuracy: 50.28409090909091
Epoch: 933. Train Loss: 0.6933121085166931. Validation Accuracy: 49.14772727272727
Epoch: 934. Train Loss: 0.6930352449417114. Validation Accuracy: 55.53977272727273
Epoch: 935. Train Loss: 0.6933193802833557. Validation Accuracy: 47.15909090909091
Epoch: 936. Train Loss: 0.6931096911430359. Validation Accuracy: 49.14772727272727
Epoch: 937. Train Loss: 0.6929914951324463. Validation Accuracy: 47.15909090909091
Epoch: 938. Train Loss: 0.6934221386909485. Validation Accuracy: 51.27840909090909
Epoch: 939. Train Loss: 0.6932438611984253. Validation Accuracy: 47.01704545454545
Epoch: 940. Train Loss: 0.6931631565093994. Validation Accuracy:

50.71022727272727

Epoch: 941. Train Loss: 0.69327712059021. Validation Accuracy: 51.84659090909091

Epoch: 942. Train Loss: 0.6929810047149658. Validation Accuracy: 48.86363636363637

Epoch: 943. Train Loss: 0.6926138997077942. Validation Accuracy: 49.28977272727273

Epoch: 944. Train Loss: 0.6929474472999573. Validation Accuracy: 51.84659090909091

Epoch: 945. Train Loss: 0.6935046315193176. Validation Accuracy: 50.28409090909091

Epoch: 946. Train Loss: 0.6932689547538757. Validation Accuracy: 51.13636363636363

Epoch: 947. Train Loss: 0.6931660175323486. Validation Accuracy: 50.56818181818182

Epoch: 948. Train Loss: 0.6937822103500366. Validation Accuracy: 50.14204545454545

Epoch: 949. Train Loss: 0.6930539011955261. Validation Accuracy: 51.27840909090909

Epoch: 950. Train Loss: 0.6933198571205139. Validation Accuracy: 50.0

Epoch: 951. Train Loss: 0.6930091977119446. Validation Accuracy: 46.44886363636363

Epoch: 952. Train Loss: 0.6930510997772217. Validation Accuracy: 51.27840909090909

Epoch: 953. Train Loss: 0.6933055520057678. Validation Accuracy: 47.44318181818182

Epoch: 954. Train Loss: 0.6931795477867126. Validation Accuracy: 51.98863636363637

Epoch: 955. Train Loss: 0.6932030320167542. Validation Accuracy: 53.55113636363637

Epoch: 956. Train Loss: 0.6932539939880371. Validation Accuracy: 49.28977272727273

Epoch: 957. Train Loss: 0.6931413412094116. Validation Accuracy: 49.71590909090909

Epoch: 958. Train Loss: 0.6928501725196838. Validation Accuracy: 48.72159090909091

Epoch: 959. Train Loss: 0.6929084658622742. Validation Accuracy: 48.4375

Epoch: 960. Train Loss: 0.692925214767456. Validation Accuracy: 50.42613636363637

Epoch: 961. Train Loss: 0.6929150819778442. Validation Accuracy: 51.42045454545455

Epoch: 962. Train Loss: 0.6928549408912659. Validation Accuracy: 52.13068181818182

Epoch: 963. Train Loss: 0.693070113658905. Validation Accuracy: 51.5625

Epoch: 964. Train Loss: 0.6933093070983887. Validation Accuracy: 50.71022727272727

Epoch: 965. Train Loss: 0.6930660605430603. Validation Accuracy: 48.4375

Epoch: 966. Train Loss: 0.6936168074607849. Validation Accuracy: 51.27840909090909

Epoch: 967. Train Loss: 0.6932551860809326. Validation Accuracy: 49.85795454545455
 Epoch: 968. Train Loss: 0.6931164264678955. Validation Accuracy: 52.55681818181818
 Epoch: 969. Train Loss: 0.6934688687324524. Validation Accuracy: 53.26704545454545
 Epoch: 970. Train Loss: 0.6933313012123108. Validation Accuracy: 46.59090909090909
 Epoch: 971. Train Loss: 0.6931993365287781. Validation Accuracy: 50.28409090909091
 Epoch: 972. Train Loss: 0.6932412385940552. Validation Accuracy: 50.0
 Epoch: 973. Train Loss: 0.6928842067718506. Validation Accuracy: 50.56818181818182
 Epoch: 974. Train Loss: 0.6935358047485352. Validation Accuracy: 50.85227272727273
 Epoch: 975. Train Loss: 0.6935955882072449. Validation Accuracy: 48.4375
 Epoch: 976. Train Loss: 0.6934636235237122. Validation Accuracy: 50.71022727272727
 Epoch: 977. Train Loss: 0.6936995387077332. Validation Accuracy: 51.5625
 Epoch: 978. Train Loss: 0.6931146383285522. Validation Accuracy: 51.42045454545455
 Epoch: 979. Train Loss: 0.6930666565895081. Validation Accuracy: 50.14204545454545
 Epoch: 980. Train Loss: 0.6932499408721924. Validation Accuracy: 49.00568181818182
 Epoch: 981. Train Loss: 0.6930887699127197. Validation Accuracy: 50.85227272727273
 Epoch: 982. Train Loss: 0.6932771801948547. Validation Accuracy: 52.84090909090909
 Epoch: 983. Train Loss: 0.6926270723342896. Validation Accuracy: 51.98863636363637
 Epoch: 984. Train Loss: 0.6927060484886169. Validation Accuracy: 49.43181818181818
 Epoch: 985. Train Loss: 0.6932717561721802. Validation Accuracy: 51.13636363636363
 Epoch: 986. Train Loss: 0.6932505965232849. Validation Accuracy: 48.01136363636363
 Epoch: 987. Train Loss: 0.6933627128601074. Validation Accuracy: 49.57386363636363
 Epoch: 988. Train Loss: 0.6914443373680115. Validation Accuracy: 50.71022727272727
 Epoch: 989. Train Loss: 0.6932187676429749. Validation Accuracy: 51.27840909090909
 Epoch: 990. Train Loss: 0.693087100982666. Validation Accuracy: 50.85227272727273
 Epoch: 991. Train Loss: 0.6941583752632141. Validation Accuracy: 50.0
 Epoch: 992. Train Loss: 0.6926186680793762. Validation Accuracy: 50.71022727272727

Epoch: 993. Train Loss: 0.6935031414031982. Validation Accuracy: 49.43181818181818
 Epoch: 994. Train Loss: 0.6933528184890747. Validation Accuracy: 48.29545454545455
 Epoch: 995. Train Loss: 0.6929429769515991. Validation Accuracy: 48.29545454545455
 Epoch: 996. Train Loss: 0.6924874782562256. Validation Accuracy: 46.30681818181818
 Epoch: 997. Train Loss: 0.6944628357887268. Validation Accuracy: 49.71590909090909
 Epoch: 998. Train Loss: 0.6938580870628357. Validation Accuracy: 49.28977272727273
 Epoch: 999. Train Loss: 0.6934323310852051. Validation Accuracy: 46.73295454545455

```
[34]: print(f"Best Parameters: Num Layers: {best_params[0]}, Hidden State Size: {best_params[1]}, Length of Input: {best_params[2]}")
      print(f"Best Validation Accuracy: {best_accuracy}")
```

Best Parameters: Num Layers: 3, Hidden State Size: 5, Length of Input: 3
 Best Validation Accuracy: 76.328125

We'll use 3 layers for our experiments going ahead.

9.5 Common Hyperparameters and model setup

```
[54]: INPUT_DIM = 2
      OUTPUT_DIM = 2
      NUM_LAYERS = 3
      LR = 0.001
      K = 64
```

9.6 Length of Input Sequence = 5

```
[55]: L = 5
```

9.6.1 Hidden State Size = 2

```
[56]: HIDDEN_DIM = 2
```

```
[57]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
      criterion = nn.CrossEntropyLoss()
      optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[58]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion, optimizer, K, L)
```

Epoch: 0. Train Loss: 0.6957761645317078. Validation Accuracy: 50.0
Epoch: 1. Train Loss: 0.703092634677887. Validation Accuracy: 47.65625
Epoch: 2. Train Loss: 0.6923783421516418. Validation Accuracy: 54.6875
Epoch: 3. Train Loss: 0.6939404606819153. Validation Accuracy: 50.0
Epoch: 4. Train Loss: 0.7003850340843201. Validation Accuracy:
52.083333333333336
Epoch: 5. Train Loss: 0.6947600841522217. Validation Accuracy: 52.34375
Epoch: 6. Train Loss: 0.6980153918266296. Validation Accuracy:
49.739583333333336
Epoch: 7. Train Loss: 0.6931083798408508. Validation Accuracy: 49.21875
Epoch: 8. Train Loss: 0.6992072463035583. Validation Accuracy:
51.041666666666664
Epoch: 9. Train Loss: 0.6934331059455872. Validation Accuracy:
48.697916666666664
Epoch: 10. Train Loss: 0.6988725662231445. Validation Accuracy:
50.260416666666664
Epoch: 11. Train Loss: 0.7001850008964539. Validation Accuracy:
51.822916666666664
Epoch: 12. Train Loss: 0.7016766667366028. Validation Accuracy:
48.958333333333336
Epoch: 13. Train Loss: 0.6975440382957458. Validation Accuracy:
48.958333333333336
Epoch: 14. Train Loss: 0.6977971196174622. Validation Accuracy:
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Epoch: 15. Train Loss: 0.6893685460090637. Validation Accuracy:
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Epoch: 16. Train Loss: 0.6958773136138916. Validation Accuracy:
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Epoch: 19. Train Loss: 0.69786137342453. Validation Accuracy: 50.78125
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Epoch: 276. Train Loss: 0.6933594346046448. Validation Accuracy: 51.822916666666664

Epoch: 277. Train Loss: 0.6934885382652283. Validation Accuracy: 48.697916666666664

Epoch: 278. Train Loss: 0.6928210258483887. Validation Accuracy: 53.645833333333336

Epoch: 279. Train Loss: 0.6930770874023438. Validation Accuracy: 50.260416666666664

Epoch: 280. Train Loss: 0.6933531165122986. Validation Accuracy: 48.177083333333336

Epoch: 281. Train Loss: 0.6932856440544128. Validation Accuracy: 48.697916666666664

Epoch: 282. Train Loss: 0.6932458877563477. Validation Accuracy: 50.0

Epoch: 283. Train Loss: 0.6931226253509521. Validation Accuracy:

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Epoch: 284. Train Loss: 0.6934041976928711. Validation Accuracy: 47.916666666666664
Epoch: 285. Train Loss: 0.6930760741233826. Validation Accuracy: 48.177083333333336
Epoch: 286. Train Loss: 0.6928609013557434. Validation Accuracy: 51.5625
Epoch: 287. Train Loss: 0.6936008334159851. Validation Accuracy: 47.65625
Epoch: 288. Train Loss: 0.6936402916908264. Validation Accuracy: 49.739583333333336
Epoch: 289. Train Loss: 0.6930716633796692. Validation Accuracy: 50.260416666666664
Epoch: 290. Train Loss: 0.6934980750083923. Validation Accuracy: 51.5625
Epoch: 291. Train Loss: 0.6934943795204163. Validation Accuracy: 52.604166666666664
Epoch: 292. Train Loss: 0.6931235194206238. Validation Accuracy: 51.041666666666664
Epoch: 293. Train Loss: 0.6929726004600525. Validation Accuracy: 52.34375
Epoch: 294. Train Loss: 0.6931858658790588. Validation Accuracy: 48.177083333333336
Epoch: 295. Train Loss: 0.6931378245353699. Validation Accuracy: 47.135416666666664
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Epoch: 297. Train Loss: 0.6932064890861511. Validation Accuracy: 52.34375
Epoch: 298. Train Loss: 0.6935856342315674. Validation Accuracy: 54.166666666666664
Epoch: 299. Train Loss: 0.6931940913200378. Validation Accuracy: 45.3125
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Epoch: 301. Train Loss: 0.6933419108390808. Validation Accuracy: 53.645833333333336
Epoch: 302. Train Loss: 0.6932122707366943. Validation Accuracy: 48.958333333333336
Epoch: 303. Train Loss: 0.6929497718811035. Validation Accuracy: 44.270833333333336
Epoch: 304. Train Loss: 0.693234384059906. Validation Accuracy: 48.4375
Epoch: 305. Train Loss: 0.693240225315094. Validation Accuracy: 48.177083333333336
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Epoch: 307. Train Loss: 0.6930325031280518. Validation Accuracy: 48.958333333333336
Epoch: 308. Train Loss: 0.6932804584503174. Validation Accuracy: 49.479166666666664
Epoch: 309. Train Loss: 0.6932551264762878. Validation Accuracy: 53.645833333333336
Epoch: 310. Train Loss: 0.6933593153953552. Validation Accuracy: 48.697916666666664
Epoch: 311. Train Loss: 0.6931464076042175. Validation Accuracy: 50.260416666666664

Epoch: 312. Train Loss: 0.6935542225837708. Validation Accuracy: 52.604166666666664
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Epoch: 315. Train Loss: 0.692744255065918. Validation Accuracy: 45.3125
Epoch: 316. Train Loss: 0.6931607127189636. Validation Accuracy: 50.260416666666664
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Epoch: 318. Train Loss: 0.692837655544281. Validation Accuracy: 50.0
Epoch: 319. Train Loss: 0.6930056214332581. Validation Accuracy: 51.041666666666664
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Epoch: 333. Train Loss: 0.6932561993598938. Validation Accuracy: 51.041666666666664
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Epoch: 336. Train Loss: 0.6924936175346375. Validation Accuracy: 50.260416666666664
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51.302083333333336
Epoch: 345. Train Loss: 0.693056583404541. Validation Accuracy:
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52.083333333333336
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47.135416666666664
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Epoch: 355. Train Loss: 0.6930892467498779. Validation Accuracy:
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Epoch: 359. Train Loss: 0.6933672428131104. Validation Accuracy: 49.21875
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Epoch: 361. Train Loss: 0.6929619312286377. Validation Accuracy:
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Epoch: 363. Train Loss: 0.6932709813117981. Validation Accuracy:
48.697916666666664
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Epoch: 365. Train Loss: 0.6931524276733398. Validation Accuracy: 45.3125
Epoch: 366. Train Loss: 0.693271815776825. Validation Accuracy:
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Epoch: 367. Train Loss: 0.6931832432746887. Validation Accuracy:
42.447916666666664

Epoch: 368. Train Loss: 0.6927599906921387. Validation Accuracy: 50.260416666666664
Epoch: 369. Train Loss: 0.6928961277008057. Validation Accuracy: 52.083333333333336
Epoch: 370. Train Loss: 0.6932986378669739. Validation Accuracy: 51.041666666666664
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Epoch: 373. Train Loss: 0.6931337714195251. Validation Accuracy: 48.697916666666664
Epoch: 374. Train Loss: 0.6938114166259766. Validation Accuracy: 50.0
Epoch: 375. Train Loss: 0.6929746270179749. Validation Accuracy: 42.708333333333336
Epoch: 376. Train Loss: 0.6931894421577454. Validation Accuracy: 50.78125
Epoch: 377. Train Loss: 0.693054735660553. Validation Accuracy: 46.09375
Epoch: 378. Train Loss: 0.6932451128959656. Validation Accuracy: 47.135416666666664
Epoch: 379. Train Loss: 0.6933665871620178. Validation Accuracy: 50.78125
Epoch: 380. Train Loss: 0.6935147643089294. Validation Accuracy: 40.885416666666664
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Epoch: 382. Train Loss: 0.6933462023735046. Validation Accuracy: 47.135416666666664
Epoch: 383. Train Loss: 0.6929536461830139. Validation Accuracy: 48.177083333333336
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Epoch: 385. Train Loss: 0.6931912899017334. Validation Accuracy: 45.572916666666664
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Epoch: 403. Train Loss: 0.6932039856910706. Validation Accuracy: 50.78125
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Epoch: 408. Train Loss: 0.6930535435676575. Validation Accuracy: 46.09375
Epoch: 409. Train Loss: 0.6929412484169006. Validation Accuracy:
45.833333333333336
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51.822916666666664
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Epoch: 413. Train Loss: 0.6934924125671387. Validation Accuracy:
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Epoch: 507. Train Loss: 0.6928892731666565. Validation Accuracy:
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Epoch: 516. Train Loss: 0.6926774382591248. Validation Accuracy: 50.78125

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Epoch: 524. Train Loss: 0.6929824948310852. Validation Accuracy: 45.833333333333336

Epoch: 525. Train Loss: 0.6930901408195496. Validation Accuracy: 48.177083333333336

Epoch: 526. Train Loss: 0.6932913661003113. Validation Accuracy: 52.34375

Epoch: 527. Train Loss: 0.6928067207336426. Validation Accuracy: 48.958333333333336

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Epoch: 533. Train Loss: 0.6931121349334717. Validation Accuracy: 51.5625

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Epoch: 536. Train Loss: 0.6928738951683044. Validation Accuracy: 52.083333333333336

Epoch: 537. Train Loss: 0.6929755210876465. Validation Accuracy: 48.958333333333336

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Epoch: 541. Train Loss: 0.6925140023231506. Validation Accuracy: 55.208333333333336
Epoch: 542. Train Loss: 0.6928191781044006. Validation Accuracy: 54.166666666666664
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Epoch: 545. Train Loss: 0.6927685141563416. Validation Accuracy: 52.083333333333336
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Epoch: 615. Train Loss: 0.6916831135749817. Validation Accuracy: 54.6875
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Epoch: 776. Train Loss: 0.6580851674079895. Validation Accuracy:
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Epoch: 777. Train Loss: 0.6507128477096558. Validation Accuracy: 63.28125

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Epoch: 780. Train Loss: 0.649164080619812. Validation Accuracy: 73.4375
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Epoch: 782. Train Loss: 0.6453879475593567. Validation Accuracy: 74.21875
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Epoch: 801. Train Loss: 0.6385491490364075. Validation Accuracy: 65.625
Epoch: 802. Train Loss: 0.6550609469413757. Validation Accuracy:
61.97916666666664
Epoch: 803. Train Loss: 0.6582152247428894. Validation Accuracy: 68.75
Epoch: 804. Train Loss: 0.6511738896369934. Validation Accuracy:
65.88541666666667
Epoch: 805. Train Loss: 0.6378100514411926. Validation Accuracy:
71.61458333333333
Epoch: 806. Train Loss: 0.6353749632835388. Validation Accuracy:
65.36458333333333
Epoch: 807. Train Loss: 0.6430880427360535. Validation Accuracy:
65.10416666666667

Epoch: 808. Train Loss: 0.6497916579246521. Validation Accuracy: 63.802083333333336
Epoch: 809. Train Loss: 0.6437621712684631. Validation Accuracy: 61.71875
Epoch: 810. Train Loss: 0.6445543169975281. Validation Accuracy: 69.79166666666667
Epoch: 811. Train Loss: 0.6691737771034241. Validation Accuracy: 57.552083333333336
Epoch: 812. Train Loss: 0.6518020629882812. Validation Accuracy: 62.760416666666664
Epoch: 813. Train Loss: 0.63705974817276. Validation Accuracy: 68.48958333333333
Epoch: 814. Train Loss: 0.6390507221221924. Validation Accuracy: 64.84375
Epoch: 815. Train Loss: 0.6531580686569214. Validation Accuracy: 69.53125
Epoch: 816. Train Loss: 0.640733540058136. Validation Accuracy: 67.1875
Epoch: 817. Train Loss: 0.6290254592895508. Validation Accuracy: 65.625
Epoch: 818. Train Loss: 0.6257136464118958. Validation Accuracy: 61.71875
Epoch: 819. Train Loss: 0.6367356181144714. Validation Accuracy: 65.36458333333333
Epoch: 820. Train Loss: 0.6326544880867004. Validation Accuracy: 65.625
Epoch: 821. Train Loss: 0.6665012240409851. Validation Accuracy: 62.760416666666664
Epoch: 822. Train Loss: 0.6474499106407166. Validation Accuracy: 70.83333333333333
Epoch: 823. Train Loss: 0.6315622925758362. Validation Accuracy: 66.14583333333333
Epoch: 824. Train Loss: 0.640753984451294. Validation Accuracy: 65.625
Epoch: 825. Train Loss: 0.6447990536689758. Validation Accuracy: 67.1875
Epoch: 826. Train Loss: 0.6297905445098877. Validation Accuracy: 71.09375
Epoch: 827. Train Loss: 0.6513535380363464. Validation Accuracy: 67.44791666666667
Epoch: 828. Train Loss: 0.6097497344017029. Validation Accuracy: 72.39583333333333
Epoch: 829. Train Loss: 0.6365014910697937. Validation Accuracy: 71.35416666666667
Epoch: 830. Train Loss: 0.6345635056495667. Validation Accuracy: 69.27083333333333
Epoch: 831. Train Loss: 0.6236332058906555. Validation Accuracy: 65.625
Epoch: 832. Train Loss: 0.6573063731193542. Validation Accuracy: 63.802083333333336
Epoch: 833. Train Loss: 0.6193976402282715. Validation Accuracy: 65.625
Epoch: 834. Train Loss: 0.6382805705070496. Validation Accuracy: 63.541666666666664
Epoch: 835. Train Loss: 0.6314496994018555. Validation Accuracy: 67.70833333333333
Epoch: 836. Train Loss: 0.6223812699317932. Validation Accuracy: 67.44791666666667
Epoch: 837. Train Loss: 0.6393716335296631. Validation Accuracy: 54.947916666666664
Epoch: 838. Train Loss: 0.6325318217277527. Validation Accuracy:

70.83333333333333
Epoch: 839. Train Loss: 0.6687518954277039. Validation Accuracy: 68.22916666666667
Epoch: 840. Train Loss: 0.6270360946655273. Validation Accuracy: 62.5
Epoch: 841. Train Loss: 0.6135140061378479. Validation Accuracy: 67.96875
Epoch: 842. Train Loss: 0.6266838908195496. Validation Accuracy: 67.96875
Epoch: 843. Train Loss: 0.6551074981689453. Validation Accuracy: 63.80208333333336
Epoch: 844. Train Loss: 0.6069570779800415. Validation Accuracy: 69.01041666666667
Epoch: 845. Train Loss: 0.6311707496643066. Validation Accuracy: 59.89583333333336
Epoch: 846. Train Loss: 0.647628128528595. Validation Accuracy: 69.01041666666667
Epoch: 847. Train Loss: 0.6413785219192505. Validation Accuracy: 65.88541666666667
Epoch: 848. Train Loss: 0.6415720582008362. Validation Accuracy: 70.83333333333333
Epoch: 849. Train Loss: 0.6383028626441956. Validation Accuracy: 66.92708333333333
Epoch: 850. Train Loss: 0.6352882385253906. Validation Accuracy: 65.625
Epoch: 851. Train Loss: 0.6363440155982971. Validation Accuracy: 70.05208333333333
Epoch: 852. Train Loss: 0.6228201985359192. Validation Accuracy: 66.40625
Epoch: 853. Train Loss: 0.6600196361541748. Validation Accuracy: 67.70833333333333
Epoch: 854. Train Loss: 0.6507033705711365. Validation Accuracy: 64.58333333333333
Epoch: 855. Train Loss: 0.6302852034568787. Validation Accuracy: 65.36458333333333
Epoch: 856. Train Loss: 0.63348788022995. Validation Accuracy: 65.36458333333333
Epoch: 857. Train Loss: 0.6470362544059753. Validation Accuracy: 65.36458333333333
Epoch: 858. Train Loss: 0.6436086297035217. Validation Accuracy: 61.71875
Epoch: 859. Train Loss: 0.6063814163208008. Validation Accuracy: 72.39583333333333
Epoch: 860. Train Loss: 0.6316441893577576. Validation Accuracy: 62.5
Epoch: 861. Train Loss: 0.6405481696128845. Validation Accuracy: 68.75
Epoch: 862. Train Loss: 0.6087121963500977. Validation Accuracy: 67.70833333333333
Epoch: 863. Train Loss: 0.6265729665756226. Validation Accuracy: 67.70833333333333
Epoch: 864. Train Loss: 0.6142207980155945. Validation Accuracy: 71.09375
Epoch: 865. Train Loss: 0.6221244931221008. Validation Accuracy: 62.23958333333336
Epoch: 866. Train Loss: 0.5916146039962769. Validation Accuracy: 67.44791666666667
Epoch: 867. Train Loss: 0.6267493367195129. Validation Accuracy: 67.1875

Epoch: 868. Train Loss: 0.6246087551116943. Validation Accuracy: 65.88541666666667
Epoch: 869. Train Loss: 0.6308480501174927. Validation Accuracy: 67.44791666666667
Epoch: 870. Train Loss: 0.6573052406311035. Validation Accuracy: 63.541666666666664
Epoch: 871. Train Loss: 0.6350582242012024. Validation Accuracy: 63.541666666666664
Epoch: 872. Train Loss: 0.6373730897903442. Validation Accuracy: 59.635416666666664
Epoch: 873. Train Loss: 0.6369742155075073. Validation Accuracy: 68.48958333333333
Epoch: 874. Train Loss: 0.640346348285675. Validation Accuracy: 65.625
Epoch: 875. Train Loss: 0.6360370516777039. Validation Accuracy: 63.28125
Epoch: 876. Train Loss: 0.5994245409965515. Validation Accuracy: 60.677083333333336
Epoch: 877. Train Loss: 0.6192651987075806. Validation Accuracy: 62.239583333333336
Epoch: 878. Train Loss: 0.6277594566345215. Validation Accuracy: 66.92708333333333
Epoch: 879. Train Loss: 0.6322579383850098. Validation Accuracy: 68.48958333333333
Epoch: 880. Train Loss: 0.596078097820282. Validation Accuracy: 65.625
Epoch: 881. Train Loss: 0.6690404415130615. Validation Accuracy: 68.75
Epoch: 882. Train Loss: 0.6555259823799133. Validation Accuracy: 63.28125
Epoch: 883. Train Loss: 0.6258978843688965. Validation Accuracy: 68.48958333333333
Epoch: 884. Train Loss: 0.6318754553794861. Validation Accuracy: 63.802083333333336
Epoch: 885. Train Loss: 0.6344683170318604. Validation Accuracy: 67.44791666666667
Epoch: 886. Train Loss: 0.6251961588859558. Validation Accuracy: 67.70833333333333
Epoch: 887. Train Loss: 0.617506206035614. Validation Accuracy: 71.61458333333333
Epoch: 888. Train Loss: 0.6525150537490845. Validation Accuracy: 69.79166666666667
Epoch: 889. Train Loss: 0.6235464215278625. Validation Accuracy: 75.0
Epoch: 890. Train Loss: 0.6129733920097351. Validation Accuracy: 68.22916666666667
Epoch: 891. Train Loss: 0.6294571161270142. Validation Accuracy: 65.36458333333333
Epoch: 892. Train Loss: 0.6230941414833069. Validation Accuracy: 60.15625
Epoch: 893. Train Loss: 0.630054235458374. Validation Accuracy: 67.1875
Epoch: 894. Train Loss: 0.5857533812522888. Validation Accuracy: 68.75
Epoch: 895. Train Loss: 0.6337882876396179. Validation Accuracy: 66.66666666666667
Epoch: 896. Train Loss: 0.6593466997146606. Validation Accuracy: 68.75

Epoch: 897. Train Loss: 0.5979719161987305. Validation Accuracy: 62.5
Epoch: 898. Train Loss: 0.6220806241035461. Validation Accuracy:
66.66666666666667
Epoch: 899. Train Loss: 0.6304272413253784. Validation Accuracy: 61.71875
Epoch: 900. Train Loss: 0.6304792761802673. Validation Accuracy: 75.0
Epoch: 901. Train Loss: 0.6436166167259216. Validation Accuracy:
75.26041666666667
Epoch: 902. Train Loss: 0.593980610370636. Validation Accuracy:
67.44791666666667
Epoch: 903. Train Loss: 0.6081944108009338. Validation Accuracy:
64.58333333333333
Epoch: 904. Train Loss: 0.6325616836547852. Validation Accuracy: 63.28125
Epoch: 905. Train Loss: 0.6043145060539246. Validation Accuracy:
66.14583333333333
Epoch: 906. Train Loss: 0.627714216709137. Validation Accuracy: 71.875
Epoch: 907. Train Loss: 0.6582807898521423. Validation Accuracy: 65.625
Epoch: 908. Train Loss: 0.6052871346473694. Validation Accuracy:
66.14583333333333
Epoch: 909. Train Loss: 0.6207157373428345. Validation Accuracy: 65.625
Epoch: 910. Train Loss: 0.622201681137085. Validation Accuracy:
65.88541666666667
Epoch: 911. Train Loss: 0.6315420269966125. Validation Accuracy:
69.27083333333333
Epoch: 912. Train Loss: 0.6641716361045837. Validation Accuracy:
65.88541666666667
Epoch: 913. Train Loss: 0.6179261803627014. Validation Accuracy:
68.22916666666667
Epoch: 914. Train Loss: 0.6284169554710388. Validation Accuracy:
66.66666666666667
Epoch: 915. Train Loss: 0.6052230000495911. Validation Accuracy:
66.92708333333333
Epoch: 916. Train Loss: 0.6424227356910706. Validation Accuracy:
70.83333333333333
Epoch: 917. Train Loss: 0.6032445430755615. Validation Accuracy:
68.22916666666667
Epoch: 918. Train Loss: 0.6108372807502747. Validation Accuracy:
63.02083333333333
Epoch: 919. Train Loss: 0.6022534966468811. Validation Accuracy:
68.48958333333333
Epoch: 920. Train Loss: 0.623852014541626. Validation Accuracy: 63.28125
Epoch: 921. Train Loss: 0.6316575407981873. Validation Accuracy:
67.70833333333333
Epoch: 922. Train Loss: 0.6175572872161865. Validation Accuracy:
66.92708333333333
Epoch: 923. Train Loss: 0.60527104139328. Validation Accuracy: 67.1875
Epoch: 924. Train Loss: 0.6214082837104797. Validation Accuracy:
71.61458333333333
Epoch: 925. Train Loss: 0.6543792486190796. Validation Accuracy:

68.22916666666667
Epoch: 926. Train Loss: 0.6050649285316467. Validation Accuracy:
73.69791666666667
Epoch: 927. Train Loss: 0.633497416973114. Validation Accuracy: 67.1875
Epoch: 928. Train Loss: 0.6500658392906189. Validation Accuracy:
66.14583333333333
Epoch: 929. Train Loss: 0.6259041428565979. Validation Accuracy:
70.83333333333333
Epoch: 930. Train Loss: 0.6429307460784912. Validation Accuracy:
65.10416666666667
Epoch: 931. Train Loss: 0.624853789806366. Validation Accuracy: 67.96875
Epoch: 932. Train Loss: 0.6438692212104797. Validation Accuracy:
59.635416666666664
Epoch: 933. Train Loss: 0.6268253922462463. Validation Accuracy:
67.70833333333333
Epoch: 934. Train Loss: 0.6190740466117859. Validation Accuracy:
66.66666666666667
Epoch: 935. Train Loss: 0.6396573185920715. Validation Accuracy:
65.36458333333333
Epoch: 936. Train Loss: 0.6341913342475891. Validation Accuracy:
70.57291666666667
Epoch: 937. Train Loss: 0.6367363333702087. Validation Accuracy:
68.22916666666667
Epoch: 938. Train Loss: 0.6483083963394165. Validation Accuracy: 64.84375
Epoch: 939. Train Loss: 0.6076716780662537. Validation Accuracy:
67.44791666666667
Epoch: 940. Train Loss: 0.5991346836090088. Validation Accuracy:
69.01041666666667
Epoch: 941. Train Loss: 0.6422370076179504. Validation Accuracy:
70.57291666666667
Epoch: 942. Train Loss: 0.64359050989151. Validation Accuracy: 65.36458333333333
Epoch: 943. Train Loss: 0.5949708819389343. Validation Accuracy:
64.32291666666667
Epoch: 944. Train Loss: 0.6072487235069275. Validation Accuracy:
68.22916666666667
Epoch: 945. Train Loss: 0.6278811097145081. Validation Accuracy:
62.239583333333336
Epoch: 946. Train Loss: 0.6408237814903259. Validation Accuracy:
63.802083333333336
Epoch: 947. Train Loss: 0.6502043604850769. Validation Accuracy:
64.58333333333333
Epoch: 948. Train Loss: 0.6125820279121399. Validation Accuracy:
69.79166666666667
Epoch: 949. Train Loss: 0.6256245970726013. Validation Accuracy:
64.58333333333333
Epoch: 950. Train Loss: 0.6099216341972351. Validation Accuracy: 65.625
Epoch: 951. Train Loss: 0.6158549189567566. Validation Accuracy:
66.14583333333333

Epoch: 952. Train Loss: 0.5970948934555054. Validation Accuracy: 64.32291666666667
Epoch: 953. Train Loss: 0.6059296727180481. Validation Accuracy: 65.36458333333333
Epoch: 954. Train Loss: 0.6030551791191101. Validation Accuracy: 66.92708333333333
Epoch: 955. Train Loss: 0.604880690574646. Validation Accuracy: 69.27083333333333
Epoch: 956. Train Loss: 0.6498354077339172. Validation Accuracy: 66.92708333333333
Epoch: 957. Train Loss: 0.582656741142273. Validation Accuracy: 67.96875
Epoch: 958. Train Loss: 0.6236922740936279. Validation Accuracy: 63.80208333333336
Epoch: 959. Train Loss: 0.626051127910614. Validation Accuracy: 61.197916666666664
Epoch: 960. Train Loss: 0.6352749466896057. Validation Accuracy: 64.58333333333333
Epoch: 961. Train Loss: 0.6267485618591309. Validation Accuracy: 61.71875
Epoch: 962. Train Loss: 0.6148008704185486. Validation Accuracy: 66.66666666666667
Epoch: 963. Train Loss: 0.623348593711853. Validation Accuracy: 70.57291666666667
Epoch: 964. Train Loss: 0.6388006210327148. Validation Accuracy: 68.48958333333333
Epoch: 965. Train Loss: 0.5899065136909485. Validation Accuracy: 59.89583333333336
Epoch: 966. Train Loss: 0.6166584491729736. Validation Accuracy: 65.10416666666667
Epoch: 967. Train Loss: 0.5906729102134705. Validation Accuracy: 65.36458333333333
Epoch: 968. Train Loss: 0.5947077870368958. Validation Accuracy: 71.09375
Epoch: 969. Train Loss: 0.6447885632514954. Validation Accuracy: 66.14583333333333
Epoch: 970. Train Loss: 0.6445178389549255. Validation Accuracy: 66.40625
Epoch: 971. Train Loss: 0.6040588617324829. Validation Accuracy: 66.14583333333333
Epoch: 972. Train Loss: 0.609250009059906. Validation Accuracy: 66.40625
Epoch: 973. Train Loss: 0.6257932782173157. Validation Accuracy: 66.14583333333333
Epoch: 974. Train Loss: 0.6348847150802612. Validation Accuracy: 58.33333333333336
Epoch: 975. Train Loss: 0.5857323408126831. Validation Accuracy: 64.58333333333333
Epoch: 976. Train Loss: 0.6230324506759644. Validation Accuracy: 65.88541666666667
Epoch: 977. Train Loss: 0.5986822843551636. Validation Accuracy: 63.541666666666664
Epoch: 978. Train Loss: 0.5975636839866638. Validation Accuracy:

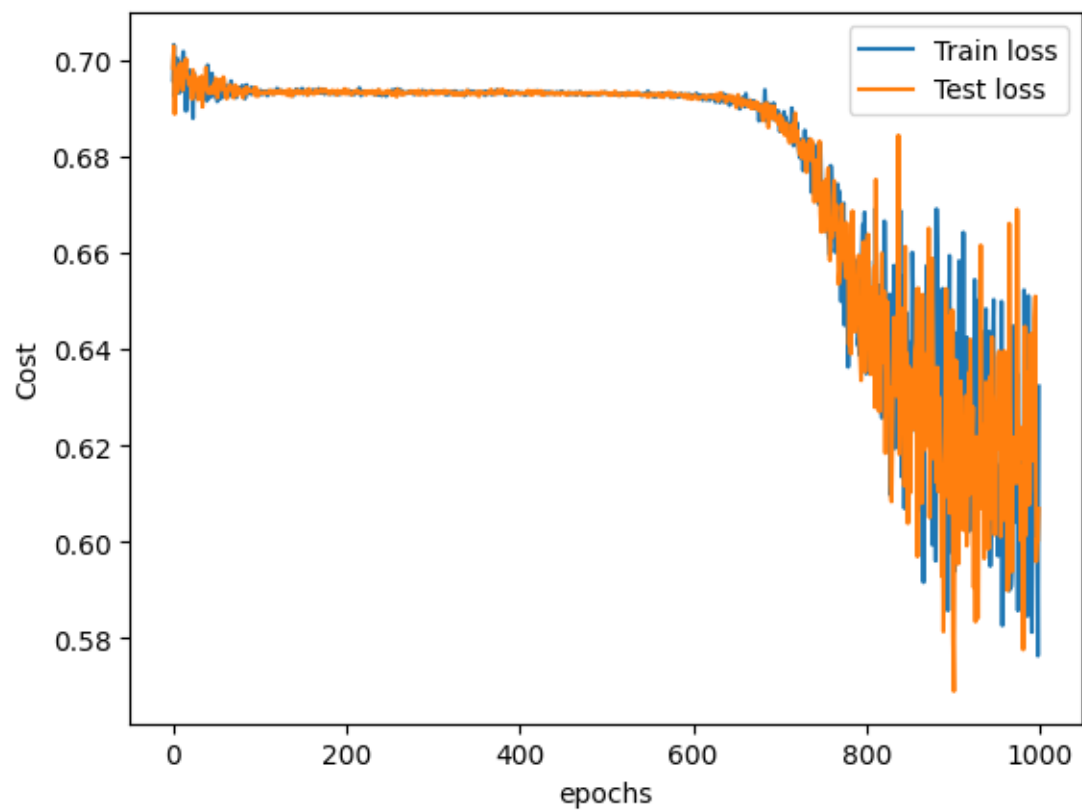
```

69.01041666666667
Epoch: 979. Train Loss: 0.6088160872459412. Validation Accuracy:
69.01041666666667
Epoch: 980. Train Loss: 0.6098979115486145. Validation Accuracy: 64.84375
Epoch: 981. Train Loss: 0.6033902764320374. Validation Accuracy:
70.83333333333333
Epoch: 982. Train Loss: 0.6522109508514404. Validation Accuracy: 65.625
Epoch: 983. Train Loss: 0.6165052056312561. Validation Accuracy: 60.9375
Epoch: 984. Train Loss: 0.6434478163719177. Validation Accuracy:
68.48958333333333
Epoch: 985. Train Loss: 0.6394051909446716. Validation Accuracy:
63.80208333333336
Epoch: 986. Train Loss: 0.5846202969551086. Validation Accuracy:
67.70833333333333
Epoch: 987. Train Loss: 0.6510366201400757. Validation Accuracy: 66.40625
Epoch: 988. Train Loss: 0.5910649299621582. Validation Accuracy:
66.14583333333333
Epoch: 989. Train Loss: 0.6049183011054993. Validation Accuracy:
67.70833333333333
Epoch: 990. Train Loss: 0.6011877655982971. Validation Accuracy:
60.67708333333336
Epoch: 991. Train Loss: 0.581287145614624. Validation Accuracy: 65.625
Epoch: 992. Train Loss: 0.6292315125465393. Validation Accuracy: 64.0625
Epoch: 993. Train Loss: 0.5987308025360107. Validation Accuracy:
66.66666666666667
Epoch: 994. Train Loss: 0.6142389178276062. Validation Accuracy: 60.9375
Epoch: 995. Train Loss: 0.6411345601081848. Validation Accuracy: 63.28125
Epoch: 996. Train Loss: 0.609307587146759. Validation Accuracy:
67.70833333333333
Epoch: 997. Train Loss: 0.6079378128051758. Validation Accuracy:
68.48958333333333
Epoch: 998. Train Loss: 0.5763736367225647. Validation Accuracy:
67.70833333333333
Epoch: 999. Train Loss: 0.6322546601295471. Validation Accuracy:
66.92708333333333

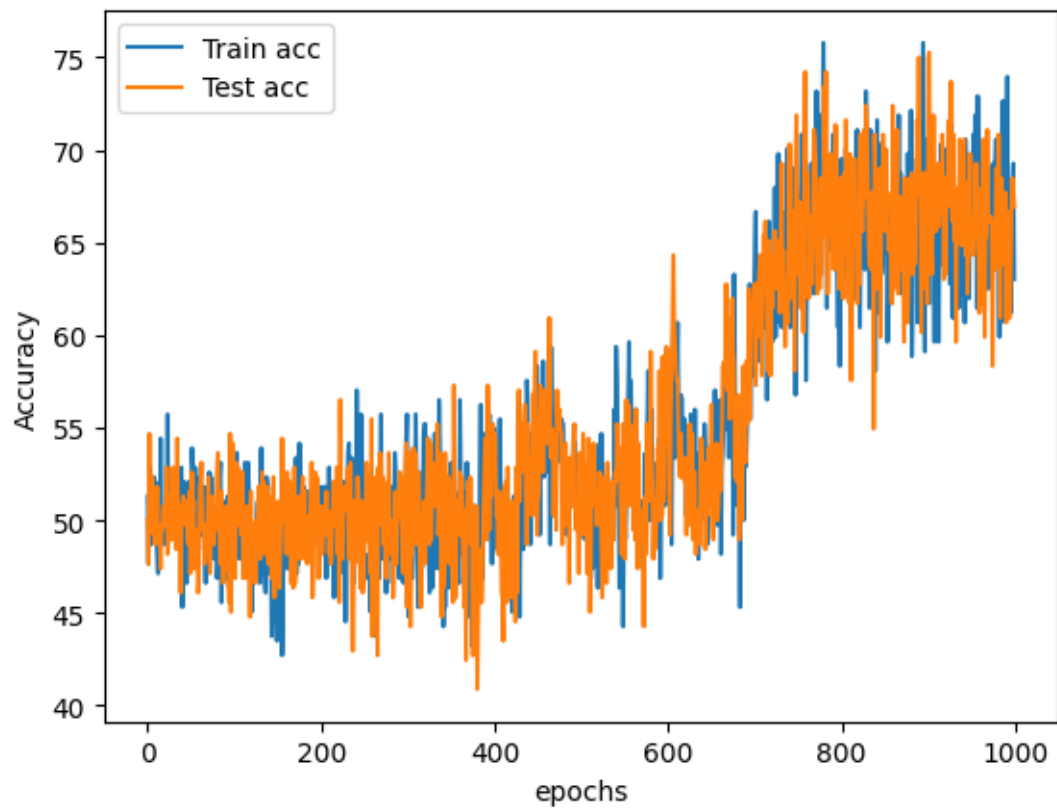
```

Train and test plots

```
[59]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



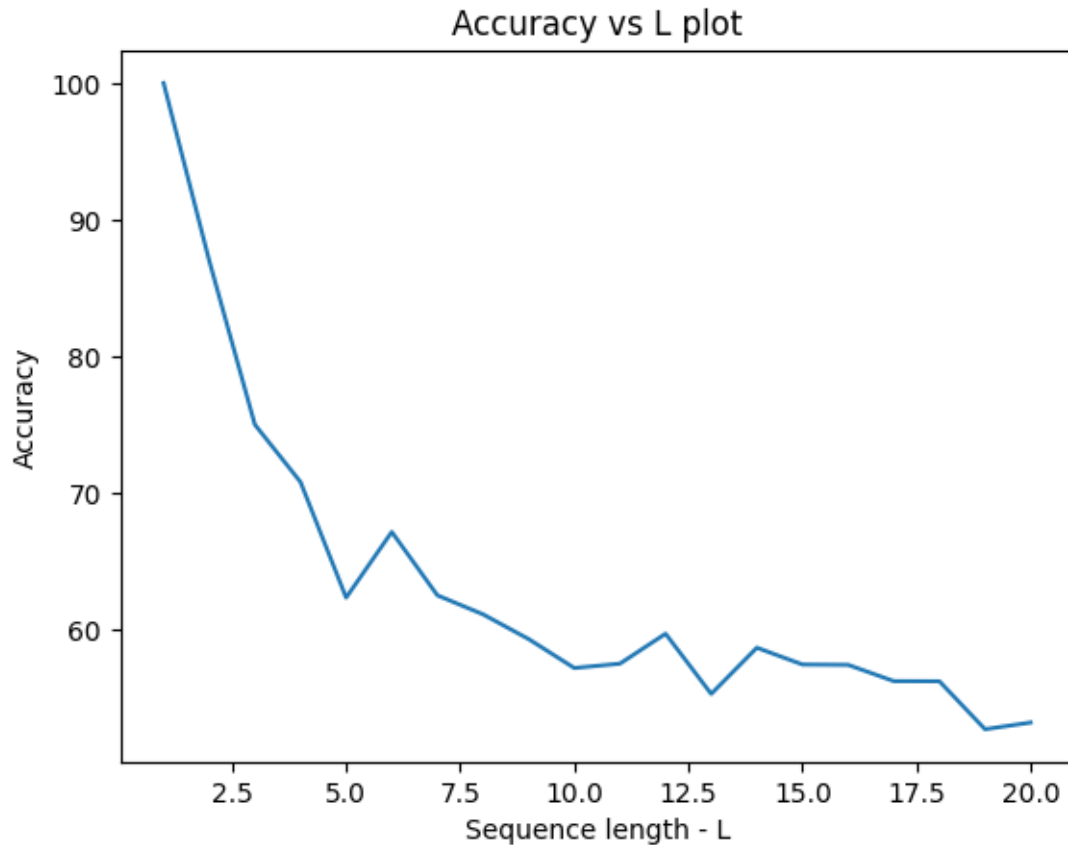
Train loss value after 1000 epochs: 0.6322546601295471
Vaildation loss value after 1000 epochs: 0.606839120388031



Best Test Accuracy: 75.26041666666667%

Bitwise Accuracy vs Length

```
[60]: plot_accuracy_vs_length(model)
```

9.6.2 Hidden State Size = 5

```
[61]: HIDDEN_DIM = 5
```

```
[62]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
      criterion = nn.CrossEntropyLoss()
      optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[63]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
      ↪optimizer, K, L)
```

Epoch: 0. Train Loss: 0.6913638710975647. Validation Accuracy: 48.697916666666664

Epoch: 1. Train Loss: 0.6915282607078552. Validation Accuracy: 50.520833333333336

Epoch: 2. Train Loss: 0.6957070827484131. Validation Accuracy: 52.083333333333336

Epoch: 3. Train Loss: 0.6964725852012634. Validation Accuracy:

48.958333333333336
Epoch: 4. Train Loss: 0.6935638785362244. Validation Accuracy: 52.864583333333336
Epoch: 5. Train Loss: 0.7013599872589111. Validation Accuracy: 52.34375
Epoch: 6. Train Loss: 0.6942768692970276. Validation Accuracy: 49.739583333333336
Epoch: 7. Train Loss: 0.6922513842582703. Validation Accuracy: 52.604166666666664
Epoch: 8. Train Loss: 0.6884399056434631. Validation Accuracy: 51.041666666666664
Epoch: 9. Train Loss: 0.692714512348175. Validation Accuracy: 50.0
Epoch: 10. Train Loss: 0.6895633339881897. Validation Accuracy: 50.0
Epoch: 11. Train Loss: 0.6899054050445557. Validation Accuracy: 51.822916666666664
Epoch: 12. Train Loss: 0.6956167817115784. Validation Accuracy: 52.083333333333336
Epoch: 13. Train Loss: 0.6923384666442871. Validation Accuracy: 49.479166666666664
Epoch: 14. Train Loss: 0.6946395039558411. Validation Accuracy: 50.520833333333336
Epoch: 15. Train Loss: 0.6962675452232361. Validation Accuracy: 51.5625
Epoch: 16. Train Loss: 0.6942726969718933. Validation Accuracy: 51.041666666666664
Epoch: 17. Train Loss: 0.6952844262123108. Validation Accuracy: 50.520833333333336
Epoch: 18. Train Loss: 0.6913025975227356. Validation Accuracy: 53.385416666666664
Epoch: 19. Train Loss: 0.6920085549354553. Validation Accuracy: 52.864583333333336
Epoch: 20. Train Loss: 0.6929304599761963. Validation Accuracy: 43.489583333333336
Epoch: 21. Train Loss: 0.6952714323997498. Validation Accuracy: 52.34375
Epoch: 22. Train Loss: 0.6951045393943787. Validation Accuracy: 46.09375
Epoch: 23. Train Loss: 0.6962323784828186. Validation Accuracy: 50.260416666666664
Epoch: 24. Train Loss: 0.6929795742034912. Validation Accuracy: 52.604166666666664
Epoch: 25. Train Loss: 0.6933512687683105. Validation Accuracy: 51.822916666666664
Epoch: 26. Train Loss: 0.6955537796020508. Validation Accuracy: 52.083333333333336
Epoch: 27. Train Loss: 0.6948598027229309. Validation Accuracy: 46.354166666666664
Epoch: 28. Train Loss: 0.6939371228218079. Validation Accuracy: 50.520833333333336
Epoch: 29. Train Loss: 0.6920464038848877. Validation Accuracy: 49.21875
Epoch: 30. Train Loss: 0.6924391388893127. Validation Accuracy: 52.083333333333336

Epoch: 31. Train Loss: 0.6927084922790527. Validation Accuracy: 50.520833333333336

Epoch: 32. Train Loss: 0.6934204697608948. Validation Accuracy: 48.958333333333336

Epoch: 33. Train Loss: 0.6926424503326416. Validation Accuracy: 46.875

Epoch: 34. Train Loss: 0.6934497952461243. Validation Accuracy: 51.302083333333336

Epoch: 35. Train Loss: 0.694130003452301. Validation Accuracy: 46.614583333333336

Epoch: 36. Train Loss: 0.692703902721405. Validation Accuracy: 51.302083333333336

Epoch: 37. Train Loss: 0.6925354599952698. Validation Accuracy: 51.5625

Epoch: 38. Train Loss: 0.6937411427497864. Validation Accuracy: 52.604166666666664

Epoch: 39. Train Loss: 0.6934093832969666. Validation Accuracy: 49.739583333333336

Epoch: 40. Train Loss: 0.6931832432746887. Validation Accuracy: 49.739583333333336

Epoch: 41. Train Loss: 0.6932809352874756. Validation Accuracy: 51.041666666666664

Epoch: 42. Train Loss: 0.6932209134101868. Validation Accuracy: 47.916666666666664

Epoch: 43. Train Loss: 0.6933204531669617. Validation Accuracy: 49.479166666666664

Epoch: 44. Train Loss: 0.6930277347564697. Validation Accuracy: 55.46875

Epoch: 45. Train Loss: 0.6935192942619324. Validation Accuracy: 46.614583333333336

Epoch: 46. Train Loss: 0.6930573582649231. Validation Accuracy: 53.385416666666664

Epoch: 47. Train Loss: 0.6925678253173828. Validation Accuracy: 50.78125

Epoch: 48. Train Loss: 0.693007230758667. Validation Accuracy: 49.739583333333336

Epoch: 49. Train Loss: 0.6928207278251648. Validation Accuracy: 49.21875

Epoch: 50. Train Loss: 0.6934616565704346. Validation Accuracy: 51.822916666666664

Epoch: 51. Train Loss: 0.693298876285553. Validation Accuracy: 49.479166666666664

Epoch: 52. Train Loss: 0.6928431391716003. Validation Accuracy: 50.260416666666664

Epoch: 53. Train Loss: 0.6939006447792053. Validation Accuracy: 44.010416666666664

Epoch: 54. Train Loss: 0.6929941177368164. Validation Accuracy: 53.385416666666664

Epoch: 55. Train Loss: 0.6932170987129211. Validation Accuracy: 47.65625

Epoch: 56. Train Loss: 0.6935041546821594. Validation Accuracy: 52.34375

Epoch: 57. Train Loss: 0.6931551098823547. Validation Accuracy: 48.697916666666664

Epoch: 58. Train Loss: 0.6931824684143066. Validation Accuracy:

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Epoch: 61. Train Loss: 0.6929080486297607. Validation Accuracy: 50.260416666666664
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Epoch: 64. Train Loss: 0.6933580040931702. Validation Accuracy: 49.739583333333336
Epoch: 65. Train Loss: 0.6932353973388672. Validation Accuracy: 51.302083333333336
Epoch: 66. Train Loss: 0.6931719779968262. Validation Accuracy: 51.041666666666664
Epoch: 67. Train Loss: 0.6931042075157166. Validation Accuracy: 53.385416666666664
Epoch: 68. Train Loss: 0.6933404803276062. Validation Accuracy: 50.0
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Epoch: 71. Train Loss: 0.6934142112731934. Validation Accuracy: 53.385416666666664
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Epoch: 73. Train Loss: 0.6931306719779968. Validation Accuracy: 52.083333333333336
Epoch: 74. Train Loss: 0.6931283473968506. Validation Accuracy: 53.125
Epoch: 75. Train Loss: 0.6929972767829895. Validation Accuracy: 49.21875
Epoch: 76. Train Loss: 0.6932158470153809. Validation Accuracy: 54.947916666666664
Epoch: 77. Train Loss: 0.6931708455085754. Validation Accuracy: 49.21875
Epoch: 78. Train Loss: 0.6930513978004456. Validation Accuracy: 46.875
Epoch: 79. Train Loss: 0.6929867267608643. Validation Accuracy: 52.604166666666664
Epoch: 80. Train Loss: 0.6932408213615417. Validation Accuracy: 46.09375
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Epoch: 83. Train Loss: 0.6931316256523132. Validation Accuracy: 52.604166666666664
Epoch: 84. Train Loss: 0.6931436657905579. Validation Accuracy: 46.09375
Epoch: 85. Train Loss: 0.6927841305732727. Validation Accuracy: 46.875
Epoch: 86. Train Loss: 0.6928502917289734. Validation Accuracy: 47.135416666666664
Epoch: 87. Train Loss: 0.692700207233429. Validation Accuracy: 51.041666666666664
Epoch: 88. Train Loss: 0.693145751953125. Validation Accuracy: 49.739583333333336

Epoch: 89. Train Loss: 0.6924571990966797. Validation Accuracy: 54.16666666666664
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Epoch: 93. Train Loss: 0.6930904388427734. Validation Accuracy: 48.69791666666664
Epoch: 94. Train Loss: 0.6935511231422424. Validation Accuracy: 52.08333333333336
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Epoch: 104. Train Loss: 0.6926989555358887. Validation Accuracy: 54.16666666666664
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Epoch: 108. Train Loss: 0.6937122344970703. Validation Accuracy: 46.875
Epoch: 109. Train Loss: 0.6930582523345947. Validation Accuracy: 46.35416666666664
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51.822916666666664
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Epoch: 125. Train Loss: 0.6924435496330261. Validation Accuracy:
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Epoch: 128. Train Loss: 0.6926745772361755. Validation Accuracy:
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Epoch: 135. Train Loss: 0.6925371289253235. Validation Accuracy:
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49.739583333333336

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Epoch: 156. Train Loss: 0.6930200457572937. Validation Accuracy: 52.083333333333336
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Epoch: 318. Train Loss: 0.6925964951515198. Validation Accuracy:

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Epoch: 579. Train Loss: 0.5803108811378479. Validation Accuracy: 66.66666666666667

Epoch: 580. Train Loss: 0.620789110660553. Validation Accuracy: 76.5625

Epoch: 581. Train Loss: 0.6176668405532837. Validation Accuracy: 65.88541666666667

Epoch: 582. Train Loss: 0.5948823094367981. Validation Accuracy: 62.239583333333336

Epoch: 583. Train Loss: 0.5828914046287537. Validation Accuracy: 69.01041666666667

Epoch: 584. Train Loss: 0.6116445064544678. Validation Accuracy: 61.979166666666664

Epoch: 585. Train Loss: 0.6140163540840149. Validation Accuracy: 74.47916666666667

Epoch: 586. Train Loss: 0.6248506903648376. Validation Accuracy: 68.48958333333333

Epoch: 587. Train Loss: 0.5945459604263306. Validation Accuracy: 65.88541666666667

Epoch: 588. Train Loss: 0.6075225472450256. Validation Accuracy: 66.92708333333333

Epoch: 589. Train Loss: 0.6070806384086609. Validation Accuracy: 63.28125

Epoch: 590. Train Loss: 0.6522958278656006. Validation Accuracy: 70.57291666666667

Epoch: 591. Train Loss: 0.5895313024520874. Validation Accuracy: 64.84375

Epoch: 592. Train Loss: 0.6195945739746094. Validation Accuracy: 64.84375

Epoch: 593. Train Loss: 0.614090621471405. Validation Accuracy: 69.79166666666667

Epoch: 594. Train Loss: 0.5788608193397522. Validation Accuracy: 58.072916666666664

Epoch: 595. Train Loss: 0.5799258351325989. Validation Accuracy: 71.09375

Epoch: 596. Train Loss: 0.6114686131477356. Validation Accuracy: 60.677083333333336

Epoch: 597. Train Loss: 0.6323041319847107. Validation Accuracy: 63.541666666666664

Epoch: 598. Train Loss: 0.6331854462623596. Validation Accuracy: 65.625

Epoch: 599. Train Loss: 0.5796092748641968. Validation Accuracy: 69.01041666666667

Epoch: 600. Train Loss: 0.5965575575828552. Validation Accuracy: 73.95833333333333

Epoch: 601. Train Loss: 0.5881526470184326. Validation Accuracy: 64.84375

Epoch: 602. Train Loss: 0.6158230900764465. Validation Accuracy: 67.1875

Epoch: 603. Train Loss: 0.6186482310295105. Validation Accuracy: 65.88541666666667

Epoch: 604. Train Loss: 0.6063650250434875. Validation Accuracy: 66.14583333333333

Epoch: 605. Train Loss: 0.5993536114692688. Validation Accuracy: 64.32291666666667

Epoch: 606. Train Loss: 0.587376594543457. Validation Accuracy: 67.1875
Epoch: 607. Train Loss: 0.6091461777687073. Validation Accuracy:
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Epoch: 608. Train Loss: 0.610511302947998. Validation Accuracy:
65.36458333333333
Epoch: 609. Train Loss: 0.6179332137107849. Validation Accuracy: 67.1875
Epoch: 610. Train Loss: 0.627060055732727. Validation Accuracy:
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Epoch: 611. Train Loss: 0.5851418375968933. Validation Accuracy:
63.02083333333336
Epoch: 612. Train Loss: 0.5913801789283752. Validation Accuracy: 71.09375
Epoch: 613. Train Loss: 0.5457131266593933. Validation Accuracy:
61.979166666666664
Epoch: 614. Train Loss: 0.6250712275505066. Validation Accuracy:
66.92708333333333
Epoch: 615. Train Loss: 0.6733495593070984. Validation Accuracy:
65.88541666666667
Epoch: 616. Train Loss: 0.5859338045120239. Validation Accuracy:
71.61458333333333
Epoch: 617. Train Loss: 0.6124764084815979. Validation Accuracy:
67.70833333333333
Epoch: 618. Train Loss: 0.6681106090545654. Validation Accuracy:
65.88541666666667
Epoch: 619. Train Loss: 0.5710068345069885. Validation Accuracy:
72.39583333333333
Epoch: 620. Train Loss: 0.6168031096458435. Validation Accuracy:
64.32291666666667
Epoch: 621. Train Loss: 0.5683088302612305. Validation Accuracy: 65.625
Epoch: 622. Train Loss: 0.6112016439437866. Validation Accuracy: 63.28125
Epoch: 623. Train Loss: 0.6100563406944275. Validation Accuracy: 67.96875
Epoch: 624. Train Loss: 0.6158655881881714. Validation Accuracy:
61.979166666666664
Epoch: 625. Train Loss: 0.5562068223953247. Validation Accuracy:
66.92708333333333
Epoch: 626. Train Loss: 0.6239967942237854. Validation Accuracy: 64.84375
Epoch: 627. Train Loss: 0.6021522283554077. Validation Accuracy: 72.65625
Epoch: 628. Train Loss: 0.6282321810722351. Validation Accuracy: 70.3125
Epoch: 629. Train Loss: 0.6044613718986511. Validation Accuracy:
61.979166666666664
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Epoch: 631. Train Loss: 0.6076756119728088. Validation Accuracy:
71.35416666666667
Epoch: 632. Train Loss: 0.6027299761772156. Validation Accuracy:
64.32291666666667
Epoch: 633. Train Loss: 0.6366652250289917. Validation Accuracy:
70.57291666666667
Epoch: 634. Train Loss: 0.6256160140037537. Validation Accuracy: 64.0625

Epoch: 635. Train Loss: 0.5904800295829773. Validation Accuracy: 64.84375
Epoch: 636. Train Loss: 0.5988272428512573. Validation Accuracy: 68.75
Epoch: 637. Train Loss: 0.6145957112312317. Validation Accuracy: 68.75
Epoch: 638. Train Loss: 0.6332695484161377. Validation Accuracy:
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Epoch: 639. Train Loss: 0.6210009455680847. Validation Accuracy:
66.66666666666667
Epoch: 640. Train Loss: 0.6373416781425476. Validation Accuracy: 66.40625
Epoch: 641. Train Loss: 0.6167907118797302. Validation Accuracy:
70.57291666666667
Epoch: 642. Train Loss: 0.6674036979675293. Validation Accuracy:
66.66666666666667
Epoch: 643. Train Loss: 0.5839739441871643. Validation Accuracy:
69.27083333333333
Epoch: 644. Train Loss: 0.6043362617492676. Validation Accuracy: 62.5
Epoch: 645. Train Loss: 0.6296406388282776. Validation Accuracy:
65.10416666666667
Epoch: 646. Train Loss: 0.5640392899513245. Validation Accuracy:
65.10416666666667
Epoch: 647. Train Loss: 0.6047882437705994. Validation Accuracy:
68.22916666666667
Epoch: 648. Train Loss: 0.6169939637184143. Validation Accuracy:
62.760416666666664
Epoch: 649. Train Loss: 0.6493095755577087. Validation Accuracy:
67.44791666666667
Epoch: 650. Train Loss: 0.5836047530174255. Validation Accuracy: 62.5
Epoch: 651. Train Loss: 0.5998373031616211. Validation Accuracy:
72.13541666666667
Epoch: 652. Train Loss: 0.6475113034248352. Validation Accuracy:
68.48958333333333
Epoch: 653. Train Loss: 0.5960173010826111. Validation Accuracy:
61.979166666666664
Epoch: 654. Train Loss: 0.6270732879638672. Validation Accuracy:
61.979166666666664
Epoch: 655. Train Loss: 0.5830661654472351. Validation Accuracy:
69.01041666666667
Epoch: 656. Train Loss: 0.6413150429725647. Validation Accuracy: 62.5
Epoch: 657. Train Loss: 0.624101459980011. Validation Accuracy:
64.58333333333333
Epoch: 658. Train Loss: 0.5517638325691223. Validation Accuracy: 64.84375
Epoch: 659. Train Loss: 0.5969986915588379. Validation Accuracy: 65.625
Epoch: 660. Train Loss: 0.6001477241516113. Validation Accuracy:
73.69791666666667
Epoch: 661. Train Loss: 0.6191979646682739. Validation Accuracy:
67.44791666666667
Epoch: 662. Train Loss: 0.568375825881958. Validation Accuracy: 71.09375
Epoch: 663. Train Loss: 0.5999907851219177. Validation Accuracy:
68.48958333333333

Epoch: 664. Train Loss: 0.6172897219657898. Validation Accuracy: 64.0625
Epoch: 665. Train Loss: 0.6012982130050659. Validation Accuracy:
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Epoch: 666. Train Loss: 0.5970084071159363. Validation Accuracy:
66.92708333333333
Epoch: 667. Train Loss: 0.6383691430091858. Validation Accuracy:
67.70833333333333
Epoch: 668. Train Loss: 0.5995830297470093. Validation Accuracy: 67.96875
Epoch: 669. Train Loss: 0.616724967956543. Validation Accuracy:
67.44791666666667
Epoch: 670. Train Loss: 0.6522359251976013. Validation Accuracy:
73.95833333333333
Epoch: 671. Train Loss: 0.6192641854286194. Validation Accuracy:
64.58333333333333
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Epoch: 673. Train Loss: 0.5930953621864319. Validation Accuracy:
66.92708333333333
Epoch: 674. Train Loss: 0.6259357929229736. Validation Accuracy:
71.35416666666667
Epoch: 675. Train Loss: 0.5708767175674438. Validation Accuracy:
63.80208333333333
Epoch: 676. Train Loss: 0.6486067175865173. Validation Accuracy: 60.9375
Epoch: 677. Train Loss: 0.5747573971748352. Validation Accuracy:
67.44791666666667
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68.48958333333333
Epoch: 679. Train Loss: 0.6058017611503601. Validation Accuracy: 69.53125
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Epoch: 681. Train Loss: 0.6301311254501343. Validation Accuracy:
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63.02083333333333
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Epoch: 691. Train Loss: 0.5864223837852478. Validation Accuracy:
70.83333333333333

Epoch: 692. Train Loss: 0.6235588192939758. Validation Accuracy: 70.83333333333333
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Epoch: 694. Train Loss: 0.5570306181907654. Validation Accuracy: 61.71875
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Epoch: 696. Train Loss: 0.6336081027984619. Validation Accuracy: 67.70833333333333
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Epoch: 701. Train Loss: 0.5880926251411438. Validation Accuracy: 65.625
Epoch: 702. Train Loss: 0.6102779507637024. Validation Accuracy: 67.96875
Epoch: 703. Train Loss: 0.6016746163368225. Validation Accuracy: 66.66666666666667
Epoch: 704. Train Loss: 0.6019557118415833. Validation Accuracy: 63.54166666666664
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Epoch: 709. Train Loss: 0.5696269869804382. Validation Accuracy: 70.57291666666667
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Epoch: 712. Train Loss: 0.6246034502983093. Validation Accuracy: 67.70833333333333
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Epoch: 715. Train Loss: 0.6086366772651672. Validation Accuracy: 70.05208333333333
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Epoch: 719. Train Loss: 0.5577072501182556. Validation Accuracy: 64.32291666666667

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Epoch: 749. Train Loss: 0.5896226763725281. Validation Accuracy: 61.458333333333336
Epoch: 750. Train Loss: 0.5858861207962036. Validation Accuracy: 66.40625
Epoch: 751. Train Loss: 0.5906568765640259. Validation Accuracy: 75.0
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Epoch: 764. Train Loss: 0.5630384087562561. Validation Accuracy: 68.48958333333333
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Epoch: 766. Train Loss: 0.6062486171722412. Validation Accuracy: 65.625
Epoch: 767. Train Loss: 0.5981842875480652. Validation Accuracy: 64.58333333333333
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Epoch: 771. Train Loss: 0.6052344441413879. Validation Accuracy: 67.1875
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Epoch: 777. Train Loss: 0.5747247934341431. Validation Accuracy:

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Epoch: 780. Train Loss: 0.5953138470649719. Validation Accuracy: 65.10416666666667
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Epoch: 788. Train Loss: 0.5473724603652954. Validation Accuracy: 67.70833333333333
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Epoch: 806. Train Loss: 0.608185887336731. Validation Accuracy: 65.36458333333333

Epoch: 807. Train Loss: 0.6146963834762573. Validation Accuracy: 70.3125

Epoch: 808. Train Loss: 0.5984050631523132. Validation Accuracy: 64.58333333333333

Epoch: 809. Train Loss: 0.6092634201049805. Validation Accuracy: 66.40625

Epoch: 810. Train Loss: 0.5641329884529114. Validation Accuracy: 65.10416666666667

Epoch: 811. Train Loss: 0.5983723998069763. Validation Accuracy: 67.1875

Epoch: 812. Train Loss: 0.5794376730918884. Validation Accuracy: 67.1875

Epoch: 813. Train Loss: 0.5698463320732117. Validation Accuracy: 65.625

Epoch: 814. Train Loss: 0.5606169104576111. Validation Accuracy: 66.92708333333333

Epoch: 815. Train Loss: 0.5570567846298218. Validation Accuracy: 65.10416666666667

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Epoch: 823. Train Loss: 0.5836243033409119. Validation Accuracy: 75.0

Epoch: 824. Train Loss: 0.589118480682373. Validation Accuracy: 69.01041666666667

Epoch: 825. Train Loss: 0.6188436150550842. Validation Accuracy: 65.625

Epoch: 826. Train Loss: 0.5582411885261536. Validation Accuracy: 63.28125

Epoch: 827. Train Loss: 0.5882558226585388. Validation Accuracy: 67.70833333333333

Epoch: 828. Train Loss: 0.5720424056053162. Validation Accuracy: 67.70833333333333

Epoch: 829. Train Loss: 0.5901898145675659. Validation Accuracy: 68.75

Epoch: 830. Train Loss: 0.5735180377960205. Validation Accuracy: 69.27083333333333

Epoch: 831. Train Loss: 0.5782389640808105. Validation Accuracy: 63.80208333333336

Epoch: 832. Train Loss: 0.6195034384727478. Validation Accuracy: 65.625

Epoch: 833. Train Loss: 0.585258424282074. Validation Accuracy: 72.65625

Epoch: 834. Train Loss: 0.5719771385192871. Validation Accuracy: 69.01041666666667

Epoch: 835. Train Loss: 0.5630279779434204. Validation Accuracy: 64.0625

Epoch: 836. Train Loss: 0.5720252394676208. Validation Accuracy:

70.05208333333333

Epoch: 837. Train Loss: 0.5654492378234863. Validation Accuracy: 64.0625

Epoch: 838. Train Loss: 0.6101723313331604. Validation Accuracy: 71.875

Epoch: 839. Train Loss: 0.5951396822929382. Validation Accuracy: 71.875

Epoch: 840. Train Loss: 0.575620710849762. Validation Accuracy: 65.10416666666667

Epoch: 841. Train Loss: 0.5744783282279968. Validation Accuracy: 68.48958333333333

Epoch: 842. Train Loss: 0.585109293460846. Validation Accuracy: 66.40625

Epoch: 843. Train Loss: 0.5899831056594849. Validation Accuracy: 70.83333333333333

Epoch: 844. Train Loss: 0.5729921460151672. Validation Accuracy: 67.1875

Epoch: 845. Train Loss: 0.5969038605690002. Validation Accuracy: 68.22916666666667

Epoch: 846. Train Loss: 0.5851393938064575. Validation Accuracy: 66.40625

Epoch: 847. Train Loss: 0.5738314390182495. Validation Accuracy: 57.291666666666664

Epoch: 848. Train Loss: 0.5892499089241028. Validation Accuracy: 64.32291666666667

Epoch: 849. Train Loss: 0.6025342345237732. Validation Accuracy: 66.40625

Epoch: 850. Train Loss: 0.562843918800354. Validation Accuracy: 66.66666666666667

Epoch: 851. Train Loss: 0.5746952295303345. Validation Accuracy: 70.3125

Epoch: 852. Train Loss: 0.583887691497803. Validation Accuracy: 59.895833333333336

Epoch: 853. Train Loss: 0.5961633324623108. Validation Accuracy: 70.57291666666667

Epoch: 854. Train Loss: 0.5839076638221741. Validation Accuracy: 68.22916666666667

Epoch: 855. Train Loss: 0.5822316408157349. Validation Accuracy: 66.14583333333333

Epoch: 856. Train Loss: 0.5767041444778442. Validation Accuracy: 68.48958333333333

Epoch: 857. Train Loss: 0.5691246390342712. Validation Accuracy: 72.13541666666667

Epoch: 858. Train Loss: 0.5614067912101746. Validation Accuracy: 67.70833333333333

Epoch: 859. Train Loss: 0.6107487678527832. Validation Accuracy: 64.32291666666667

Epoch: 860. Train Loss: 0.565863311290741. Validation Accuracy: 68.48958333333333

Epoch: 861. Train Loss: 0.5951053500175476. Validation Accuracy: 65.88541666666667

Epoch: 862. Train Loss: 0.5744197964668274. Validation Accuracy: 67.96875

Epoch: 863. Train Loss: 0.5417138338088989. Validation Accuracy: 65.88541666666667

Epoch: 864. Train Loss: 0.570888102054596. Validation Accuracy: 61.71875

Epoch: 865. Train Loss: 0.5544936656951904. Validation Accuracy:

68.48958333333333
Epoch: 866. Train Loss: 0.5730084180831909. Validation Accuracy:
71.35416666666667
Epoch: 867. Train Loss: 0.5903401970863342. Validation Accuracy: 64.0625
Epoch: 868. Train Loss: 0.568805456161499. Validation Accuracy: 67.1875
Epoch: 869. Train Loss: 0.5442959666252136. Validation Accuracy:
62.239583333333336
Epoch: 870. Train Loss: 0.5851340889930725. Validation Accuracy:
62.760416666666664
Epoch: 871. Train Loss: 0.5635021328926086. Validation Accuracy:
68.22916666666667
Epoch: 872. Train Loss: 0.571286141872406. Validation Accuracy:
63.020833333333336
Epoch: 873. Train Loss: 0.5740993618965149. Validation Accuracy:
65.10416666666667
Epoch: 874. Train Loss: 0.5845826268196106. Validation Accuracy:
68.48958333333333
Epoch: 875. Train Loss: 0.5791510939598083. Validation Accuracy:
65.10416666666667
Epoch: 876. Train Loss: 0.5919383764266968. Validation Accuracy:
67.70833333333333
Epoch: 877. Train Loss: 0.5717757344245911. Validation Accuracy: 62.5
Epoch: 878. Train Loss: 0.5671234130859375. Validation Accuracy:
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Epoch: 879. Train Loss: 0.5675839781761169. Validation Accuracy:
69.01041666666667
Epoch: 880. Train Loss: 0.5956060886383057. Validation Accuracy: 69.53125
Epoch: 881. Train Loss: 0.5870501399040222. Validation Accuracy:
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Epoch: 882. Train Loss: 0.549917459487915. Validation Accuracy: 67.96875
Epoch: 883. Train Loss: 0.5779203772544861. Validation Accuracy: 69.53125
Epoch: 884. Train Loss: 0.5667847394943237. Validation Accuracy:
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Epoch: 885. Train Loss: 0.560147225856781. Validation Accuracy:
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Epoch: 886. Train Loss: 0.5792314410209656. Validation Accuracy: 64.0625
Epoch: 887. Train Loss: 0.5886269211769104. Validation Accuracy:
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Epoch: 888. Train Loss: 0.562528133392334. Validation Accuracy: 67.96875
Epoch: 889. Train Loss: 0.6073298454284668. Validation Accuracy:
66.92708333333333
Epoch: 890. Train Loss: 0.6072041988372803. Validation Accuracy: 67.96875
Epoch: 891. Train Loss: 0.5824679136276245. Validation Accuracy: 63.28125
Epoch: 892. Train Loss: 0.563892126083374. Validation Accuracy:
71.35416666666667
Epoch: 893. Train Loss: 0.5633613467216492. Validation Accuracy:
62.239583333333336
Epoch: 894. Train Loss: 0.5865831971168518. Validation Accuracy:

63.541666666666664
Epoch: 895. Train Loss: 0.5762526392936707. Validation Accuracy: 67.1875
Epoch: 896. Train Loss: 0.5804961323738098. Validation Accuracy: 68.229166666666667
Epoch: 897. Train Loss: 0.584380567073822. Validation Accuracy: 72.135416666666667
Epoch: 898. Train Loss: 0.6115497946739197. Validation Accuracy: 64.84375
Epoch: 899. Train Loss: 0.5918949246406555. Validation Accuracy: 72.39583333333333
Epoch: 900. Train Loss: 0.5653930306434631. Validation Accuracy: 66.92708333333333
Epoch: 901. Train Loss: 0.6035652756690979. Validation Accuracy: 66.14583333333333
Epoch: 902. Train Loss: 0.5765031576156616. Validation Accuracy: 66.40625
Epoch: 903. Train Loss: 0.56992107629776. Validation Accuracy: 64.0625
Epoch: 904. Train Loss: 0.5712804198265076. Validation Accuracy: 67.447916666666667
Epoch: 905. Train Loss: 0.5973663926124573. Validation Accuracy: 70.3125
Epoch: 906. Train Loss: 0.5859535336494446. Validation Accuracy: 67.70833333333333
Epoch: 907. Train Loss: 0.5756365656852722. Validation Accuracy: 69.010416666666667
Epoch: 908. Train Loss: 0.577700674533844. Validation Accuracy: 69.27083333333333
Epoch: 909. Train Loss: 0.5564611554145813. Validation Accuracy: 63.802083333333336
Epoch: 910. Train Loss: 0.583279550075531. Validation Accuracy: 64.0625
Epoch: 911. Train Loss: 0.5908260941505432. Validation Accuracy: 66.14583333333333
Epoch: 912. Train Loss: 0.5493715405464172. Validation Accuracy: 67.70833333333333
Epoch: 913. Train Loss: 0.568006694316864. Validation Accuracy: 62.5
Epoch: 914. Train Loss: 0.5936657786369324. Validation Accuracy: 66.14583333333333
Epoch: 915. Train Loss: 0.6040271520614624. Validation Accuracy: 73.95833333333333
Epoch: 916. Train Loss: 0.6134545803070068. Validation Accuracy: 64.84375
Epoch: 917. Train Loss: 0.5809609293937683. Validation Accuracy: 63.020833333333336
Epoch: 918. Train Loss: 0.5808334946632385. Validation Accuracy: 69.27083333333333
Epoch: 919. Train Loss: 0.5750156044960022. Validation Accuracy: 61.197916666666664
Epoch: 920. Train Loss: 0.5899727940559387. Validation Accuracy: 62.5
Epoch: 921. Train Loss: 0.5996864438056946. Validation Accuracy: 69.53125
Epoch: 922. Train Loss: 0.5901985764503479. Validation Accuracy: 65.885416666666667
Epoch: 923. Train Loss: 0.576833963394165. Validation Accuracy: 61.71875

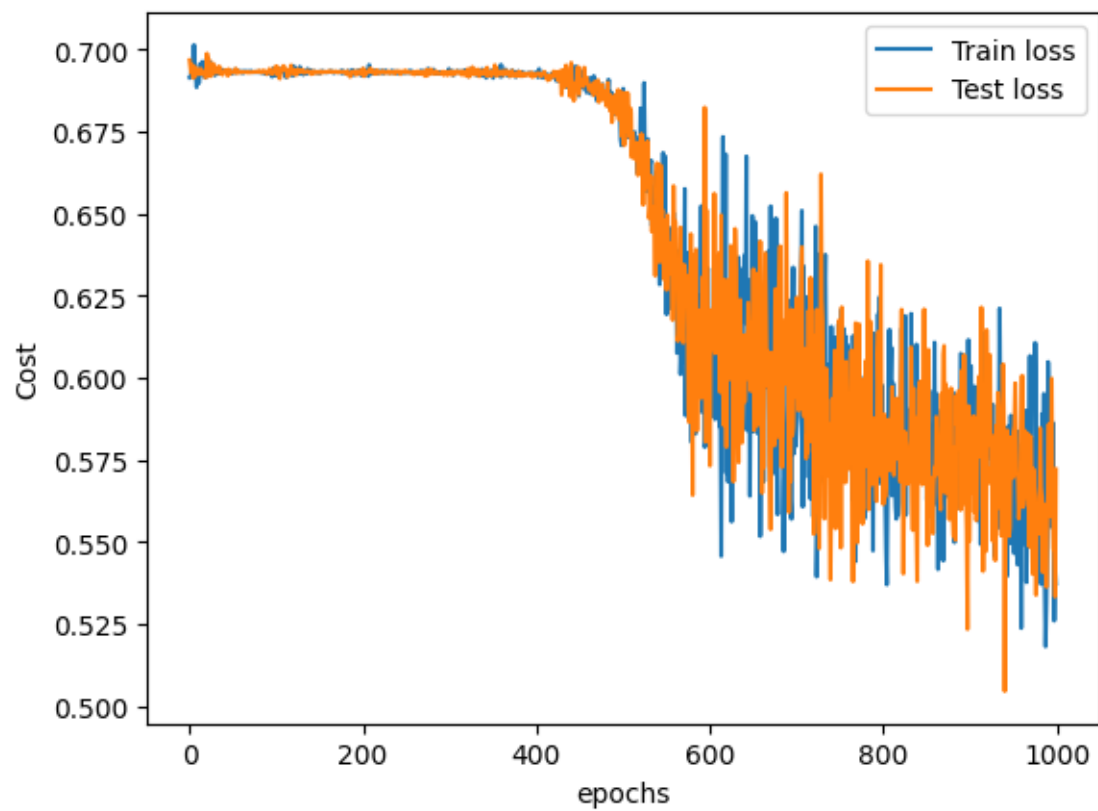
Epoch: 924. Train Loss: 0.5778588652610779. Validation Accuracy: 67.96875
Epoch: 925. Train Loss: 0.567871630191803. Validation Accuracy: 65.625
Epoch: 926. Train Loss: 0.591896116733551. Validation Accuracy:
68.48958333333333
Epoch: 927. Train Loss: 0.5654852986335754. Validation Accuracy:
66.92708333333333
Epoch: 928. Train Loss: 0.5460003614425659. Validation Accuracy:
66.14583333333333
Epoch: 929. Train Loss: 0.5453867316246033. Validation Accuracy:
67.44791666666667
Epoch: 930. Train Loss: 0.5772282481193542. Validation Accuracy:
64.58333333333333
Epoch: 931. Train Loss: 0.5540239214897156. Validation Accuracy:
69.01041666666667
Epoch: 932. Train Loss: 0.5593951940536499. Validation Accuracy:
65.36458333333333
Epoch: 933. Train Loss: 0.5737679600715637. Validation Accuracy: 65.625
Epoch: 934. Train Loss: 0.6211115717887878. Validation Accuracy:
66.92708333333333
Epoch: 935. Train Loss: 0.588057816028595. Validation Accuracy: 65.625
Epoch: 936. Train Loss: 0.5877144932746887. Validation Accuracy:
72.39583333333333
Epoch: 937. Train Loss: 0.5851889848709106. Validation Accuracy:
66.92708333333333
Epoch: 938. Train Loss: 0.5595641136169434. Validation Accuracy:
63.54166666666666
Epoch: 939. Train Loss: 0.5777612924575806. Validation Accuracy:
62.76041666666666
Epoch: 940. Train Loss: 0.5843032002449036. Validation Accuracy:
74.47916666666667
Epoch: 941. Train Loss: 0.5790770053863525. Validation Accuracy: 69.53125
Epoch: 942. Train Loss: 0.5654383897781372. Validation Accuracy:
60.67708333333333
Epoch: 943. Train Loss: 0.5397272109985352. Validation Accuracy:
62.76041666666666
Epoch: 944. Train Loss: 0.5852265357971191. Validation Accuracy:
65.88541666666667
Epoch: 945. Train Loss: 0.5732946991920471. Validation Accuracy:
67.70833333333333
Epoch: 946. Train Loss: 0.5495984554290771. Validation Accuracy: 68.75
Epoch: 947. Train Loss: 0.5885199904441833. Validation Accuracy:
62.23958333333333
Epoch: 948. Train Loss: 0.5689793229103088. Validation Accuracy: 67.1875
Epoch: 949. Train Loss: 0.5775492191314697. Validation Accuracy:
64.32291666666667
Epoch: 950. Train Loss: 0.5793318748474121. Validation Accuracy: 66.40625
Epoch: 951. Train Loss: 0.5465123057365417. Validation Accuracy:
66.14583333333333

Epoch: 952. Train Loss: 0.5646604895591736. Validation Accuracy: 63.28125
 Epoch: 953. Train Loss: 0.55174320936203. Validation Accuracy: 67.70833333333333
 Epoch: 954. Train Loss: 0.5837104320526123. Validation Accuracy:
 64.32291666666667
 Epoch: 955. Train Loss: 0.5430651903152466. Validation Accuracy: 65.625
 Epoch: 956. Train Loss: 0.5738297700881958. Validation Accuracy:
 69.27083333333333
 Epoch: 957. Train Loss: 0.5600274205207825. Validation Accuracy:
 66.14583333333333
 Epoch: 958. Train Loss: 0.5765594840049744. Validation Accuracy:
 63.80208333333333
 Epoch: 959. Train Loss: 0.5237921476364136. Validation Accuracy:
 64.32291666666667
 Epoch: 960. Train Loss: 0.5797081589698792. Validation Accuracy:
 65.10416666666667
 Epoch: 961. Train Loss: 0.5674005746841431. Validation Accuracy: 67.96875
 Epoch: 962. Train Loss: 0.5494719743728638. Validation Accuracy:
 65.10416666666667
 Epoch: 963. Train Loss: 0.5568471550941467. Validation Accuracy: 63.28125
 Epoch: 964. Train Loss: 0.5900189876556396. Validation Accuracy:
 68.48958333333333
 Epoch: 965. Train Loss: 0.5377373099327087. Validation Accuracy: 62.5
 Epoch: 966. Train Loss: 0.5671347379684448. Validation Accuracy: 63.28125
 Epoch: 967. Train Loss: 0.5556296706199646. Validation Accuracy: 68.75
 Epoch: 968. Train Loss: 0.5830028653144836. Validation Accuracy:
 69.27083333333333
 Epoch: 969. Train Loss: 0.6066545844078064. Validation Accuracy:
 70.05208333333333
 Epoch: 970. Train Loss: 0.564338743686676. Validation Accuracy:
 61.19791666666667
 Epoch: 971. Train Loss: 0.5700691342353821. Validation Accuracy: 66.40625
 Epoch: 972. Train Loss: 0.5525580644607544. Validation Accuracy: 67.1875
 Epoch: 973. Train Loss: 0.5811797976493835. Validation Accuracy: 67.96875
 Epoch: 974. Train Loss: 0.5431591868400574. Validation Accuracy: 68.75
 Epoch: 975. Train Loss: 0.6106629967689514. Validation Accuracy:
 67.44791666666667
 Epoch: 976. Train Loss: 0.5879412293434143. Validation Accuracy: 71.09375
 Epoch: 977. Train Loss: 0.5683459043502808. Validation Accuracy:
 66.66666666666667
 Epoch: 978. Train Loss: 0.5626082420349121. Validation Accuracy: 67.96875
 Epoch: 979. Train Loss: 0.5730915069580078. Validation Accuracy:
 69.01041666666667
 Epoch: 980. Train Loss: 0.5538055300712585. Validation Accuracy: 66.40625
 Epoch: 981. Train Loss: 0.5811148285865784. Validation Accuracy:
 66.92708333333333
 Epoch: 982. Train Loss: 0.5371282696723938. Validation Accuracy:
 71.35416666666667
 Epoch: 983. Train Loss: 0.5889729857444763. Validation Accuracy:

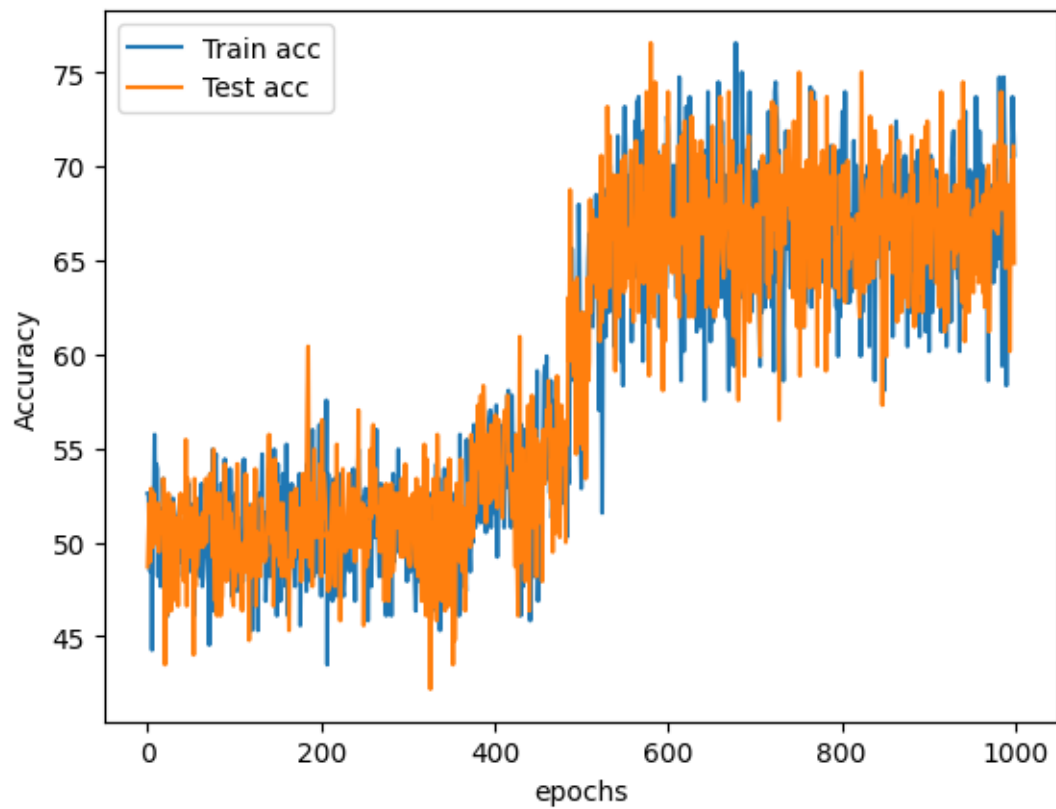
69.79166666666667
Epoch: 984. Train Loss: 0.5678612589836121. Validation Accuracy:
73.95833333333333
Epoch: 985. Train Loss: 0.5951240658760071. Validation Accuracy:
67.70833333333333
Epoch: 986. Train Loss: 0.5400359034538269. Validation Accuracy: 68.75
Epoch: 987. Train Loss: 0.5182098746299744. Validation Accuracy:
68.22916666666667
Epoch: 988. Train Loss: 0.5314128994941711. Validation Accuracy: 71.09375
Epoch: 989. Train Loss: 0.5518538951873779. Validation Accuracy:
64.58333333333333
Epoch: 990. Train Loss: 0.6048387885093689. Validation Accuracy:
69.01041666666667
Epoch: 991. Train Loss: 0.5903801321983337. Validation Accuracy:
65.36458333333333
Epoch: 992. Train Loss: 0.5715198516845703. Validation Accuracy:
65.88541666666667
Epoch: 993. Train Loss: 0.5807161927223206. Validation Accuracy:
69.01041666666667
Epoch: 994. Train Loss: 0.5545793175697327. Validation Accuracy: 60.15625
Epoch: 995. Train Loss: 0.5864464640617371. Validation Accuracy:
67.44791666666667
Epoch: 996. Train Loss: 0.5525132417678833. Validation Accuracy: 70.3125
Epoch: 997. Train Loss: 0.5260427594184875. Validation Accuracy:
68.22916666666667
Epoch: 998. Train Loss: 0.5430564284324646. Validation Accuracy: 71.09375
Epoch: 999. Train Loss: 0.5373022556304932. Validation Accuracy: 64.84375

Train and test plots

```
[64]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



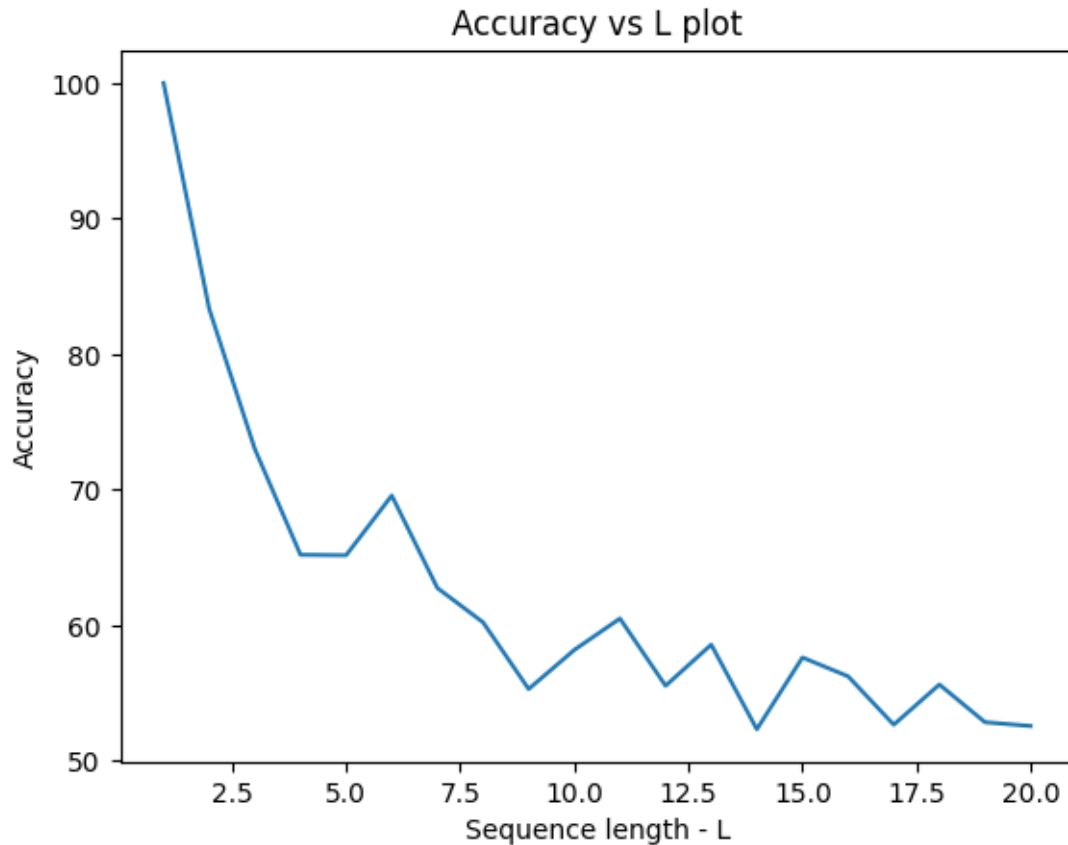
Train loss value after 1000 epochs: 0.5373022556304932
Vaildation loss value after 1000 epochs: 0.572155237197876



Best Test Accuracy: 76.5625%

Bitwise Accuracy vs Length

```
[65]: plot_accuracy_vs_length(model)
```



9.6.3 Hidden State Size = 10

```
[66]: HIDDEN_DIM = 10
```

```
[67]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
      criterion = nn.CrossEntropyLoss()
      optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[68]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
      ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.6988318562507629. Validation Accuracy:
48.697916666666664
Epoch: 1. Train Loss: 0.6959030628204346. Validation Accuracy:
49.479166666666664
Epoch: 2. Train Loss: 0.6925856471061707. Validation Accuracy:
51.822916666666664
Epoch: 3. Train Loss: 0.6948150992393494. Validation Accuracy:
```

52.604166666666664
Epoch: 4. Train Loss: 0.6923754215240479. Validation Accuracy: 50.520833333333336
Epoch: 5. Train Loss: 0.6975924372673035. Validation Accuracy: 44.791666666666664
Epoch: 6. Train Loss: 0.6995091438293457. Validation Accuracy: 51.302083333333336
Epoch: 7. Train Loss: 0.6935998797416687. Validation Accuracy: 50.78125
Epoch: 8. Train Loss: 0.7013750672340393. Validation Accuracy: 48.958333333333336
Epoch: 9. Train Loss: 0.6939648985862732. Validation Accuracy: 50.0
Epoch: 10. Train Loss: 0.6920711398124695. Validation Accuracy: 52.083333333333336
Epoch: 11. Train Loss: 0.6928055882453918. Validation Accuracy: 50.0
Epoch: 12. Train Loss: 0.6951730251312256. Validation Accuracy: 50.78125
Epoch: 13. Train Loss: 0.6956940293312073. Validation Accuracy: 53.90625
Epoch: 14. Train Loss: 0.6914329528808594. Validation Accuracy: 49.739583333333336
Epoch: 15. Train Loss: 0.6924953460693359. Validation Accuracy: 49.21875
Epoch: 16. Train Loss: 0.6935402750968933. Validation Accuracy: 51.5625
Epoch: 17. Train Loss: 0.6929517388343811. Validation Accuracy: 51.041666666666664
Epoch: 18. Train Loss: 0.6926807761192322. Validation Accuracy: 52.604166666666664
Epoch: 19. Train Loss: 0.6920299530029297. Validation Accuracy: 49.739583333333336
Epoch: 20. Train Loss: 0.6931350231170654. Validation Accuracy: 51.822916666666664
Epoch: 21. Train Loss: 0.6913163661956787. Validation Accuracy: 47.65625
Epoch: 22. Train Loss: 0.6914841532707214. Validation Accuracy: 51.302083333333336
Epoch: 23. Train Loss: 0.6947920918464661. Validation Accuracy: 50.260416666666664
Epoch: 24. Train Loss: 0.6921439170837402. Validation Accuracy: 50.78125
Epoch: 25. Train Loss: 0.6931405067443848. Validation Accuracy: 51.041666666666664
Epoch: 26. Train Loss: 0.6937363743782043. Validation Accuracy: 51.822916666666664
Epoch: 27. Train Loss: 0.6931006908416748. Validation Accuracy: 51.041666666666664
Epoch: 28. Train Loss: 0.6936716437339783. Validation Accuracy: 50.260416666666664
Epoch: 29. Train Loss: 0.6919012665748596. Validation Accuracy: 49.21875
Epoch: 30. Train Loss: 0.6927067637443542. Validation Accuracy: 49.479166666666664
Epoch: 31. Train Loss: 0.6944049000740051. Validation Accuracy: 49.739583333333336
Epoch: 32. Train Loss: 0.6938270926475525. Validation Accuracy:

48.958333333333336
Epoch: 33. Train Loss: 0.6940999031066895. Validation Accuracy:
49.479166666666664
Epoch: 34. Train Loss: 0.6926043629646301. Validation Accuracy: 51.5625
Epoch: 35. Train Loss: 0.6916785836219788. Validation Accuracy:
47.916666666666664
Epoch: 36. Train Loss: 0.6938214302062988. Validation Accuracy: 53.125
Epoch: 37. Train Loss: 0.6924453377723694. Validation Accuracy:
46.354166666666664
Epoch: 38. Train Loss: 0.6933162808418274. Validation Accuracy:
53.385416666666664
Epoch: 39. Train Loss: 0.6926672458648682. Validation Accuracy: 50.78125
Epoch: 40. Train Loss: 0.6936468482017517. Validation Accuracy:
49.479166666666664
Epoch: 41. Train Loss: 0.6935093998908997. Validation Accuracy:
44.010416666666664
Epoch: 42. Train Loss: 0.6909319758415222. Validation Accuracy: 48.4375
Epoch: 43. Train Loss: 0.6935346126556396. Validation Accuracy:
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Epoch: 44. Train Loss: 0.6924728751182556. Validation Accuracy: 50.78125
Epoch: 45. Train Loss: 0.693342387676239. Validation Accuracy:
49.739583333333336
Epoch: 46. Train Loss: 0.6929659247398376. Validation Accuracy: 50.0
Epoch: 47. Train Loss: 0.691178023815155. Validation Accuracy: 47.65625
Epoch: 48. Train Loss: 0.6953701972961426. Validation Accuracy: 54.6875
Epoch: 49. Train Loss: 0.6936566233634949. Validation Accuracy:
48.177083333333336
Epoch: 50. Train Loss: 0.6914176940917969. Validation Accuracy:
49.479166666666664
Epoch: 51. Train Loss: 0.6951994895935059. Validation Accuracy:
49.739583333333336
Epoch: 52. Train Loss: 0.6941540837287903. Validation Accuracy:
52.083333333333336
Epoch: 53. Train Loss: 0.6935651302337646. Validation Accuracy:
49.739583333333336
Epoch: 54. Train Loss: 0.6938828825950623. Validation Accuracy:
50.260416666666664
Epoch: 55. Train Loss: 0.6938492655754089. Validation Accuracy:
51.302083333333336
Epoch: 56. Train Loss: 0.692683219909668. Validation Accuracy: 50.78125
Epoch: 57. Train Loss: 0.691878080368042. Validation Accuracy:
55.208333333333336
Epoch: 58. Train Loss: 0.6921830177307129. Validation Accuracy:
52.864583333333336
Epoch: 59. Train Loss: 0.6947948336601257. Validation Accuracy: 50.78125
Epoch: 60. Train Loss: 0.6943119168281555. Validation Accuracy: 52.34375
Epoch: 61. Train Loss: 0.6944556832313538. Validation Accuracy:
51.822916666666664

Epoch: 62. Train Loss: 0.6936197280883789. Validation Accuracy:
49.479166666666664
Epoch: 63. Train Loss: 0.6926400065422058. Validation Accuracy: 50.0
Epoch: 64. Train Loss: 0.6944689750671387. Validation Accuracy:
54.947916666666664
Epoch: 65. Train Loss: 0.6935911178588867. Validation Accuracy:
48.697916666666664
Epoch: 66. Train Loss: 0.6937183737754822. Validation Accuracy: 46.875
Epoch: 67. Train Loss: 0.693818986415863. Validation Accuracy:
50.260416666666664
Epoch: 68. Train Loss: 0.6947608590126038. Validation Accuracy:
50.520833333333336
Epoch: 69. Train Loss: 0.6926872730255127. Validation Accuracy:
53.385416666666664
Epoch: 70. Train Loss: 0.6941527724266052. Validation Accuracy:
46.354166666666664
Epoch: 71. Train Loss: 0.6942980289459229. Validation Accuracy:
48.177083333333336
Epoch: 72. Train Loss: 0.6923591494560242. Validation Accuracy:
51.302083333333336
Epoch: 73. Train Loss: 0.6945690512657166. Validation Accuracy: 52.34375
Epoch: 74. Train Loss: 0.6939175128936768. Validation Accuracy:
54.427083333333336
Epoch: 75. Train Loss: 0.6913091540336609. Validation Accuracy:
52.864583333333336
Epoch: 76. Train Loss: 0.6950051784515381. Validation Accuracy: 51.5625
Epoch: 77. Train Loss: 0.692831814289093. Validation Accuracy:
49.739583333333336
Epoch: 78. Train Loss: 0.6917921900749207. Validation Accuracy: 48.4375
Epoch: 79. Train Loss: 0.6935485005378723. Validation Accuracy:
51.041666666666664
Epoch: 80. Train Loss: 0.6936187148094177. Validation Accuracy:
49.739583333333336
Epoch: 81. Train Loss: 0.6931586265563965. Validation Accuracy:
52.083333333333336
Epoch: 82. Train Loss: 0.6935064792633057. Validation Accuracy: 51.5625
Epoch: 83. Train Loss: 0.6923710703849792. Validation Accuracy:
52.083333333333336
Epoch: 84. Train Loss: 0.6936864852905273. Validation Accuracy:
48.177083333333336
Epoch: 85. Train Loss: 0.6945724487304688. Validation Accuracy:
51.822916666666664
Epoch: 86. Train Loss: 0.693382978439331. Validation Accuracy: 49.21875
Epoch: 87. Train Loss: 0.6928471922874451. Validation Accuracy:
52.864583333333336
Epoch: 88. Train Loss: 0.6921049952507019. Validation Accuracy:
48.958333333333336
Epoch: 89. Train Loss: 0.6948958039283752. Validation Accuracy: 50.0

Epoch: 90. Train Loss: 0.6934805512428284. Validation Accuracy: 47.916666666666664
Epoch: 91. Train Loss: 0.6929502487182617. Validation Accuracy: 47.135416666666664
Epoch: 92. Train Loss: 0.6923055052757263. Validation Accuracy: 52.864583333333336
Epoch: 93. Train Loss: 0.6936941146850586. Validation Accuracy: 48.4375
Epoch: 94. Train Loss: 0.6930637359619141. Validation Accuracy: 52.083333333333336
Epoch: 95. Train Loss: 0.6930752396583557. Validation Accuracy: 49.21875
Epoch: 96. Train Loss: 0.6925237774848938. Validation Accuracy: 49.21875
Epoch: 97. Train Loss: 0.6922027468681335. Validation Accuracy: 50.260416666666664
Epoch: 98. Train Loss: 0.6933538317680359. Validation Accuracy: 52.083333333333336
Epoch: 99. Train Loss: 0.6939549446105957. Validation Accuracy: 51.5625
Epoch: 100. Train Loss: 0.6941204071044922. Validation Accuracy: 48.958333333333336
Epoch: 101. Train Loss: 0.6933126449584961. Validation Accuracy: 48.4375
Epoch: 102. Train Loss: 0.691913366317749. Validation Accuracy: 50.520833333333336
Epoch: 103. Train Loss: 0.6924216747283936. Validation Accuracy: 50.78125
Epoch: 104. Train Loss: 0.6908969879150391. Validation Accuracy: 50.260416666666664
Epoch: 105. Train Loss: 0.6918671727180481. Validation Accuracy: 53.125
Epoch: 106. Train Loss: 0.6921815276145935. Validation Accuracy: 47.395833333333336
Epoch: 107. Train Loss: 0.6931411623954773. Validation Accuracy: 48.958333333333336
Epoch: 108. Train Loss: 0.6923331618309021. Validation Accuracy: 51.822916666666664
Epoch: 109. Train Loss: 0.6942484378814697. Validation Accuracy: 46.09375
Epoch: 110. Train Loss: 0.6945736408233643. Validation Accuracy: 52.604166666666664
Epoch: 111. Train Loss: 0.6931113600730896. Validation Accuracy: 57.291666666666664
Epoch: 112. Train Loss: 0.694293737411499. Validation Accuracy: 48.4375
Epoch: 113. Train Loss: 0.6914839744567871. Validation Accuracy: 50.0
Epoch: 114. Train Loss: 0.6927106976509094. Validation Accuracy: 54.427083333333336
Epoch: 115. Train Loss: 0.6935461163520813. Validation Accuracy: 52.604166666666664
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Epoch: 117. Train Loss: 0.6924347281455994. Validation Accuracy: 53.125
Epoch: 118. Train Loss: 0.6947243213653564. Validation Accuracy: 44.791666666666664
Epoch: 119. Train Loss: 0.691062867641449. Validation Accuracy: 52.864583333333336

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Epoch: 122. Train Loss: 0.694973886013031. Validation Accuracy:
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Epoch: 123. Train Loss: 0.6942956447601318. Validation Accuracy: 50.0
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Epoch: 129. Train Loss: 0.6921164989471436. Validation Accuracy:
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Epoch: 130. Train Loss: 0.6947889924049377. Validation Accuracy:
48.17708333333336
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Epoch: 132. Train Loss: 0.6929294466972351. Validation Accuracy:
47.916666666666664
Epoch: 133. Train Loss: 0.6935225129127502. Validation Accuracy: 50.78125
Epoch: 134. Train Loss: 0.6959170699119568. Validation Accuracy:
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Epoch: 135. Train Loss: 0.6916821599006653. Validation Accuracy:
51.041666666666664
Epoch: 136. Train Loss: 0.6922094821929932. Validation Accuracy:
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Epoch: 141. Train Loss: 0.6927387714385986. Validation Accuracy:
48.95833333333336
Epoch: 142. Train Loss: 0.6941967606544495. Validation Accuracy:
51.041666666666664
Epoch: 143. Train Loss: 0.6919535994529724. Validation Accuracy: 47.65625
Epoch: 144. Train Loss: 0.6929078102111816. Validation Accuracy: 51.5625
Epoch: 145. Train Loss: 0.6934921145439148. Validation Accuracy:
49.73958333333336
Epoch: 146. Train Loss: 0.6944335103034973. Validation Accuracy: 51.5625
Epoch: 147. Train Loss: 0.6940838694572449. Validation Accuracy: 52.34375
Epoch: 148. Train Loss: 0.6952939629554749. Validation Accuracy:
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Epoch: 149. Train Loss: 0.6918825507164001. Validation Accuracy: 48.4375

Epoch: 150. Train Loss: 0.6928823590278625. Validation Accuracy: 52.08333333333336

Epoch: 151. Train Loss: 0.6932371258735657. Validation Accuracy: 48.4375

Epoch: 152. Train Loss: 0.6927728652954102. Validation Accuracy: 51.5625

Epoch: 153. Train Loss: 0.6933568120002747. Validation Accuracy: 53.64583333333336

Epoch: 154. Train Loss: 0.6925925612449646. Validation Accuracy: 54.166666666666664

Epoch: 155. Train Loss: 0.6927292943000793. Validation Accuracy: 53.90625

Epoch: 156. Train Loss: 0.6928824782371521. Validation Accuracy: 49.73958333333336

Epoch: 157. Train Loss: 0.6936324238777161. Validation Accuracy: 43.229166666666664

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Epoch: 159. Train Loss: 0.6941528916358948. Validation Accuracy: 52.86458333333336

Epoch: 160. Train Loss: 0.6934349536895752. Validation Accuracy: 45.83333333333336

Epoch: 161. Train Loss: 0.6936445832252502. Validation Accuracy: 49.73958333333336

Epoch: 162. Train Loss: 0.6936821937561035. Validation Accuracy: 48.17708333333336

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Epoch: 164. Train Loss: 0.6947300434112549. Validation Accuracy: 53.125

Epoch: 165. Train Loss: 0.6924915313720703. Validation Accuracy: 52.34375

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Epoch: 167. Train Loss: 0.6920985579490662. Validation Accuracy: 49.479166666666664

Epoch: 168. Train Loss: 0.6933042407035828. Validation Accuracy: 53.90625

Epoch: 169. Train Loss: 0.6930472254753113. Validation Accuracy: 48.697916666666664

Epoch: 170. Train Loss: 0.6924137473106384. Validation Accuracy: 48.697916666666664

Epoch: 171. Train Loss: 0.6931148171424866. Validation Accuracy: 57.8125

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Epoch: 173. Train Loss: 0.6937968730926514. Validation Accuracy: 52.08333333333336

Epoch: 174. Train Loss: 0.6911010146141052. Validation Accuracy: 46.354166666666664

Epoch: 175. Train Loss: 0.6924447417259216. Validation Accuracy: 51.5625

Epoch: 176. Train Loss: 0.6938830018043518. Validation Accuracy: 46.354166666666664

Epoch: 177. Train Loss: 0.6947605609893799. Validation Accuracy: 52.86458333333336

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Epoch: 182. Train Loss: 0.6939031481742859. Validation Accuracy: 50.260416666666664
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Epoch: 192. Train Loss: 0.6921824812889099. Validation Accuracy: 55.208333333333336
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Epoch: 204. Train Loss: 0.6934587359428406. Validation Accuracy: 51.041666666666664
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Epoch: 208. Train Loss: 0.693195104598999. Validation Accuracy:
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Epoch: 213. Train Loss: 0.6926777362823486. Validation Accuracy: 53.125
Epoch: 214. Train Loss: 0.6935954689979553. Validation Accuracy:
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48.958333333333336
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54.1666666666666664

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Epoch: 268. Train Loss: 0.6927174925804138. Validation Accuracy: 47.395833333333336
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Epoch: 349. Train Loss: 0.6957877278327942. Validation Accuracy: 56.770833333333336
Epoch: 350. Train Loss: 0.6891202330589294. Validation Accuracy: 57.03125
Epoch: 351. Train Loss: 0.6896827816963196. Validation Accuracy: 55.208333333333336
Epoch: 352. Train Loss: 0.6924336552619934. Validation Accuracy: 47.65625
Epoch: 353. Train Loss: 0.6886679530143738. Validation Accuracy: 52.864583333333336
Epoch: 354. Train Loss: 0.6899325847625732. Validation Accuracy: 52.083333333333336
Epoch: 355. Train Loss: 0.6900086402893066. Validation Accuracy: 51.822916666666664

Epoch: 356. Train Loss: 0.687633216381073. Validation Accuracy: 48.4375
Epoch: 357. Train Loss: 0.6932985186576843. Validation Accuracy: 53.125
Epoch: 358. Train Loss: 0.6875465512275696. Validation Accuracy:
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Epoch: 359. Train Loss: 0.6918563842773438. Validation Accuracy:
53.3854166666666664
Epoch: 360. Train Loss: 0.6879941821098328. Validation Accuracy: 50.78125
Epoch: 361. Train Loss: 0.6915557384490967. Validation Accuracy: 58.59375
Epoch: 362. Train Loss: 0.690058708190918. Validation Accuracy:
54.427083333333336
Epoch: 363. Train Loss: 0.6883764266967773. Validation Accuracy: 50.78125
Epoch: 364. Train Loss: 0.6905826926231384. Validation Accuracy:
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57.2916666666666664
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Epoch: 369. Train Loss: 0.6825642585754395. Validation Accuracy:
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Epoch: 426. Train Loss: 0.6679868698120117. Validation Accuracy: 57.03125

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Epoch: 613. Train Loss: 0.6227659583091736. Validation Accuracy: 66.92708333333333

Epoch: 614. Train Loss: 0.5843758583068848. Validation Accuracy: 61.197916666666664

Epoch: 615. Train Loss: 0.5933836102485657. Validation Accuracy: 66.40625

Epoch: 616. Train Loss: 0.6292480230331421. Validation Accuracy: 63.802083333333336

Epoch: 617. Train Loss: 0.5735276341438293. Validation Accuracy: 70.05208333333333

Epoch: 618. Train Loss: 0.5548220872879028. Validation Accuracy: 68.75

Epoch: 619. Train Loss: 0.5480058789253235. Validation Accuracy: 71.875

Epoch: 620. Train Loss: 0.5749014019966125. Validation Accuracy: 69.79166666666667

Epoch: 621. Train Loss: 0.6018645167350769. Validation Accuracy: 66.92708333333333

Epoch: 622. Train Loss: 0.5586965680122375. Validation Accuracy: 64.84375

Epoch: 623. Train Loss: 0.5547446608543396. Validation Accuracy: 68.22916666666667

Epoch: 624. Train Loss: 0.5865623354911804. Validation Accuracy: 70.3125

Epoch: 625. Train Loss: 0.6025711894035339. Validation Accuracy: 66.40625

Epoch: 626. Train Loss: 0.5410320162773132. Validation Accuracy: 64.58333333333333

Epoch: 627. Train Loss: 0.6020893454551697. Validation Accuracy: 67.70833333333333

Epoch: 628. Train Loss: 0.5733242630958557. Validation Accuracy: 66.40625

Epoch: 629. Train Loss: 0.5764301419258118. Validation Accuracy: 69.79166666666667

Epoch: 630. Train Loss: 0.5880752205848694. Validation Accuracy: 70.3125

Epoch: 631. Train Loss: 0.5692303776741028. Validation Accuracy: 67.44791666666667

Epoch: 632. Train Loss: 0.6050595641136169. Validation Accuracy: 65.36458333333333

Epoch: 633. Train Loss: 0.547593355178833. Validation Accuracy: 69.79166666666667

Epoch: 634. Train Loss: 0.5431990623474121. Validation Accuracy: 65.36458333333333

Epoch: 635. Train Loss: 0.5813465118408203. Validation Accuracy: 75.0

Epoch: 636. Train Loss: 0.595583438873291. Validation Accuracy: 69.01041666666667

Epoch: 637. Train Loss: 0.5819310545921326. Validation Accuracy: 69.53125

Epoch: 638. Train Loss: 0.579020082950592. Validation Accuracy: 60.9375

Epoch: 639. Train Loss: 0.5641009211540222. Validation Accuracy: 64.58333333333333

Epoch: 640. Train Loss: 0.5790275931358337. Validation Accuracy: 67.1875

Epoch: 641. Train Loss: 0.5964980125427246. Validation Accuracy: 64.84375

Epoch: 642. Train Loss: 0.5585523247718811. Validation Accuracy: 66.66666666666667

Epoch: 643. Train Loss: 0.6204922199249268. Validation Accuracy:

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Epoch: 644. Train Loss: 0.5747092366218567. Validation Accuracy:
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Epoch: 645. Train Loss: 0.5492972135543823. Validation Accuracy: 70.3125
Epoch: 646. Train Loss: 0.5640350580215454. Validation Accuracy:
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Epoch: 647. Train Loss: 0.564265251159668. Validation Accuracy: 58.59375
Epoch: 648. Train Loss: 0.6031796336174011. Validation Accuracy: 68.75
Epoch: 649. Train Loss: 0.5447726845741272. Validation Accuracy:
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Epoch: 653. Train Loss: 0.5954809188842773. Validation Accuracy:
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Epoch: 654. Train Loss: 0.5590959191322327. Validation Accuracy: 67.1875
Epoch: 655. Train Loss: 0.6112939715385437. Validation Accuracy:
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Epoch: 656. Train Loss: 0.5904656052589417. Validation Accuracy:
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Epoch: 657. Train Loss: 0.5753665566444397. Validation Accuracy:
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Epoch: 658. Train Loss: 0.6041691303253174. Validation Accuracy:
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Epoch: 659. Train Loss: 0.564551055431366. Validation Accuracy:
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Epoch: 662. Train Loss: 0.5405563116073608. Validation Accuracy: 63.28125
Epoch: 663. Train Loss: 0.5456482768058777. Validation Accuracy:
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Epoch: 664. Train Loss: 0.5853548049926758. Validation Accuracy: 66.40625
Epoch: 665. Train Loss: 0.5731678605079651. Validation Accuracy:
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Epoch: 666. Train Loss: 0.5744734406471252. Validation Accuracy:
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Epoch: 667. Train Loss: 0.5620343089103699. Validation Accuracy:
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Epoch: 668. Train Loss: 0.5929344296455383. Validation Accuracy: 66.40625
Epoch: 669. Train Loss: 0.553827166557312. Validation Accuracy: 64.0625
Epoch: 670. Train Loss: 0.5282624363899231. Validation Accuracy: 69.53125
Epoch: 671. Train Loss: 0.5870228409767151. Validation Accuracy:
73.697916666666667

Epoch: 672. Train Loss: 0.5680420994758606. Validation Accuracy: 67.96875
 Epoch: 673. Train Loss: 0.561714231967926. Validation Accuracy: 69.53125
 Epoch: 674. Train Loss: 0.5542636513710022. Validation Accuracy: 63.28125
 Epoch: 675. Train Loss: 0.5761098265647888. Validation Accuracy:
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 Epoch: 676. Train Loss: 0.5569320917129517. Validation Accuracy: 67.96875
 Epoch: 677. Train Loss: 0.5746877789497375. Validation Accuracy: 67.96875
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 Epoch: 698. Train Loss: 0.5729309320449829. Validation Accuracy:
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 71.61458333333333
 Epoch: 701. Train Loss: 0.5651291012763977. Validation Accuracy: 74.21875

Epoch: 702. Train Loss: 0.5578093528747559. Validation Accuracy: 71.35416666666667
Epoch: 703. Train Loss: 0.588784396648407. Validation Accuracy: 67.70833333333333
Epoch: 704. Train Loss: 0.5629517436027527. Validation Accuracy: 63.541666666666664
Epoch: 705. Train Loss: 0.5577277541160583. Validation Accuracy: 67.96875
Epoch: 706. Train Loss: 0.5831334590911865. Validation Accuracy: 68.48958333333333
Epoch: 707. Train Loss: 0.545973002910614. Validation Accuracy: 65.88541666666667
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Epoch: 709. Train Loss: 0.5660455822944641. Validation Accuracy: 66.14583333333333
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Epoch: 711. Train Loss: 0.5700057148933411. Validation Accuracy: 62.760416666666664
Epoch: 712. Train Loss: 0.5557743906974792. Validation Accuracy: 70.83333333333333
Epoch: 713. Train Loss: 0.5675603747367859. Validation Accuracy: 59.635416666666664
Epoch: 714. Train Loss: 0.5554028153419495. Validation Accuracy: 72.65625
Epoch: 715. Train Loss: 0.562053918838501. Validation Accuracy: 63.020833333333336
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Epoch: 717. Train Loss: 0.6230863928794861. Validation Accuracy: 63.802083333333336
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Epoch: 725. Train Loss: 0.5657364726066589. Validation Accuracy: 71.875
Epoch: 726. Train Loss: 0.5587359070777893. Validation Accuracy: 65.88541666666667
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Epoch: 744. Train Loss: 0.5787689089775085. Validation Accuracy: 63.28125
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Epoch: 752. Train Loss: 0.5636568665504456. Validation Accuracy: 65.36458333333333
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66.14583333333333
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Epoch: 787. Train Loss: 0.560528576374054. Validation Accuracy:
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Epoch: 802. Train Loss: 0.5935609936714172. Validation Accuracy:
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Epoch: 807. Train Loss: 0.5666193962097168. Validation Accuracy:
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Epoch: 858. Train Loss: 0.5581231713294983. Validation Accuracy:
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71.35416666666667
Epoch: 867. Train Loss: 0.5470980405807495. Validation Accuracy:
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Epoch: 869. Train Loss: 0.5504928231239319. Validation Accuracy:
67.70833333333333

Epoch: 870. Train Loss: 0.5487344861030579. Validation Accuracy: 67.1875
 Epoch: 871. Train Loss: 0.5672512650489807. Validation Accuracy: 64.58333333333333
 Epoch: 872. Train Loss: 0.5580820441246033. Validation Accuracy: 69.01041666666667
 Epoch: 873. Train Loss: 0.5459486842155457. Validation Accuracy: 69.79166666666667
 Epoch: 874. Train Loss: 0.5597912073135376. Validation Accuracy: 67.1875
 Epoch: 875. Train Loss: 0.564419686794281. Validation Accuracy: 66.40625
 Epoch: 876. Train Loss: 0.5634262561798096. Validation Accuracy: 70.57291666666667
 Epoch: 877. Train Loss: 0.5610924363136292. Validation Accuracy: 67.70833333333333
 Epoch: 878. Train Loss: 0.5441541075706482. Validation Accuracy: 68.22916666666667
 Epoch: 879. Train Loss: 0.5523706078529358. Validation Accuracy: 61.71875
 Epoch: 880. Train Loss: 0.537667989730835. Validation Accuracy: 62.760416666666664
 Epoch: 881. Train Loss: 0.5651074051856995. Validation Accuracy: 69.01041666666667
 Epoch: 882. Train Loss: 0.5850856900215149. Validation Accuracy: 67.1875
 Epoch: 883. Train Loss: 0.5555112361907959. Validation Accuracy: 68.48958333333333
 Epoch: 884. Train Loss: 0.5782819390296936. Validation Accuracy: 62.760416666666664
 Epoch: 885. Train Loss: 0.5488541126251221. Validation Accuracy: 67.70833333333333
 Epoch: 886. Train Loss: 0.5769123435020447. Validation Accuracy: 70.83333333333333
 Epoch: 887. Train Loss: 0.5495345592498779. Validation Accuracy: 63.020833333333336
 Epoch: 888. Train Loss: 0.5609104633331299. Validation Accuracy: 60.677083333333336
 Epoch: 889. Train Loss: 0.5493353009223938. Validation Accuracy: 68.22916666666667
 Epoch: 890. Train Loss: 0.5409581661224365. Validation Accuracy: 67.96875
 Epoch: 891. Train Loss: 0.5620081424713135. Validation Accuracy: 65.10416666666667
 Epoch: 892. Train Loss: 0.5628381967544556. Validation Accuracy: 70.05208333333333
 Epoch: 893. Train Loss: 0.5756047368049622. Validation Accuracy: 70.83333333333333
 Epoch: 894. Train Loss: 0.5618064403533936. Validation Accuracy: 58.854166666666664
 Epoch: 895. Train Loss: 0.5697234869003296. Validation Accuracy: 65.36458333333333
 Epoch: 896. Train Loss: 0.5896856784820557. Validation Accuracy: 69.27083333333333

Epoch: 897. Train Loss: 0.5524075627326965. Validation Accuracy: 69.01041666666667

Epoch: 898. Train Loss: 0.5653380751609802. Validation Accuracy: 66.14583333333333

Epoch: 899. Train Loss: 0.5568518042564392. Validation Accuracy: 67.96875

Epoch: 900. Train Loss: 0.5731410384178162. Validation Accuracy: 66.14583333333333

Epoch: 901. Train Loss: 0.5687119960784912. Validation Accuracy: 72.91666666666667

Epoch: 902. Train Loss: 0.5436002612113953. Validation Accuracy: 64.84375

Epoch: 903. Train Loss: 0.5816017389297485. Validation Accuracy: 70.83333333333333

Epoch: 904. Train Loss: 0.5484344363212585. Validation Accuracy: 69.53125

Epoch: 905. Train Loss: 0.5603503584861755. Validation Accuracy: 66.92708333333333

Epoch: 906. Train Loss: 0.559866726398468. Validation Accuracy: 72.91666666666667

Epoch: 907. Train Loss: 0.5594685673713684. Validation Accuracy: 68.48958333333333

Epoch: 908. Train Loss: 0.5314615368843079. Validation Accuracy: 67.96875

Epoch: 909. Train Loss: 0.5481141209602356. Validation Accuracy: 57.8125

Epoch: 910. Train Loss: 0.6063975691795349. Validation Accuracy: 71.09375

Epoch: 911. Train Loss: 0.5676890015602112. Validation Accuracy: 68.75

Epoch: 912. Train Loss: 0.5708166360855103. Validation Accuracy: 67.96875

Epoch: 913. Train Loss: 0.5382012724876404. Validation Accuracy: 64.84375

Epoch: 914. Train Loss: 0.5611919164657593. Validation Accuracy: 66.66666666666667

Epoch: 915. Train Loss: 0.5340738892555237. Validation Accuracy: 66.92708333333333

Epoch: 916. Train Loss: 0.5660317540168762. Validation Accuracy: 64.32291666666667

Epoch: 917. Train Loss: 0.5154647827148438. Validation Accuracy: 66.66666666666667

Epoch: 918. Train Loss: 0.5819840431213379. Validation Accuracy: 64.0625

Epoch: 919. Train Loss: 0.5407065749168396. Validation Accuracy: 61.458333333333336

Epoch: 920. Train Loss: 0.573904275894165. Validation Accuracy: 72.91666666666667

Epoch: 921. Train Loss: 0.5312925577163696. Validation Accuracy: 61.197916666666664

Epoch: 922. Train Loss: 0.5261864066123962. Validation Accuracy: 69.79166666666667

Epoch: 923. Train Loss: 0.5736386179924011. Validation Accuracy: 70.3125

Epoch: 924. Train Loss: 0.5362188816070557. Validation Accuracy: 57.291666666666664

Epoch: 925. Train Loss: 0.5679479837417603. Validation Accuracy: 69.79166666666667

Epoch: 926. Train Loss: 0.565396249294281. Validation Accuracy:

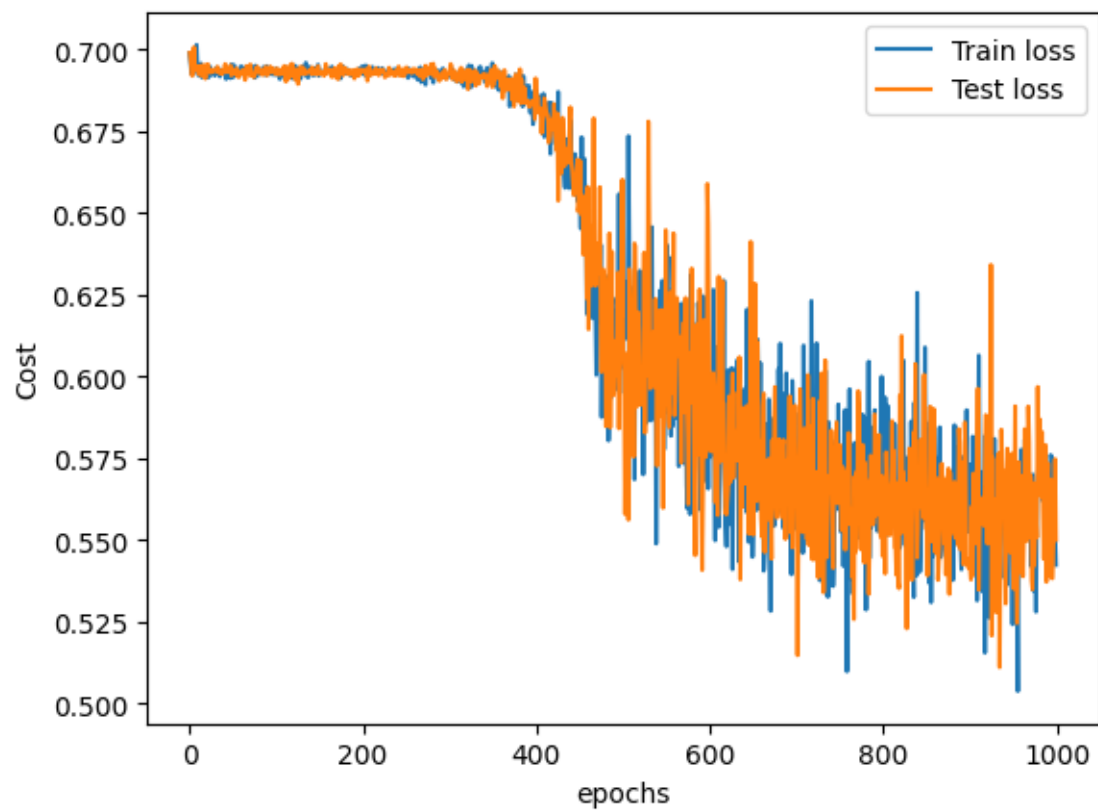
64.32291666666667
Epoch: 927. Train Loss: 0.543988049030304. Validation Accuracy:
69.79166666666667
Epoch: 928. Train Loss: 0.5808977484703064. Validation Accuracy: 66.40625
Epoch: 929. Train Loss: 0.5338470339775085. Validation Accuracy:
65.10416666666667
Epoch: 930. Train Loss: 0.5593162775039673. Validation Accuracy:
72.39583333333333
Epoch: 931. Train Loss: 0.5465791821479797. Validation Accuracy:
65.36458333333333
Epoch: 932. Train Loss: 0.5398434400558472. Validation Accuracy: 70.3125
Epoch: 933. Train Loss: 0.5697216391563416. Validation Accuracy:
61.45833333333333
Epoch: 934. Train Loss: 0.5449856519699097. Validation Accuracy:
72.39583333333333
Epoch: 935. Train Loss: 0.5562270283699036. Validation Accuracy: 68.75
Epoch: 936. Train Loss: 0.5596361756324768. Validation Accuracy:
65.10416666666667
Epoch: 937. Train Loss: 0.5583050847053528. Validation Accuracy:
68.22916666666667
Epoch: 938. Train Loss: 0.5580818057060242. Validation Accuracy:
69.27083333333333
Epoch: 939. Train Loss: 0.5655357837677002. Validation Accuracy:
68.48958333333333
Epoch: 940. Train Loss: 0.5383079648017883. Validation Accuracy: 63.28125
Epoch: 941. Train Loss: 0.5476316213607788. Validation Accuracy:
70.83333333333333
Epoch: 942. Train Loss: 0.5360186696052551. Validation Accuracy:
66.66666666666667
Epoch: 943. Train Loss: 0.5642004609107971. Validation Accuracy:
63.54166666666664
Epoch: 944. Train Loss: 0.5526873469352722. Validation Accuracy:
64.32291666666667
Epoch: 945. Train Loss: 0.5518308877944946. Validation Accuracy:
67.70833333333333
Epoch: 946. Train Loss: 0.5722346901893616. Validation Accuracy: 67.1875
Epoch: 947. Train Loss: 0.553318977355957. Validation Accuracy:
65.88541666666667
Epoch: 948. Train Loss: 0.544090211391449. Validation Accuracy:
64.32291666666667
Epoch: 949. Train Loss: 0.5241608023643494. Validation Accuracy:
71.61458333333333
Epoch: 950. Train Loss: 0.542184054851532. Validation Accuracy:
69.79166666666667
Epoch: 951. Train Loss: 0.5434247851371765. Validation Accuracy:
68.48958333333333
Epoch: 952. Train Loss: 0.5720979571342468. Validation Accuracy:
64.58333333333333

Epoch: 953. Train Loss: 0.5731229782104492. Validation Accuracy: 69.01041666666667
Epoch: 954. Train Loss: 0.5328788161277771. Validation Accuracy: 71.35416666666667
Epoch: 955. Train Loss: 0.5037238597869873. Validation Accuracy: 67.96875
Epoch: 956. Train Loss: 0.5660314559936523. Validation Accuracy: 63.02083333333336
Epoch: 957. Train Loss: 0.568666398525238. Validation Accuracy: 64.84375
Epoch: 958. Train Loss: 0.5585439801216125. Validation Accuracy: 68.48958333333333
Epoch: 959. Train Loss: 0.5775638818740845. Validation Accuracy: 61.71875
Epoch: 960. Train Loss: 0.5765231251716614. Validation Accuracy: 69.01041666666667
Epoch: 961. Train Loss: 0.560218095779419. Validation Accuracy: 68.48958333333333
Epoch: 962. Train Loss: 0.5525418519973755. Validation Accuracy: 63.28125
Epoch: 963. Train Loss: 0.5806436538696289. Validation Accuracy: 64.32291666666667
Epoch: 964. Train Loss: 0.5627732872962952. Validation Accuracy: 68.22916666666667
Epoch: 965. Train Loss: 0.570369303226471. Validation Accuracy: 65.10416666666667
Epoch: 966. Train Loss: 0.5817787647247314. Validation Accuracy: 63.28125
Epoch: 967. Train Loss: 0.577492892742157. Validation Accuracy: 59.89583333333336
Epoch: 968. Train Loss: 0.556056022644043. Validation Accuracy: 70.3125
Epoch: 969. Train Loss: 0.5688133835792542. Validation Accuracy: 62.23958333333336
Epoch: 970. Train Loss: 0.5420755743980408. Validation Accuracy: 64.32291666666667
Epoch: 971. Train Loss: 0.5478164553642273. Validation Accuracy: 69.79166666666667
Epoch: 972. Train Loss: 0.5699748992919922. Validation Accuracy: 68.75
Epoch: 973. Train Loss: 0.5345086455345154. Validation Accuracy: 69.01041666666667
Epoch: 974. Train Loss: 0.567003071308136. Validation Accuracy: 71.61458333333333
Epoch: 975. Train Loss: 0.5553700923919678. Validation Accuracy: 67.70833333333333
Epoch: 976. Train Loss: 0.5280289053916931. Validation Accuracy: 69.53125
Epoch: 977. Train Loss: 0.5641321539878845. Validation Accuracy: 61.197916666666664
Epoch: 978. Train Loss: 0.5698098540306091. Validation Accuracy: 63.28125
Epoch: 979. Train Loss: 0.5724264979362488. Validation Accuracy: 64.0625
Epoch: 980. Train Loss: 0.5837722420692444. Validation Accuracy: 58.33333333333336
Epoch: 981. Train Loss: 0.5747974514961243. Validation Accuracy: 66.14583333333333

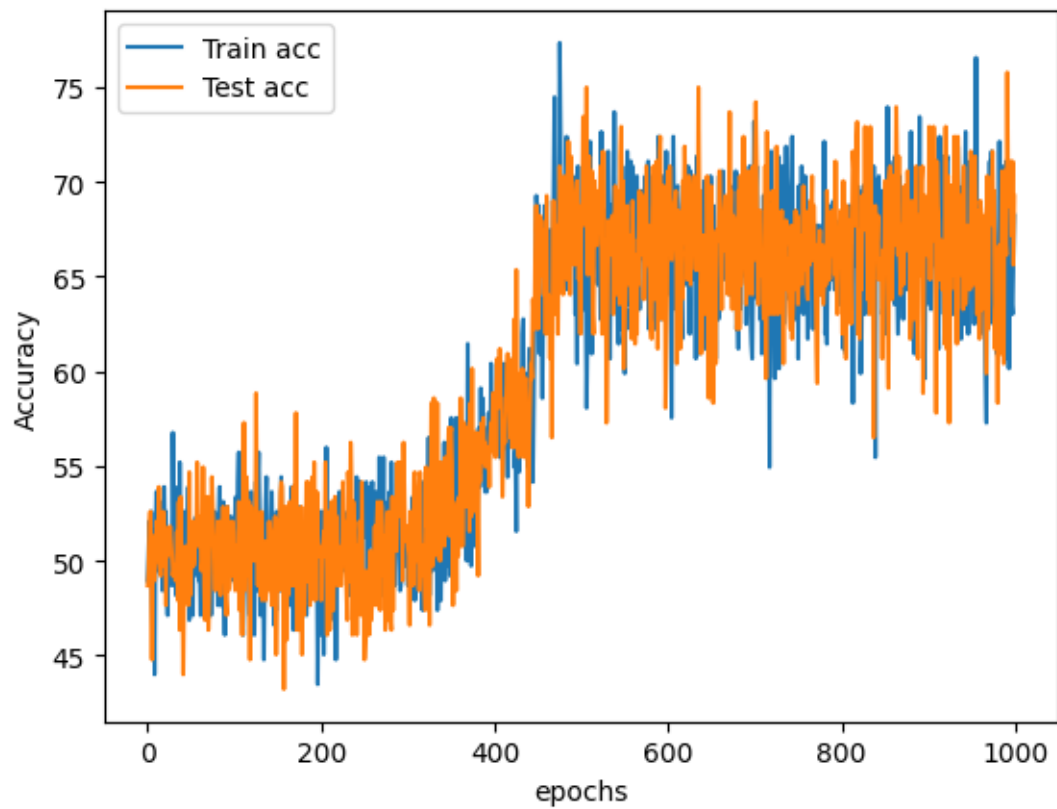
Epoch: 982. Train Loss: 0.5645257234573364. Validation Accuracy:
66.66666666666667
Epoch: 983. Train Loss: 0.5668820738792419. Validation Accuracy: 60.9375
Epoch: 984. Train Loss: 0.5618433356285095. Validation Accuracy:
66.14583333333333
Epoch: 985. Train Loss: 0.5624322891235352. Validation Accuracy:
70.57291666666667
Epoch: 986. Train Loss: 0.5727851986885071. Validation Accuracy:
62.23958333333336
Epoch: 987. Train Loss: 0.5513613224029541. Validation Accuracy:
60.41666666666664
Epoch: 988. Train Loss: 0.5659076571464539. Validation Accuracy:
70.57291666666667
Epoch: 989. Train Loss: 0.5619255900382996. Validation Accuracy:
66.92708333333333
Epoch: 990. Train Loss: 0.5408106446266174. Validation Accuracy:
66.14583333333333
Epoch: 991. Train Loss: 0.5605869889259338. Validation Accuracy: 75.78125
Epoch: 992. Train Loss: 0.543339192867279. Validation Accuracy:
69.27083333333333
Epoch: 993. Train Loss: 0.5759583711624146. Validation Accuracy: 68.75
Epoch: 994. Train Loss: 0.5752049088478088. Validation Accuracy: 71.09375
Epoch: 995. Train Loss: 0.5484417080879211. Validation Accuracy:
70.05208333333333
Epoch: 996. Train Loss: 0.5536767244338989. Validation Accuracy: 67.1875
Epoch: 997. Train Loss: 0.562351644039154. Validation Accuracy: 71.09375
Epoch: 998. Train Loss: 0.5533289909362793. Validation Accuracy: 65.625
Epoch: 999. Train Loss: 0.542336642742157. Validation Accuracy:
69.27083333333333

Train and test plots

```
[69]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



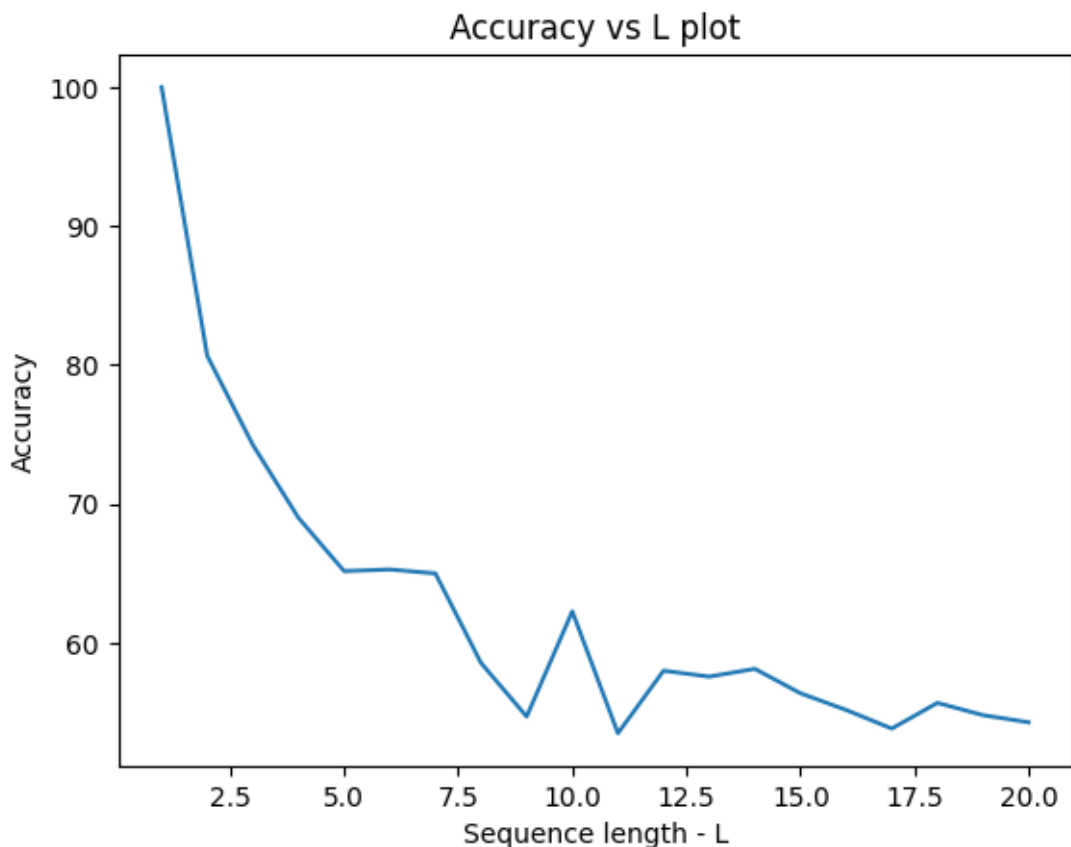
Train loss value after 1000 epochs: 0.542336642742157
Vaildation loss value after 1000 epochs: 0.5499600768089294



Best Test Accuracy: 75.78125%

Bitwise Accuracy vs Length

```
[70]: plot_accuracy_vs_length(model)
```



9.6.4 Summary of Results

Sequence length = 5

Epochs for training = 1000

| State Size | Train loss | Validation Loss | Bitwise Accuracy |
|------------|------------|-----------------|------------------|
| 2 | 0.6322 | 0.6068 | 75.26% |
| 5 | 0.5373 | 0.5721 | 76.56% |
| 10 | 0.5423 | 0.55 | 75.78% |

The performance is comparable but it seems like a hidden state size of 5 or 10 is more ideal. We might discover a trend when we try with other binary string lengths.

Analyzing the relationship between sequence lengths and bitwise accuracy from the plots, there's a noticeable decline in performance with increasing sequence lengths. This performance degradation becomes more pronounced for sequences longer than the ones used during training (in this instance, sequences of length 5). An accuracy nearing 50% isn't commendable for this task. Given that the input consists of binary strings, where the model essentially has to "predict" either 0 or 1, an accuracy of 50% implies that the model is performing no better than random guessing.

9.7 Length of Input Sequence = 3

```
[82]: L = 3
```

9.7.1 Hidden State Size = 2

```
[98]: HIDDEN_DIM = 2
```

```
[99]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
      criterion = nn.CrossEntropyLoss()
      optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[100]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
    ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.7047699093818665. Validation Accuracy: 51.953125
Epoch: 1. Train Loss: 0.7034203410148621. Validation Accuracy: 51.5625
Epoch: 2. Train Loss: 0.6994909644126892. Validation Accuracy: 51.5625
Epoch: 3. Train Loss: 0.6980426907539368. Validation Accuracy: 49.609375
Epoch: 4. Train Loss: 0.7078401446342468. Validation Accuracy: 50.390625
Epoch: 5. Train Loss: 0.705805242061615. Validation Accuracy: 46.875
Epoch: 6. Train Loss: 0.6986811757087708. Validation Accuracy: 50.390625
Epoch: 7. Train Loss: 0.6914618015289307. Validation Accuracy: 48.4375
Epoch: 8. Train Loss: 0.6968361139297485. Validation Accuracy: 50.0
Epoch: 9. Train Loss: 0.6901028156280518. Validation Accuracy: 49.21875
Epoch: 10. Train Loss: 0.6977769136428833. Validation Accuracy: 53.515625
Epoch: 11. Train Loss: 0.6968796849250793. Validation Accuracy: 47.265625
Epoch: 12. Train Loss: 0.6984935998916626. Validation Accuracy: 50.78125
Epoch: 13. Train Loss: 0.701556384563446. Validation Accuracy: 46.875
Epoch: 14. Train Loss: 0.7006503939628601. Validation Accuracy: 53.90625
Epoch: 15. Train Loss: 0.6996426582336426. Validation Accuracy: 47.65625
Epoch: 16. Train Loss: 0.6958375573158264. Validation Accuracy: 49.21875
Epoch: 17. Train Loss: 0.6924371123313904. Validation Accuracy: 46.484375
Epoch: 18. Train Loss: 0.7062935829162598. Validation Accuracy: 50.0
Epoch: 19. Train Loss: 0.6995577812194824. Validation Accuracy: 52.34375
Epoch: 20. Train Loss: 0.6971331834793091. Validation Accuracy: 47.265625
Epoch: 21. Train Loss: 0.6966360807418823. Validation Accuracy: 49.609375
Epoch: 22. Train Loss: 0.6893569231033325. Validation Accuracy: 51.171875
Epoch: 23. Train Loss: 0.6962075233459473. Validation Accuracy: 48.046875
Epoch: 24. Train Loss: 0.6990547776222229. Validation Accuracy: 50.0
Epoch: 25. Train Loss: 0.700353741645813. Validation Accuracy: 53.125
Epoch: 26. Train Loss: 0.7048843502998352. Validation Accuracy: 47.65625
Epoch: 27. Train Loss: 0.6952252388000488. Validation Accuracy: 46.875
Epoch: 28. Train Loss: 0.6969618201255798. Validation Accuracy: 47.65625
Epoch: 29. Train Loss: 0.698712944984436. Validation Accuracy: 48.046875
Epoch: 30. Train Loss: 0.6952887177467346. Validation Accuracy: 48.046875
```

Epoch: 31. Train Loss: 0.6934328079223633. Validation Accuracy: 51.953125
Epoch: 32. Train Loss: 0.695074737071991. Validation Accuracy: 49.609375
Epoch: 33. Train Loss: 0.6899257302284241. Validation Accuracy: 52.34375
Epoch: 34. Train Loss: 0.6859163641929626. Validation Accuracy: 49.21875
Epoch: 35. Train Loss: 0.6960067749023438. Validation Accuracy: 52.734375
Epoch: 36. Train Loss: 0.6964049935340881. Validation Accuracy: 47.265625
Epoch: 37. Train Loss: 0.6915532350540161. Validation Accuracy: 50.390625
Epoch: 38. Train Loss: 0.6884500980377197. Validation Accuracy: 51.953125
Epoch: 39. Train Loss: 0.6973133683204651. Validation Accuracy: 51.171875
Epoch: 40. Train Loss: 0.695439338684082. Validation Accuracy: 49.21875
Epoch: 41. Train Loss: 0.6905331611633301. Validation Accuracy: 49.21875
Epoch: 42. Train Loss: 0.6927372217178345. Validation Accuracy: 49.21875
Epoch: 43. Train Loss: 0.692602276802063. Validation Accuracy: 48.828125
Epoch: 44. Train Loss: 0.6945294737815857. Validation Accuracy: 49.609375
Epoch: 45. Train Loss: 0.6944705247879028. Validation Accuracy: 49.609375
Epoch: 46. Train Loss: 0.6933614611625671. Validation Accuracy: 49.21875
Epoch: 47. Train Loss: 0.6880271434783936. Validation Accuracy: 50.0
Epoch: 48. Train Loss: 0.6904969811439514. Validation Accuracy: 51.953125
Epoch: 49. Train Loss: 0.6916146278381348. Validation Accuracy: 51.171875
Epoch: 50. Train Loss: 0.6906164884567261. Validation Accuracy: 49.21875
Epoch: 51. Train Loss: 0.6918475031852722. Validation Accuracy: 52.734375
Epoch: 52. Train Loss: 0.6897527575492859. Validation Accuracy: 50.390625
Epoch: 53. Train Loss: 0.6909334063529968. Validation Accuracy: 50.0
Epoch: 54. Train Loss: 0.6895126700401306. Validation Accuracy: 46.484375
Epoch: 55. Train Loss: 0.6890684962272644. Validation Accuracy: 53.90625
Epoch: 56. Train Loss: 0.6911104917526245. Validation Accuracy: 50.78125
Epoch: 57. Train Loss: 0.6928880214691162. Validation Accuracy: 54.6875
Epoch: 58. Train Loss: 0.6926726698875427. Validation Accuracy: 56.25
Epoch: 59. Train Loss: 0.6950631737709045. Validation Accuracy: 50.390625
Epoch: 60. Train Loss: 0.6964715719223022. Validation Accuracy: 53.515625
Epoch: 61. Train Loss: 0.6919016242027283. Validation Accuracy: 55.46875
Epoch: 62. Train Loss: 0.6916191577911377. Validation Accuracy: 51.953125
Epoch: 63. Train Loss: 0.6914065480232239. Validation Accuracy: 57.421875
Epoch: 64. Train Loss: 0.688850998878479. Validation Accuracy: 54.296875
Epoch: 65. Train Loss: 0.6894269585609436. Validation Accuracy: 54.6875
Epoch: 66. Train Loss: 0.6936250925064087. Validation Accuracy: 58.203125
Epoch: 67. Train Loss: 0.6912903785705566. Validation Accuracy: 53.90625
Epoch: 68. Train Loss: 0.6923288106918335. Validation Accuracy: 51.5625
Epoch: 69. Train Loss: 0.68719881772995. Validation Accuracy: 56.25
Epoch: 70. Train Loss: 0.6950881481170654. Validation Accuracy: 52.34375
Epoch: 71. Train Loss: 0.6909918189048767. Validation Accuracy: 55.078125
Epoch: 72. Train Loss: 0.6916745901107788. Validation Accuracy: 49.609375
Epoch: 73. Train Loss: 0.6935303807258606. Validation Accuracy: 53.125
Epoch: 74. Train Loss: 0.6905272006988525. Validation Accuracy: 53.90625
Epoch: 75. Train Loss: 0.6903140544891357. Validation Accuracy: 56.25
Epoch: 76. Train Loss: 0.6880785822868347. Validation Accuracy: 51.5625
Epoch: 77. Train Loss: 0.6937450170516968. Validation Accuracy: 52.734375
Epoch: 78. Train Loss: 0.6880515217781067. Validation Accuracy: 53.515625

Epoch: 79. Train Loss: 0.685484766960144. Validation Accuracy: 54.6875
Epoch: 80. Train Loss: 0.6914474964141846. Validation Accuracy: 54.296875
Epoch: 81. Train Loss: 0.6887099742889404. Validation Accuracy: 51.953125
Epoch: 82. Train Loss: 0.6887340545654297. Validation Accuracy: 56.25
Epoch: 83. Train Loss: 0.6864898204803467. Validation Accuracy: 54.6875
Epoch: 84. Train Loss: 0.6948773860931396. Validation Accuracy: 52.34375
Epoch: 85. Train Loss: 0.6888874173164368. Validation Accuracy: 48.4375
Epoch: 86. Train Loss: 0.688346803188324. Validation Accuracy: 52.734375
Epoch: 87. Train Loss: 0.693395733833313. Validation Accuracy: 57.421875
Epoch: 88. Train Loss: 0.6881475448608398. Validation Accuracy: 55.46875
Epoch: 89. Train Loss: 0.6926761269569397. Validation Accuracy: 58.203125
Epoch: 90. Train Loss: 0.6859793663024902. Validation Accuracy: 52.734375
Epoch: 91. Train Loss: 0.6893185973167419. Validation Accuracy: 50.390625
Epoch: 92. Train Loss: 0.6922100186347961. Validation Accuracy: 54.6875
Epoch: 93. Train Loss: 0.6824043989181519. Validation Accuracy: 53.90625
Epoch: 94. Train Loss: 0.6901189684867859. Validation Accuracy: 51.171875
Epoch: 95. Train Loss: 0.6871674656867981. Validation Accuracy: 48.4375
Epoch: 96. Train Loss: 0.693199872970581. Validation Accuracy: 56.25
Epoch: 97. Train Loss: 0.6926397085189819. Validation Accuracy: 56.25
Epoch: 98. Train Loss: 0.6903191208839417. Validation Accuracy: 53.515625
Epoch: 99. Train Loss: 0.6901722550392151. Validation Accuracy: 55.859375
Epoch: 100. Train Loss: 0.6886674165725708. Validation Accuracy: 47.65625
Epoch: 101. Train Loss: 0.6946980953216553. Validation Accuracy: 60.9375
Epoch: 102. Train Loss: 0.6799551844596863. Validation Accuracy: 48.828125
Epoch: 103. Train Loss: 0.6896066069602966. Validation Accuracy: 53.90625
Epoch: 104. Train Loss: 0.6858617663383484. Validation Accuracy: 49.609375
Epoch: 105. Train Loss: 0.6872998476028442. Validation Accuracy: 52.34375
Epoch: 106. Train Loss: 0.6823373436927795. Validation Accuracy: 46.875
Epoch: 107. Train Loss: 0.6888241767883301. Validation Accuracy: 54.6875
Epoch: 108. Train Loss: 0.6823562383651733. Validation Accuracy: 60.15625
Epoch: 109. Train Loss: 0.6905550360679626. Validation Accuracy: 57.03125
Epoch: 110. Train Loss: 0.6881006956100464. Validation Accuracy: 55.078125
Epoch: 111. Train Loss: 0.6961437463760376. Validation Accuracy: 50.390625
Epoch: 112. Train Loss: 0.691378653049469. Validation Accuracy: 59.375
Epoch: 113. Train Loss: 0.6935171484947205. Validation Accuracy: 60.15625
Epoch: 114. Train Loss: 0.6935670375823975. Validation Accuracy: 53.515625
Epoch: 115. Train Loss: 0.6879175305366516. Validation Accuracy: 51.5625
Epoch: 116. Train Loss: 0.6937697529792786. Validation Accuracy: 51.5625
Epoch: 117. Train Loss: 0.6909202933311462. Validation Accuracy: 59.765625
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Epoch: 121. Train Loss: 0.6877169013023376. Validation Accuracy: 55.46875
Epoch: 122. Train Loss: 0.6888898015022278. Validation Accuracy: 58.203125
Epoch: 123. Train Loss: 0.6979545950889587. Validation Accuracy: 49.21875
Epoch: 124. Train Loss: 0.6907689571380615. Validation Accuracy: 51.5625
Epoch: 125. Train Loss: 0.6922953128814697. Validation Accuracy: 46.484375
Epoch: 126. Train Loss: 0.6912153959274292. Validation Accuracy: 51.5625

Epoch: 127. Train Loss: 0.6903213858604431. Validation Accuracy: 57.421875
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Epoch: 272. Train Loss: 0.6908672451972961. Validation Accuracy: 57.8125
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 Epoch: 408. Train Loss: 0.6783016920089722. Validation Accuracy: 57.8125
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 Epoch: 413. Train Loss: 0.6911202669143677. Validation Accuracy: 53.125
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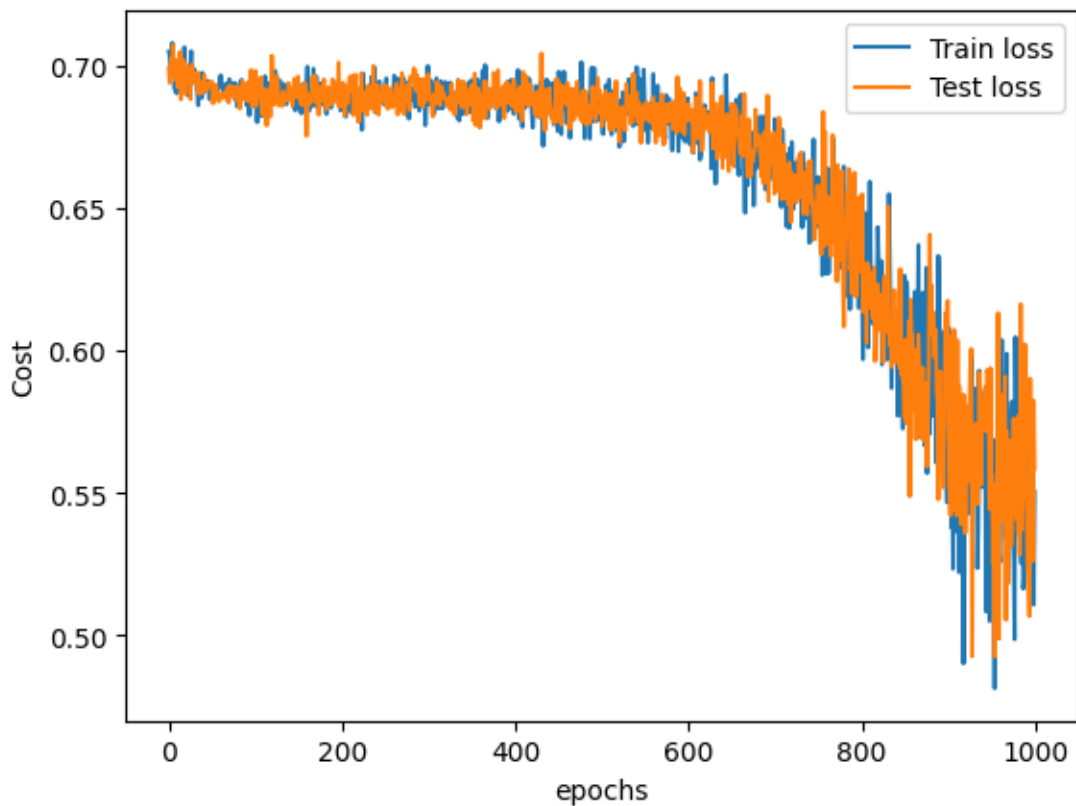
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Epoch: 969. Train Loss: 0.5292006731033325. Validation Accuracy: 76.171875
Epoch: 970. Train Loss: 0.5388004779815674. Validation Accuracy: 75.390625
Epoch: 971. Train Loss: 0.5593249201774597. Validation Accuracy: 71.875
Epoch: 972. Train Loss: 0.574039101600647. Validation Accuracy: 76.953125
Epoch: 973. Train Loss: 0.5820157527923584. Validation Accuracy: 75.390625
Epoch: 974. Train Loss: 0.5358664989471436. Validation Accuracy: 76.171875
Epoch: 975. Train Loss: 0.5261734127998352. Validation Accuracy: 71.875
Epoch: 976. Train Loss: 0.49861639738082886. Validation Accuracy: 73.828125
Epoch: 977. Train Loss: 0.6046304106712341. Validation Accuracy: 72.65625
Epoch: 978. Train Loss: 0.5716195702552795. Validation Accuracy: 75.0
Epoch: 979. Train Loss: 0.5626869797706604. Validation Accuracy: 72.265625
Epoch: 980. Train Loss: 0.5953704118728638. Validation Accuracy: 76.953125
Epoch: 981. Train Loss: 0.5645548105239868. Validation Accuracy: 72.65625
Epoch: 982. Train Loss: 0.534570574760437. Validation Accuracy: 77.34375
Epoch: 983. Train Loss: 0.5342130064964294. Validation Accuracy: 67.578125
Epoch: 984. Train Loss: 0.5251474380493164. Validation Accuracy: 76.5625
Epoch: 985. Train Loss: 0.5484061241149902. Validation Accuracy: 69.921875
Epoch: 986. Train Loss: 0.5163079500198364. Validation Accuracy: 73.046875
Epoch: 987. Train Loss: 0.5197663903236389. Validation Accuracy: 73.828125
Epoch: 988. Train Loss: 0.5501098036766052. Validation Accuracy: 69.140625
Epoch: 989. Train Loss: 0.5850316882133484. Validation Accuracy: 74.609375
Epoch: 990. Train Loss: 0.5538104176521301. Validation Accuracy: 75.78125

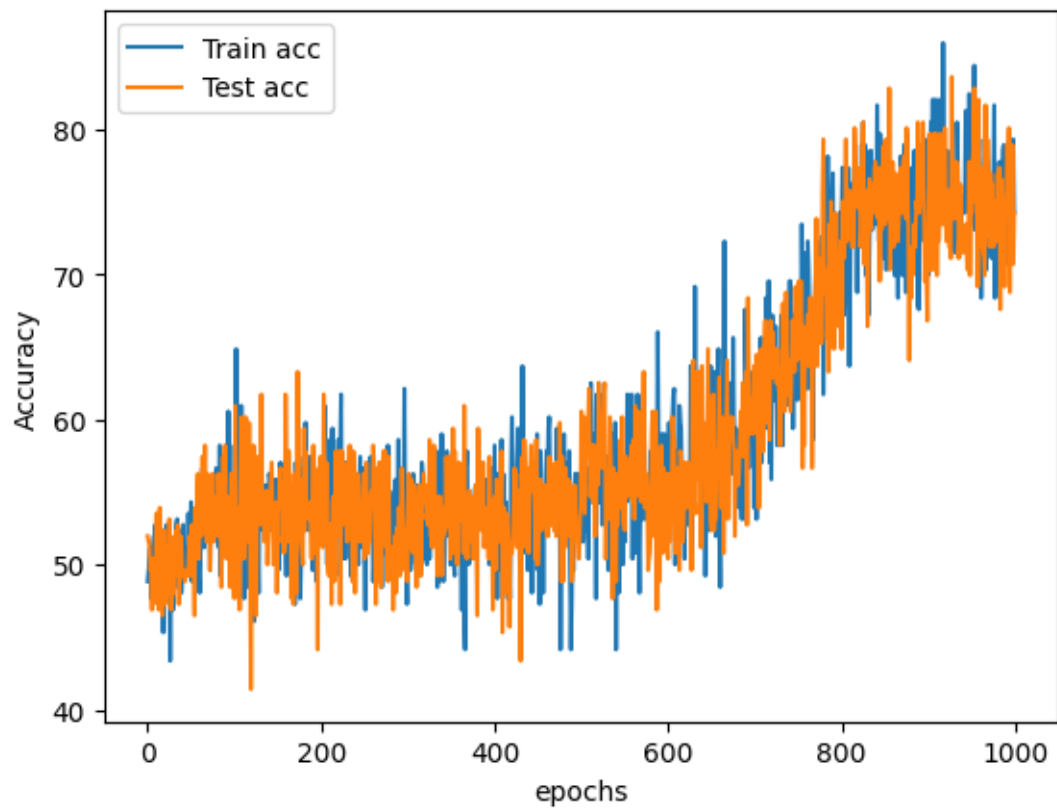
Epoch: 991. Train Loss: 0.5379517078399658. Validation Accuracy: 78.90625
Epoch: 992. Train Loss: 0.5452202558517456. Validation Accuracy: 77.34375
Epoch: 993. Train Loss: 0.5636724829673767. Validation Accuracy: 80.078125
Epoch: 994. Train Loss: 0.5777072906494141. Validation Accuracy: 68.75
Epoch: 995. Train Loss: 0.5615279674530029. Validation Accuracy: 76.5625
Epoch: 996. Train Loss: 0.5677133798599243. Validation Accuracy: 73.046875
Epoch: 997. Train Loss: 0.554614245891571. Validation Accuracy: 78.90625
Epoch: 998. Train Loss: 0.5107326507568359. Validation Accuracy: 70.703125
Epoch: 999. Train Loss: 0.5504103302955627. Validation Accuracy: 74.21875

Train and test plots

```
[101]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



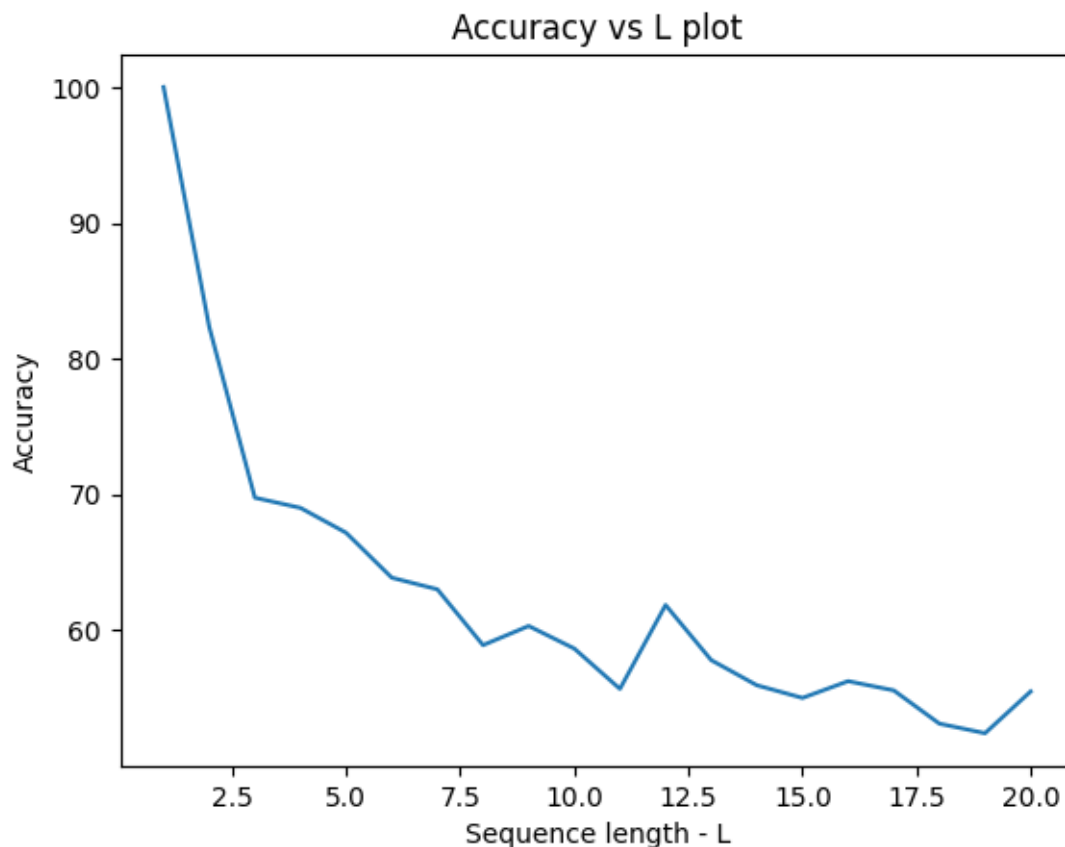
Train loss value after 1000 epochs: 0.5504103302955627
Vaildation loss value after 1000 epochs: 0.5584276914596558



Best Test Accuracy: 83.59375%

Bitwise Accuracy vs Length

```
[102]: plot_accuracy_vs_length(model)
```



9.7.2 Hidden State Size = 5

```
[103]: HIDDEN_DIM = 5
```

```
[104]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
        criterion = nn.CrossEntropyLoss()
        optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[105]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
        ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.696895182132721. Validation Accuracy: 49.609375
Epoch: 1. Train Loss: 0.6937692165374756. Validation Accuracy: 46.875
Epoch: 2. Train Loss: 0.6918464303016663. Validation Accuracy: 50.78125
Epoch: 3. Train Loss: 0.6944811940193176. Validation Accuracy: 50.78125
Epoch: 4. Train Loss: 0.6939907670021057. Validation Accuracy: 49.21875
Epoch: 5. Train Loss: 0.693337619304657. Validation Accuracy: 49.609375
Epoch: 6. Train Loss: 0.6939125061035156. Validation Accuracy: 46.875
```

Epoch: 7. Train Loss: 0.6904668211936951. Validation Accuracy: 51.5625
Epoch: 8. Train Loss: 0.6916535496711731. Validation Accuracy: 48.4375
Epoch: 9. Train Loss: 0.6915280222892761. Validation Accuracy: 51.171875
Epoch: 10. Train Loss: 0.6915940642356873. Validation Accuracy: 49.21875
Epoch: 11. Train Loss: 0.6930185556411743. Validation Accuracy: 52.34375
Epoch: 12. Train Loss: 0.6902339458465576. Validation Accuracy: 54.6875
Epoch: 13. Train Loss: 0.6932101845741272. Validation Accuracy: 46.484375
Epoch: 14. Train Loss: 0.6920575499534607. Validation Accuracy: 49.21875
Epoch: 15. Train Loss: 0.6928775310516357. Validation Accuracy: 53.125
Epoch: 16. Train Loss: 0.6936972141265869. Validation Accuracy: 49.21875
Epoch: 17. Train Loss: 0.6919437646865845. Validation Accuracy: 53.125
Epoch: 18. Train Loss: 0.6921665072441101. Validation Accuracy: 49.609375
Epoch: 19. Train Loss: 0.6892935633659363. Validation Accuracy: 48.828125
Epoch: 20. Train Loss: 0.6905829906463623. Validation Accuracy: 55.078125
Epoch: 21. Train Loss: 0.691827118396759. Validation Accuracy: 53.125
Epoch: 22. Train Loss: 0.691054105758667. Validation Accuracy: 50.390625
Epoch: 23. Train Loss: 0.69176185131073. Validation Accuracy: 51.171875
Epoch: 24. Train Loss: 0.6923848390579224. Validation Accuracy: 57.03125
Epoch: 25. Train Loss: 0.6928629875183105. Validation Accuracy: 54.6875
Epoch: 26. Train Loss: 0.6909424662590027. Validation Accuracy: 51.953125
Epoch: 27. Train Loss: 0.6918378472328186. Validation Accuracy: 55.859375
Epoch: 28. Train Loss: 0.6915565729141235. Validation Accuracy: 57.8125
Epoch: 29. Train Loss: 0.6922076344490051. Validation Accuracy: 52.34375
Epoch: 30. Train Loss: 0.6902616024017334. Validation Accuracy: 51.953125
Epoch: 31. Train Loss: 0.6877771019935608. Validation Accuracy: 50.0
Epoch: 32. Train Loss: 0.6913527846336365. Validation Accuracy: 57.421875
Epoch: 33. Train Loss: 0.6912369132041931. Validation Accuracy: 50.78125
Epoch: 34. Train Loss: 0.6916000843048096. Validation Accuracy: 49.21875
Epoch: 35. Train Loss: 0.6933144927024841. Validation Accuracy: 46.875
Epoch: 36. Train Loss: 0.6883033514022827. Validation Accuracy: 57.8125
Epoch: 37. Train Loss: 0.6918251514434814. Validation Accuracy: 56.25
Epoch: 38. Train Loss: 0.6911346912384033. Validation Accuracy: 54.296875
Epoch: 39. Train Loss: 0.6911897659301758. Validation Accuracy: 52.734375
Epoch: 40. Train Loss: 0.6916995048522949. Validation Accuracy: 53.125
Epoch: 41. Train Loss: 0.6926683187484741. Validation Accuracy: 55.859375
Epoch: 42. Train Loss: 0.6907516717910767. Validation Accuracy: 55.46875
Epoch: 43. Train Loss: 0.6933504939079285. Validation Accuracy: 45.3125
Epoch: 44. Train Loss: 0.6906681656837463. Validation Accuracy: 43.75
Epoch: 45. Train Loss: 0.6898740530014038. Validation Accuracy: 53.125
Epoch: 46. Train Loss: 0.6898356676101685. Validation Accuracy: 56.25
Epoch: 47. Train Loss: 0.6888304948806763. Validation Accuracy: 46.875
Epoch: 48. Train Loss: 0.6936434507369995. Validation Accuracy: 50.390625
Epoch: 49. Train Loss: 0.6928490996360779. Validation Accuracy: 57.03125
Epoch: 50. Train Loss: 0.6878466010093689. Validation Accuracy: 52.34375
Epoch: 51. Train Loss: 0.6904071569442749. Validation Accuracy: 58.203125
Epoch: 52. Train Loss: 0.6905403137207031. Validation Accuracy: 54.6875
Epoch: 53. Train Loss: 0.6911656260490417. Validation Accuracy: 49.609375
Epoch: 54. Train Loss: 0.6931211948394775. Validation Accuracy: 44.140625

Epoch: 55. Train Loss: 0.6911751627922058. Validation Accuracy: 54.6875
Epoch: 56. Train Loss: 0.6886373162269592. Validation Accuracy: 55.46875
Epoch: 57. Train Loss: 0.691372811794281. Validation Accuracy: 53.515625
Epoch: 58. Train Loss: 0.6909719705581665. Validation Accuracy: 55.859375
Epoch: 59. Train Loss: 0.6892651915550232. Validation Accuracy: 48.828125
Epoch: 60. Train Loss: 0.6911954283714294. Validation Accuracy: 52.34375
Epoch: 61. Train Loss: 0.6915801167488098. Validation Accuracy: 50.0
Epoch: 62. Train Loss: 0.694084644317627. Validation Accuracy: 49.609375
Epoch: 63. Train Loss: 0.6936143636703491. Validation Accuracy: 55.859375
Epoch: 64. Train Loss: 0.6908061504364014. Validation Accuracy: 57.03125
Epoch: 65. Train Loss: 0.6967936158180237. Validation Accuracy: 53.515625
Epoch: 66. Train Loss: 0.6935849785804749. Validation Accuracy: 53.90625
Epoch: 67. Train Loss: 0.6880974769592285. Validation Accuracy: 53.125
Epoch: 68. Train Loss: 0.6902228593826294. Validation Accuracy: 54.296875
Epoch: 69. Train Loss: 0.6916958689689636. Validation Accuracy: 50.0
Epoch: 70. Train Loss: 0.693513035774231. Validation Accuracy: 50.390625
Epoch: 71. Train Loss: 0.689942479133606. Validation Accuracy: 52.734375
Epoch: 72. Train Loss: 0.6934525966644287. Validation Accuracy: 58.59375
Epoch: 73. Train Loss: 0.6923714280128479. Validation Accuracy: 58.203125
Epoch: 74. Train Loss: 0.689211905002594. Validation Accuracy: 59.375
Epoch: 75. Train Loss: 0.6909849643707275. Validation Accuracy: 56.640625
Epoch: 76. Train Loss: 0.6895167827606201. Validation Accuracy: 59.765625
Epoch: 77. Train Loss: 0.6936708688735962. Validation Accuracy: 54.296875
Epoch: 78. Train Loss: 0.6937121152877808. Validation Accuracy: 51.171875
Epoch: 79. Train Loss: 0.6934844255447388. Validation Accuracy: 50.78125
Epoch: 80. Train Loss: 0.6908773183822632. Validation Accuracy: 46.484375
Epoch: 81. Train Loss: 0.690386950969696. Validation Accuracy: 45.703125
Epoch: 82. Train Loss: 0.6909613609313965. Validation Accuracy: 58.984375
Epoch: 83. Train Loss: 0.6865295767784119. Validation Accuracy: 52.34375
Epoch: 84. Train Loss: 0.6919742226600647. Validation Accuracy: 51.5625
Epoch: 85. Train Loss: 0.6958779692649841. Validation Accuracy: 47.65625
Epoch: 86. Train Loss: 0.6915105581283569. Validation Accuracy: 50.78125
Epoch: 87. Train Loss: 0.6910189986228943. Validation Accuracy: 52.734375
Epoch: 88. Train Loss: 0.6919678449630737. Validation Accuracy: 52.734375
Epoch: 89. Train Loss: 0.6931906342506409. Validation Accuracy: 60.9375
Epoch: 90. Train Loss: 0.689059317111969. Validation Accuracy: 48.4375
Epoch: 91. Train Loss: 0.6913180351257324. Validation Accuracy: 55.46875
Epoch: 92. Train Loss: 0.6883367300033569. Validation Accuracy: 43.75
Epoch: 93. Train Loss: 0.6933769583702087. Validation Accuracy: 55.859375
Epoch: 94. Train Loss: 0.6915777921676636. Validation Accuracy: 51.953125
Epoch: 95. Train Loss: 0.6911309957504272. Validation Accuracy: 58.59375
Epoch: 96. Train Loss: 0.6904684901237488. Validation Accuracy: 51.953125
Epoch: 97. Train Loss: 0.6892386078834534. Validation Accuracy: 57.421875
Epoch: 98. Train Loss: 0.6874433755874634. Validation Accuracy: 57.8125
Epoch: 99. Train Loss: 0.6897866129875183. Validation Accuracy: 55.078125
Epoch: 100. Train Loss: 0.6909220814704895. Validation Accuracy: 51.5625
Epoch: 101. Train Loss: 0.6891816854476929. Validation Accuracy: 56.25
Epoch: 102. Train Loss: 0.6910613179206848. Validation Accuracy: 49.21875

Epoch: 103. Train Loss: 0.6914610266685486. Validation Accuracy: 51.953125
Epoch: 104. Train Loss: 0.6881216168403625. Validation Accuracy: 55.078125
Epoch: 105. Train Loss: 0.6878567934036255. Validation Accuracy: 60.546875
Epoch: 106. Train Loss: 0.6911446452140808. Validation Accuracy: 49.21875
Epoch: 107. Train Loss: 0.6907998919487. Validation Accuracy: 55.078125
Epoch: 108. Train Loss: 0.6853370070457458. Validation Accuracy: 57.421875
Epoch: 109. Train Loss: 0.6873332858085632. Validation Accuracy: 53.515625
Epoch: 110. Train Loss: 0.6877496838569641. Validation Accuracy: 57.421875
Epoch: 111. Train Loss: 0.6905282735824585. Validation Accuracy: 49.609375
Epoch: 112. Train Loss: 0.6891573667526245. Validation Accuracy: 53.515625
Epoch: 113. Train Loss: 0.6932569146156311. Validation Accuracy: 56.640625
Epoch: 114. Train Loss: 0.6917007565498352. Validation Accuracy: 58.59375
Epoch: 115. Train Loss: 0.6864781379699707. Validation Accuracy: 60.546875
Epoch: 116. Train Loss: 0.6871697306632996. Validation Accuracy: 59.375
Epoch: 117. Train Loss: 0.6897263526916504. Validation Accuracy: 53.515625
Epoch: 118. Train Loss: 0.6915919184684753. Validation Accuracy: 53.90625
Epoch: 119. Train Loss: 0.6881670355796814. Validation Accuracy: 57.8125
Epoch: 120. Train Loss: 0.6948161125183105. Validation Accuracy: 48.046875
Epoch: 121. Train Loss: 0.6933810710906982. Validation Accuracy: 47.265625
Epoch: 122. Train Loss: 0.6883984208106995. Validation Accuracy: 46.484375
Epoch: 123. Train Loss: 0.6940189599990845. Validation Accuracy: 53.90625
Epoch: 124. Train Loss: 0.6888233423233032. Validation Accuracy: 50.0
Epoch: 125. Train Loss: 0.6868987083435059. Validation Accuracy: 58.203125
Epoch: 126. Train Loss: 0.6924865245819092. Validation Accuracy: 56.25
Epoch: 127. Train Loss: 0.6934579014778137. Validation Accuracy: 48.4375
Epoch: 128. Train Loss: 0.6944200992584229. Validation Accuracy: 52.734375
Epoch: 129. Train Loss: 0.6887981295585632. Validation Accuracy: 63.28125
Epoch: 130. Train Loss: 0.693155825138092. Validation Accuracy: 60.546875
Epoch: 131. Train Loss: 0.6952287554740906. Validation Accuracy: 52.34375
Epoch: 132. Train Loss: 0.6933465600013733. Validation Accuracy: 53.515625
Epoch: 133. Train Loss: 0.6950129270553589. Validation Accuracy: 48.828125
Epoch: 134. Train Loss: 0.6922382712364197. Validation Accuracy: 52.34375
Epoch: 135. Train Loss: 0.6923679113388062. Validation Accuracy: 53.125
Epoch: 136. Train Loss: 0.695106029510498. Validation Accuracy: 52.734375
Epoch: 137. Train Loss: 0.6903575658798218. Validation Accuracy: 51.953125
Epoch: 138. Train Loss: 0.6883853673934937. Validation Accuracy: 54.296875
Epoch: 139. Train Loss: 0.6914687752723694. Validation Accuracy: 57.8125
Epoch: 140. Train Loss: 0.6892788410186768. Validation Accuracy: 55.078125
Epoch: 141. Train Loss: 0.6909666061401367. Validation Accuracy: 46.484375
Epoch: 142. Train Loss: 0.6949484348297119. Validation Accuracy: 58.59375
Epoch: 143. Train Loss: 0.6892377138137817. Validation Accuracy: 52.734375
Epoch: 144. Train Loss: 0.6922966241836548. Validation Accuracy: 53.515625
Epoch: 145. Train Loss: 0.6849809885025024. Validation Accuracy: 50.78125
Epoch: 146. Train Loss: 0.6884723901748657. Validation Accuracy: 54.6875
Epoch: 147. Train Loss: 0.6918646693229675. Validation Accuracy: 58.984375
Epoch: 148. Train Loss: 0.693834662437439. Validation Accuracy: 53.125
Epoch: 149. Train Loss: 0.6874946355819702. Validation Accuracy: 59.375
Epoch: 150. Train Loss: 0.6971412897109985. Validation Accuracy: 51.5625

Epoch: 151. Train Loss: 0.6874537467956543. Validation Accuracy: 57.8125
Epoch: 152. Train Loss: 0.6898108124732971. Validation Accuracy: 55.46875
Epoch: 153. Train Loss: 0.6904894709587097. Validation Accuracy: 51.5625
Epoch: 154. Train Loss: 0.690159022808075. Validation Accuracy: 48.828125
Epoch: 155. Train Loss: 0.6908302903175354. Validation Accuracy: 54.6875
Epoch: 156. Train Loss: 0.6939290165901184. Validation Accuracy: 62.5
Epoch: 157. Train Loss: 0.6919392347335815. Validation Accuracy: 60.546875
Epoch: 158. Train Loss: 0.6904815435409546. Validation Accuracy: 45.703125
Epoch: 159. Train Loss: 0.6888604164123535. Validation Accuracy: 56.25
Epoch: 160. Train Loss: 0.6847153902053833. Validation Accuracy: 55.46875
Epoch: 161. Train Loss: 0.690311074256897. Validation Accuracy: 52.34375
Epoch: 162. Train Loss: 0.6846271753311157. Validation Accuracy: 51.5625
Epoch: 163. Train Loss: 0.6925833225250244. Validation Accuracy: 55.078125
Epoch: 164. Train Loss: 0.6875995993614197. Validation Accuracy: 55.078125
Epoch: 165. Train Loss: 0.69139564037323. Validation Accuracy: 54.6875
Epoch: 166. Train Loss: 0.6875481605529785. Validation Accuracy: 55.078125
Epoch: 167. Train Loss: 0.689693808555603. Validation Accuracy: 52.34375
Epoch: 168. Train Loss: 0.6899607181549072. Validation Accuracy: 54.6875
Epoch: 169. Train Loss: 0.6899570226669312. Validation Accuracy: 57.03125
Epoch: 170. Train Loss: 0.6873194575309753. Validation Accuracy: 51.171875
Epoch: 171. Train Loss: 0.6879950165748596. Validation Accuracy: 50.0
Epoch: 172. Train Loss: 0.6982637047767639. Validation Accuracy: 52.734375
Epoch: 173. Train Loss: 0.68755704164505. Validation Accuracy: 49.609375
Epoch: 174. Train Loss: 0.6933944821357727. Validation Accuracy: 53.90625
Epoch: 175. Train Loss: 0.6864686608314514. Validation Accuracy: 55.859375
Epoch: 176. Train Loss: 0.685897707939148. Validation Accuracy: 51.953125
Epoch: 177. Train Loss: 0.6932622194290161. Validation Accuracy: 52.734375
Epoch: 178. Train Loss: 0.6894968152046204. Validation Accuracy: 55.078125
Epoch: 179. Train Loss: 0.6914151310920715. Validation Accuracy: 54.6875
Epoch: 180. Train Loss: 0.6884200572967529. Validation Accuracy: 53.515625
Epoch: 181. Train Loss: 0.6889938116073608. Validation Accuracy: 52.734375
Epoch: 182. Train Loss: 0.6886535882949829. Validation Accuracy: 56.640625
Epoch: 183. Train Loss: 0.6912822127342224. Validation Accuracy: 52.734375
Epoch: 184. Train Loss: 0.6866902709007263. Validation Accuracy: 55.078125
Epoch: 185. Train Loss: 0.688204824924469. Validation Accuracy: 51.171875
Epoch: 186. Train Loss: 0.6943911910057068. Validation Accuracy: 52.34375
Epoch: 187. Train Loss: 0.6926190853118896. Validation Accuracy: 54.296875
Epoch: 188. Train Loss: 0.6926227807998657. Validation Accuracy: 58.984375
Epoch: 189. Train Loss: 0.6847242116928101. Validation Accuracy: 50.78125
Epoch: 190. Train Loss: 0.6882673501968384. Validation Accuracy: 52.734375
Epoch: 191. Train Loss: 0.6849508881568909. Validation Accuracy: 51.953125
Epoch: 192. Train Loss: 0.6840896606445312. Validation Accuracy: 49.609375
Epoch: 193. Train Loss: 0.6938244104385376. Validation Accuracy: 53.515625
Epoch: 194. Train Loss: 0.6860364079475403. Validation Accuracy: 53.515625
Epoch: 195. Train Loss: 0.6954768896102905. Validation Accuracy: 55.078125
Epoch: 196. Train Loss: 0.687572717666626. Validation Accuracy: 51.953125
Epoch: 197. Train Loss: 0.6869811415672302. Validation Accuracy: 55.859375
Epoch: 198. Train Loss: 0.6899462342262268. Validation Accuracy: 52.734375

Epoch: 199. Train Loss: 0.6892019510269165. Validation Accuracy: 51.171875
Epoch: 200. Train Loss: 0.6847056746482849. Validation Accuracy: 53.515625
Epoch: 201. Train Loss: 0.689170777797699. Validation Accuracy: 54.6875
Epoch: 202. Train Loss: 0.6878605484962463. Validation Accuracy: 52.734375
Epoch: 203. Train Loss: 0.6920992732048035. Validation Accuracy: 55.859375
Epoch: 204. Train Loss: 0.6917964220046997. Validation Accuracy: 56.640625
Epoch: 205. Train Loss: 0.6894702911376953. Validation Accuracy: 55.859375
Epoch: 206. Train Loss: 0.6881913542747498. Validation Accuracy: 52.34375
Epoch: 207. Train Loss: 0.6977297067642212. Validation Accuracy: 52.34375
Epoch: 208. Train Loss: 0.6968060731887817. Validation Accuracy: 51.5625
Epoch: 209. Train Loss: 0.6843608021736145. Validation Accuracy: 54.6875
Epoch: 210. Train Loss: 0.6876279711723328. Validation Accuracy: 56.25
Epoch: 211. Train Loss: 0.6905261874198914. Validation Accuracy: 53.515625
Epoch: 212. Train Loss: 0.6901136040687561. Validation Accuracy: 55.078125
Epoch: 213. Train Loss: 0.6894616484642029. Validation Accuracy: 51.953125
Epoch: 214. Train Loss: 0.6859816312789917. Validation Accuracy: 53.515625
Epoch: 215. Train Loss: 0.6818979978561401. Validation Accuracy: 53.90625
Epoch: 216. Train Loss: 0.6859139800071716. Validation Accuracy: 54.6875
Epoch: 217. Train Loss: 0.6863771677017212. Validation Accuracy: 52.34375
Epoch: 218. Train Loss: 0.688922643661499. Validation Accuracy: 55.078125
Epoch: 219. Train Loss: 0.6889017224311829. Validation Accuracy: 51.5625
Epoch: 220. Train Loss: 0.689889669418335. Validation Accuracy: 51.953125
Epoch: 221. Train Loss: 0.6873815655708313. Validation Accuracy: 54.6875
Epoch: 222. Train Loss: 0.6864912509918213. Validation Accuracy: 52.34375
Epoch: 223. Train Loss: 0.6973707675933838. Validation Accuracy: 55.078125
Epoch: 224. Train Loss: 0.6842371821403503. Validation Accuracy: 53.515625
Epoch: 225. Train Loss: 0.6865565180778503. Validation Accuracy: 52.734375
Epoch: 226. Train Loss: 0.6921500563621521. Validation Accuracy: 55.078125
Epoch: 227. Train Loss: 0.6898150444030762. Validation Accuracy: 55.46875
Epoch: 228. Train Loss: 0.6841757297515869. Validation Accuracy: 45.703125
Epoch: 229. Train Loss: 0.6907703280448914. Validation Accuracy: 60.9375
Epoch: 230. Train Loss: 0.687039852142334. Validation Accuracy: 50.390625
Epoch: 231. Train Loss: 0.6885786056518555. Validation Accuracy: 53.90625
Epoch: 232. Train Loss: 0.6927001476287842. Validation Accuracy: 51.953125
Epoch: 233. Train Loss: 0.6918957829475403. Validation Accuracy: 50.390625
Epoch: 234. Train Loss: 0.6943019032478333. Validation Accuracy: 56.640625
Epoch: 235. Train Loss: 0.6937362551689148. Validation Accuracy: 57.03125
Epoch: 236. Train Loss: 0.6862230896949768. Validation Accuracy: 58.203125
Epoch: 237. Train Loss: 0.6884768009185791. Validation Accuracy: 48.828125
Epoch: 238. Train Loss: 0.689176619052887. Validation Accuracy: 50.390625
Epoch: 239. Train Loss: 0.6882864236831665. Validation Accuracy: 57.8125
Epoch: 240. Train Loss: 0.6822046637535095. Validation Accuracy: 54.6875
Epoch: 241. Train Loss: 0.6908062100410461. Validation Accuracy: 52.34375
Epoch: 242. Train Loss: 0.6896044611930847. Validation Accuracy: 57.421875
Epoch: 243. Train Loss: 0.6901364326477051. Validation Accuracy: 47.65625
Epoch: 244. Train Loss: 0.6852900385856628. Validation Accuracy: 52.734375
Epoch: 245. Train Loss: 0.6853876709938049. Validation Accuracy: 53.125
Epoch: 246. Train Loss: 0.683218240737915. Validation Accuracy: 52.734375

Epoch: 247. Train Loss: 0.6902259588241577. Validation Accuracy: 55.078125
Epoch: 248. Train Loss: 0.6854375004768372. Validation Accuracy: 57.421875
Epoch: 249. Train Loss: 0.6795256733894348. Validation Accuracy: 50.78125
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Epoch: 255. Train Loss: 0.689354419708252. Validation Accuracy: 53.515625
Epoch: 256. Train Loss: 0.6893467307090759. Validation Accuracy: 51.953125
Epoch: 257. Train Loss: 0.6868164539337158. Validation Accuracy: 55.859375
Epoch: 258. Train Loss: 0.6846868395805359. Validation Accuracy: 52.734375
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Epoch: 270. Train Loss: 0.6863269209861755. Validation Accuracy: 60.9375
Epoch: 271. Train Loss: 0.6853001713752747. Validation Accuracy: 53.515625
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Epoch: 342. Train Loss: 0.6834720969200134. Validation Accuracy: 58.984375

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Epoch: 533. Train Loss: 0.5735096335411072. Validation Accuracy: 79.296875
Epoch: 534. Train Loss: 0.5593249797821045. Validation Accuracy: 82.421875

Epoch: 535. Train Loss: 0.5114403963088989. Validation Accuracy: 81.25
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Epoch: 537. Train Loss: 0.5318685173988342. Validation Accuracy: 72.265625
Epoch: 538. Train Loss: 0.5489105582237244. Validation Accuracy: 73.046875
Epoch: 539. Train Loss: 0.5092163681983948. Validation Accuracy: 71.875
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Epoch: 541. Train Loss: 0.5926638245582581. Validation Accuracy: 75.390625
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Epoch: 543. Train Loss: 0.5571722388267517. Validation Accuracy: 73.828125
Epoch: 544. Train Loss: 0.5284557938575745. Validation Accuracy: 78.125
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Epoch: 546. Train Loss: 0.5305712223052979. Validation Accuracy: 77.34375
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Epoch: 635. Train Loss: 0.4495033919811249. Validation Accuracy: 73.046875
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Epoch: 677. Train Loss: 0.45163315534591675. Validation Accuracy: 75.0
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Epoch: 774. Train Loss: 0.5059139728546143. Validation Accuracy: 77.34375

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Epoch: 776. Train Loss: 0.5036977529525757. Validation Accuracy: 73.828125
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Epoch: 814. Train Loss: 0.5061317086219788. Validation Accuracy: 74.21875
Epoch: 815. Train Loss: 0.5140554904937744. Validation Accuracy: 75.390625
Epoch: 816. Train Loss: 0.4733985364437103. Validation Accuracy: 75.78125
Epoch: 817. Train Loss: 0.5524020791053772. Validation Accuracy: 73.828125
Epoch: 818. Train Loss: 0.47625333070755005. Validation Accuracy: 70.3125
Epoch: 819. Train Loss: 0.48582273721694946. Validation Accuracy: 72.65625
Epoch: 820. Train Loss: 0.4954568147659302. Validation Accuracy: 82.03125
Epoch: 821. Train Loss: 0.4823145568370819. Validation Accuracy: 76.171875
Epoch: 822. Train Loss: 0.4679950475692749. Validation Accuracy: 73.4375

Epoch: 823. Train Loss: 0.4545973241329193. Validation Accuracy: 71.484375
Epoch: 824. Train Loss: 0.5360058546066284. Validation Accuracy: 75.0
Epoch: 825. Train Loss: 0.46706002950668335. Validation Accuracy: 75.78125
Epoch: 826. Train Loss: 0.5194796919822693. Validation Accuracy: 70.3125
Epoch: 827. Train Loss: 0.4708399772644043. Validation Accuracy: 77.34375
Epoch: 828. Train Loss: 0.4241126477718353. Validation Accuracy: 77.734375
Epoch: 829. Train Loss: 0.5478926301002502. Validation Accuracy: 73.046875
Epoch: 830. Train Loss: 0.4484194219112396. Validation Accuracy: 75.78125
Epoch: 831. Train Loss: 0.47744020819664. Validation Accuracy: 73.046875
Epoch: 832. Train Loss: 0.43963587284088135. Validation Accuracy: 71.09375
Epoch: 833. Train Loss: 0.46713995933532715. Validation Accuracy: 69.140625
Epoch: 834. Train Loss: 0.437328040599823. Validation Accuracy: 75.0
Epoch: 835. Train Loss: 0.44669002294540405. Validation Accuracy: 80.46875
Epoch: 836. Train Loss: 0.48043912649154663. Validation Accuracy: 72.265625
Epoch: 837. Train Loss: 0.49984443187713623. Validation Accuracy: 71.875
Epoch: 838. Train Loss: 0.49645963311195374. Validation Accuracy: 75.78125
Epoch: 839. Train Loss: 0.49338582158088684. Validation Accuracy: 73.4375
Epoch: 840. Train Loss: 0.5934765338897705. Validation Accuracy: 73.046875
Epoch: 841. Train Loss: 0.4835025668144226. Validation Accuracy: 74.21875
Epoch: 842. Train Loss: 0.5110087394714355. Validation Accuracy: 69.140625
Epoch: 843. Train Loss: 0.45916664600372314. Validation Accuracy: 75.78125
Epoch: 844. Train Loss: 0.5128883123397827. Validation Accuracy: 77.734375
Epoch: 845. Train Loss: 0.5191888213157654. Validation Accuracy: 74.609375
Epoch: 846. Train Loss: 0.48872655630111694. Validation Accuracy: 78.125
Epoch: 847. Train Loss: 0.44623082876205444. Validation Accuracy: 77.734375
Epoch: 848. Train Loss: 0.46272435784339905. Validation Accuracy: 76.171875
Epoch: 849. Train Loss: 0.5023735165596008. Validation Accuracy: 72.65625
Epoch: 850. Train Loss: 0.4719211161136627. Validation Accuracy: 76.5625
Epoch: 851. Train Loss: 0.454467862844446716. Validation Accuracy: 77.34375
Epoch: 852. Train Loss: 0.5219720005989075. Validation Accuracy: 75.78125
Epoch: 853. Train Loss: 0.5639840364456177. Validation Accuracy: 81.25
Epoch: 854. Train Loss: 0.4483641982078552. Validation Accuracy: 76.5625
Epoch: 855. Train Loss: 0.49637115001678467. Validation Accuracy: 73.046875
Epoch: 856. Train Loss: 0.4339958131313324. Validation Accuracy: 74.609375
Epoch: 857. Train Loss: 0.46586865186691284. Validation Accuracy: 71.875
Epoch: 858. Train Loss: 0.48314958810806274. Validation Accuracy: 75.78125
Epoch: 859. Train Loss: 0.4468691647052765. Validation Accuracy: 69.140625
Epoch: 860. Train Loss: 0.5145110487937927. Validation Accuracy: 71.875
Epoch: 861. Train Loss: 0.48668092489242554. Validation Accuracy: 78.90625
Epoch: 862. Train Loss: 0.41813480854034424. Validation Accuracy: 71.875
Epoch: 863. Train Loss: 0.4837520718574524. Validation Accuracy: 76.953125
Epoch: 864. Train Loss: 0.43214109539985657. Validation Accuracy: 72.265625
Epoch: 865. Train Loss: 0.5140383839607239. Validation Accuracy: 78.90625
Epoch: 866. Train Loss: 0.5222189426422119. Validation Accuracy: 75.78125
Epoch: 867. Train Loss: 0.4928632974624634. Validation Accuracy: 77.734375
Epoch: 868. Train Loss: 0.4954088032245636. Validation Accuracy: 83.203125
Epoch: 869. Train Loss: 0.4472363591194153. Validation Accuracy: 68.75
Epoch: 870. Train Loss: 0.48153623938560486. Validation Accuracy: 75.390625

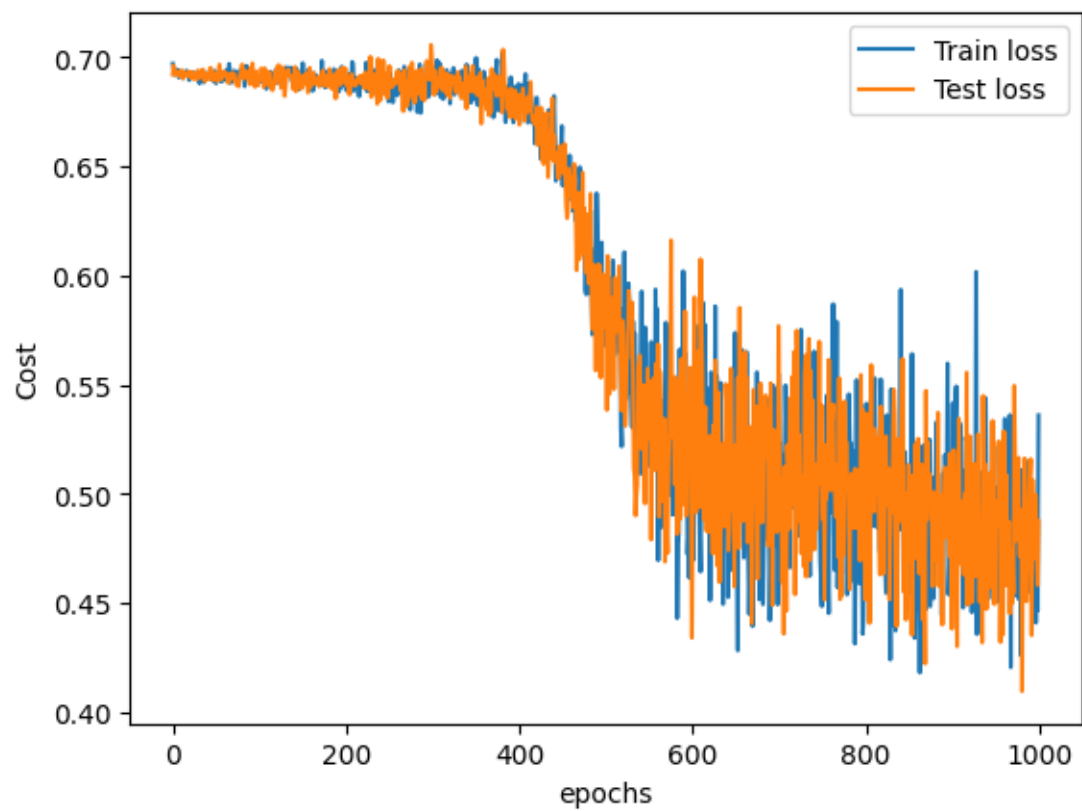
Epoch: 871. Train Loss: 0.4629404544830322. Validation Accuracy: 70.703125
Epoch: 872. Train Loss: 0.49652284383773804. Validation Accuracy: 73.828125
Epoch: 873. Train Loss: 0.5249654650688171. Validation Accuracy: 75.0
Epoch: 874. Train Loss: 0.44847092032432556. Validation Accuracy: 74.609375
Epoch: 875. Train Loss: 0.461517333984375. Validation Accuracy: 76.5625
Epoch: 876. Train Loss: 0.5076084136962891. Validation Accuracy: 75.390625
Epoch: 877. Train Loss: 0.504578709602356. Validation Accuracy: 77.734375
Epoch: 878. Train Loss: 0.4521884024143219. Validation Accuracy: 77.34375
Epoch: 879. Train Loss: 0.47915980219841003. Validation Accuracy: 73.046875
Epoch: 880. Train Loss: 0.5015084147453308. Validation Accuracy: 76.5625
Epoch: 881. Train Loss: 0.5315767526626587. Validation Accuracy: 73.828125
Epoch: 882. Train Loss: 0.5331409573554993. Validation Accuracy: 75.78125
Epoch: 883. Train Loss: 0.511909544467926. Validation Accuracy: 72.265625
Epoch: 884. Train Loss: 0.48269394040107727. Validation Accuracy: 76.171875
Epoch: 885. Train Loss: 0.49494484066963196. Validation Accuracy: 75.0
Epoch: 886. Train Loss: 0.4746379852294922. Validation Accuracy: 77.34375
Epoch: 887. Train Loss: 0.4443190395832062. Validation Accuracy: 75.78125
Epoch: 888. Train Loss: 0.4666220545768738. Validation Accuracy: 79.296875
Epoch: 889. Train Loss: 0.5092979669570923. Validation Accuracy: 75.0
Epoch: 890. Train Loss: 0.4880102872848511. Validation Accuracy: 77.34375
Epoch: 891. Train Loss: 0.517784595489502. Validation Accuracy: 73.4375
Epoch: 892. Train Loss: 0.5073928236961365. Validation Accuracy: 73.046875
Epoch: 893. Train Loss: 0.505848228931427. Validation Accuracy: 73.046875
Epoch: 894. Train Loss: 0.5596426129341125. Validation Accuracy: 75.0
Epoch: 895. Train Loss: 0.45388004183769226. Validation Accuracy: 73.4375
Epoch: 896. Train Loss: 0.46651625633239746. Validation Accuracy: 78.125
Epoch: 897. Train Loss: 0.46427202224731445. Validation Accuracy: 73.828125
Epoch: 898. Train Loss: 0.4617917835712433. Validation Accuracy: 75.78125
Epoch: 899. Train Loss: 0.4843766689300537. Validation Accuracy: 82.03125
Epoch: 900. Train Loss: 0.5414406061172485. Validation Accuracy: 77.734375
Epoch: 901. Train Loss: 0.47463488578796387. Validation Accuracy: 69.921875
Epoch: 902. Train Loss: 0.49413594603538513. Validation Accuracy: 73.828125
Epoch: 903. Train Loss: 0.5369272232055664. Validation Accuracy: 74.609375
Epoch: 904. Train Loss: 0.5491666197776794. Validation Accuracy: 76.171875
Epoch: 905. Train Loss: 0.4724265933036804. Validation Accuracy: 81.25
Epoch: 906. Train Loss: 0.5185217261314392. Validation Accuracy: 74.609375
Epoch: 907. Train Loss: 0.48801976442337036. Validation Accuracy: 67.96875
Epoch: 908. Train Loss: 0.5323755741119385. Validation Accuracy: 75.0
Epoch: 909. Train Loss: 0.5233057141304016. Validation Accuracy: 78.515625
Epoch: 910. Train Loss: 0.5259080529212952. Validation Accuracy: 74.21875
Epoch: 911. Train Loss: 0.49730032682418823. Validation Accuracy: 77.734375
Epoch: 912. Train Loss: 0.44785451889038086. Validation Accuracy: 76.953125
Epoch: 913. Train Loss: 0.5103268623352051. Validation Accuracy: 79.6875
Epoch: 914. Train Loss: 0.45325595140457153. Validation Accuracy: 75.390625
Epoch: 915. Train Loss: 0.45435068011283875. Validation Accuracy: 75.0
Epoch: 916. Train Loss: 0.4987036883831024. Validation Accuracy: 67.578125
Epoch: 917. Train Loss: 0.4931950867176056. Validation Accuracy: 80.46875
Epoch: 918. Train Loss: 0.500785768032074. Validation Accuracy: 73.4375

Epoch: 919. Train Loss: 0.47437065839767456. Validation Accuracy: 74.21875
Epoch: 920. Train Loss: 0.5085060596466064. Validation Accuracy: 69.921875
Epoch: 921. Train Loss: 0.4692949056625366. Validation Accuracy: 75.390625
Epoch: 922. Train Loss: 0.44570544362068176. Validation Accuracy: 80.859375
Epoch: 923. Train Loss: 0.46744534373283386. Validation Accuracy: 75.390625
Epoch: 924. Train Loss: 0.48043277859687805. Validation Accuracy: 72.265625
Epoch: 925. Train Loss: 0.493034303188324. Validation Accuracy: 75.0
Epoch: 926. Train Loss: 0.49612152576446533. Validation Accuracy: 73.828125
Epoch: 927. Train Loss: 0.6015621423721313. Validation Accuracy: 74.21875
Epoch: 928. Train Loss: 0.43568849563598633. Validation Accuracy: 76.5625
Epoch: 929. Train Loss: 0.46496352553367615. Validation Accuracy: 70.3125
Epoch: 930. Train Loss: 0.4913104772567749. Validation Accuracy: 75.78125
Epoch: 931. Train Loss: 0.462227463722229. Validation Accuracy: 79.6875
Epoch: 932. Train Loss: 0.4892273545265198. Validation Accuracy: 75.390625
Epoch: 933. Train Loss: 0.5092539191246033. Validation Accuracy: 71.09375
Epoch: 934. Train Loss: 0.49158838391304016. Validation Accuracy: 82.421875
Epoch: 935. Train Loss: 0.5103433728218079. Validation Accuracy: 68.359375
Epoch: 936. Train Loss: 0.4535539746284485. Validation Accuracy: 73.4375
Epoch: 937. Train Loss: 0.49781110882759094. Validation Accuracy: 72.65625
Epoch: 938. Train Loss: 0.5437660217285156. Validation Accuracy: 71.875
Epoch: 939. Train Loss: 0.5054192543029785. Validation Accuracy: 78.125
Epoch: 940. Train Loss: 0.49453040957450867. Validation Accuracy: 75.78125
Epoch: 941. Train Loss: 0.45183318853378296. Validation Accuracy: 73.4375
Epoch: 942. Train Loss: 0.46166419982910156. Validation Accuracy: 79.296875
Epoch: 943. Train Loss: 0.465378075838089. Validation Accuracy: 73.828125
Epoch: 944. Train Loss: 0.49736475944519043. Validation Accuracy: 71.875
Epoch: 945. Train Loss: 0.45907843112945557. Validation Accuracy: 76.171875
Epoch: 946. Train Loss: 0.49338963627815247. Validation Accuracy: 66.796875
Epoch: 947. Train Loss: 0.4682106077671051. Validation Accuracy: 73.4375
Epoch: 948. Train Loss: 0.49001336097717285. Validation Accuracy: 81.640625
Epoch: 949. Train Loss: 0.5030336976051331. Validation Accuracy: 75.0
Epoch: 950. Train Loss: 0.4622015357017517. Validation Accuracy: 75.78125
Epoch: 951. Train Loss: 0.4555739462375641. Validation Accuracy: 74.609375
Epoch: 952. Train Loss: 0.4507249593734741. Validation Accuracy: 74.609375
Epoch: 953. Train Loss: 0.5217576026916504. Validation Accuracy: 71.875
Epoch: 954. Train Loss: 0.49448162317276. Validation Accuracy: 76.5625
Epoch: 955. Train Loss: 0.4827786982059479. Validation Accuracy: 78.90625
Epoch: 956. Train Loss: 0.5134193301200867. Validation Accuracy: 76.953125
Epoch: 957. Train Loss: 0.4864566922187805. Validation Accuracy: 71.09375
Epoch: 958. Train Loss: 0.5052797794342041. Validation Accuracy: 76.953125
Epoch: 959. Train Loss: 0.458567351102829. Validation Accuracy: 71.09375
Epoch: 960. Train Loss: 0.534308910369873. Validation Accuracy: 73.4375
Epoch: 961. Train Loss: 0.47549307346343994. Validation Accuracy: 77.34375
Epoch: 962. Train Loss: 0.47278574109077454. Validation Accuracy: 71.484375
Epoch: 963. Train Loss: 0.4758101999759674. Validation Accuracy: 75.0
Epoch: 964. Train Loss: 0.45832592248916626. Validation Accuracy: 75.0
Epoch: 965. Train Loss: 0.5105227828025818. Validation Accuracy: 79.296875
Epoch: 966. Train Loss: 0.536048412322998. Validation Accuracy: 80.078125

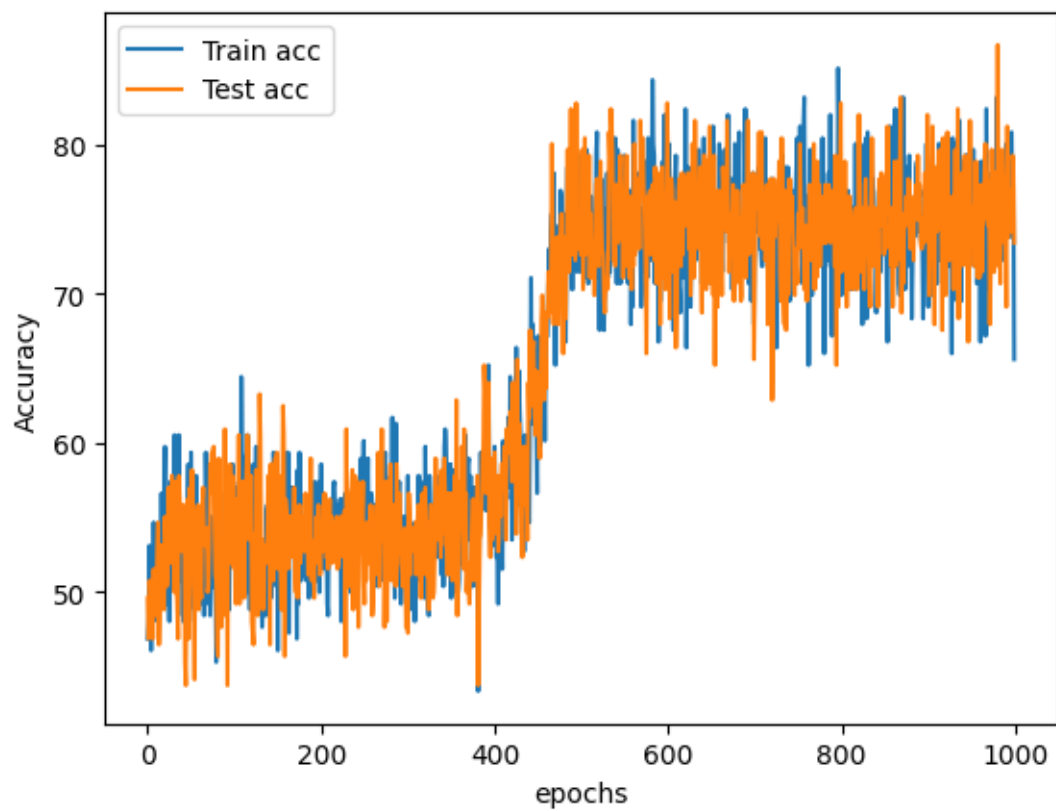
Epoch: 967. Train Loss: 0.42058369517326355. Validation Accuracy: 78.125
Epoch: 968. Train Loss: 0.5263984203338623. Validation Accuracy: 77.34375
Epoch: 969. Train Loss: 0.4841287434101105. Validation Accuracy: 74.609375
Epoch: 970. Train Loss: 0.47348564863204956. Validation Accuracy: 76.171875
Epoch: 971. Train Loss: 0.5125622749328613. Validation Accuracy: 67.96875
Epoch: 972. Train Loss: 0.4900580644607544. Validation Accuracy: 71.484375
Epoch: 973. Train Loss: 0.4533493220806122. Validation Accuracy: 79.6875
Epoch: 974. Train Loss: 0.47684556245803833. Validation Accuracy: 75.390625
Epoch: 975. Train Loss: 0.46095043420791626. Validation Accuracy: 73.4375
Epoch: 976. Train Loss: 0.45184504985809326. Validation Accuracy: 71.484375
Epoch: 977. Train Loss: 0.45884495973587036. Validation Accuracy: 78.125
Epoch: 978. Train Loss: 0.5110316276550293. Validation Accuracy: 71.875
Epoch: 979. Train Loss: 0.42590630054473877. Validation Accuracy: 72.65625
Epoch: 980. Train Loss: 0.46078288555145264. Validation Accuracy: 86.71875
Epoch: 981. Train Loss: 0.48688217997550964. Validation Accuracy: 75.390625
Epoch: 982. Train Loss: 0.4517098665237427. Validation Accuracy: 74.21875
Epoch: 983. Train Loss: 0.5156179070472717. Validation Accuracy: 70.703125
Epoch: 984. Train Loss: 0.4745967984199524. Validation Accuracy: 78.125
Epoch: 985. Train Loss: 0.5137689113616943. Validation Accuracy: 79.6875
Epoch: 986. Train Loss: 0.4646003544330597. Validation Accuracy: 77.34375
Epoch: 987. Train Loss: 0.49020570516586304. Validation Accuracy: 75.390625
Epoch: 988. Train Loss: 0.48173239827156067. Validation Accuracy: 73.4375
Epoch: 989. Train Loss: 0.4742805063724518. Validation Accuracy: 73.828125
Epoch: 990. Train Loss: 0.4547813832759857. Validation Accuracy: 69.140625
Epoch: 991. Train Loss: 0.4727970361709595. Validation Accuracy: 81.25
Epoch: 992. Train Loss: 0.4687524437904358. Validation Accuracy: 73.828125
Epoch: 993. Train Loss: 0.47264957427978516. Validation Accuracy: 76.953125
Epoch: 994. Train Loss: 0.4943462908267975. Validation Accuracy: 75.390625
Epoch: 995. Train Loss: 0.4707322418689728. Validation Accuracy: 74.21875
Epoch: 996. Train Loss: 0.44100019335746765. Validation Accuracy: 74.609375
Epoch: 997. Train Loss: 0.46422645449638367. Validation Accuracy: 79.296875
Epoch: 998. Train Loss: 0.446603924036026. Validation Accuracy: 78.90625
Epoch: 999. Train Loss: 0.5359713435173035. Validation Accuracy: 73.4375

Train and test plots

[106]: `plot_curves(train_costs, train_acc, val_costs, val_acc)`



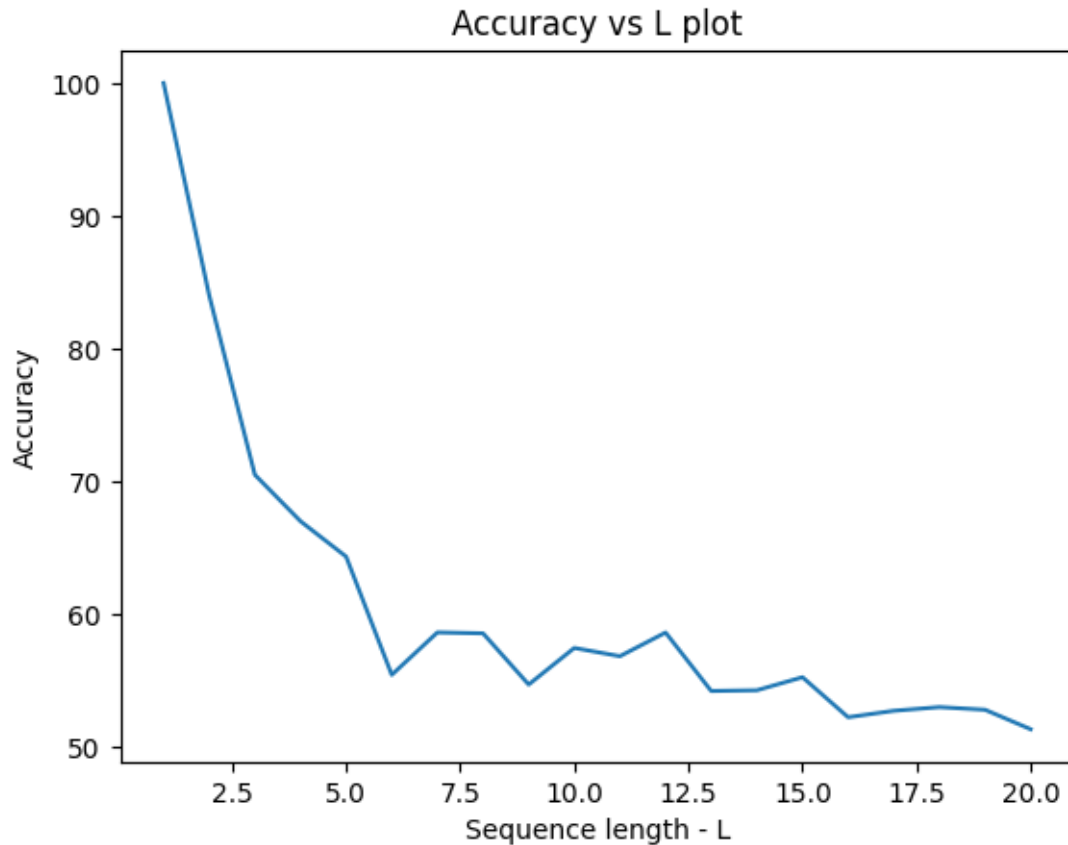
Train loss value after 1000 epochs: 0.5359713435173035
Vaildation loss value after 1000 epochs: 0.4874132573604584



Best Test Accuracy: 86.71875%

Bitwise Accuracy vs Length

```
[107]: plot_accuracy_vs_length(model)
```



9.7.3 Hidden State Size = 10

```
[108]: HIDDEN_DIM = 10
```

```
[109]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
        criterion = nn.CrossEntropyLoss()
        optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[110]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
        ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.7030448317527771. Validation Accuracy: 53.125
Epoch: 1. Train Loss: 0.6959405541419983. Validation Accuracy: 52.734375
Epoch: 2. Train Loss: 0.6992778182029724. Validation Accuracy: 48.828125
Epoch: 3. Train Loss: 0.6988399028778076. Validation Accuracy: 50.0
Epoch: 4. Train Loss: 0.6958133578300476. Validation Accuracy: 51.171875
Epoch: 5. Train Loss: 0.6981773972511292. Validation Accuracy: 50.390625
Epoch: 6. Train Loss: 0.703985869884491. Validation Accuracy: 49.21875
```

Epoch: 7. Train Loss: 0.6964614987373352. Validation Accuracy: 51.171875
Epoch: 8. Train Loss: 0.705502986907959. Validation Accuracy: 50.390625
Epoch: 9. Train Loss: 0.6939699053764343. Validation Accuracy: 50.0
Epoch: 10. Train Loss: 0.6949734687805176. Validation Accuracy: 52.734375
Epoch: 11. Train Loss: 0.6996622681617737. Validation Accuracy: 50.390625
Epoch: 12. Train Loss: 0.6976218819618225. Validation Accuracy: 51.5625
Epoch: 13. Train Loss: 0.6888226270675659. Validation Accuracy: 47.265625
Epoch: 14. Train Loss: 0.6904445886611938. Validation Accuracy: 45.703125
Epoch: 15. Train Loss: 0.6926946043968201. Validation Accuracy: 50.0
Epoch: 16. Train Loss: 0.6941851377487183. Validation Accuracy: 48.4375
Epoch: 17. Train Loss: 0.6905766129493713. Validation Accuracy: 48.828125
Epoch: 18. Train Loss: 0.6976722478866577. Validation Accuracy: 48.4375
Epoch: 19. Train Loss: 0.6953233480453491. Validation Accuracy: 50.390625
Epoch: 20. Train Loss: 0.6930090188980103. Validation Accuracy: 49.609375
Epoch: 21. Train Loss: 0.697422206401825. Validation Accuracy: 45.703125
Epoch: 22. Train Loss: 0.6920503973960876. Validation Accuracy: 51.953125
Epoch: 23. Train Loss: 0.6965823173522949. Validation Accuracy: 50.390625
Epoch: 24. Train Loss: 0.6910929679870605. Validation Accuracy: 48.4375
Epoch: 25. Train Loss: 0.6910977959632874. Validation Accuracy: 50.78125
Epoch: 26. Train Loss: 0.6936970949172974. Validation Accuracy: 44.921875
Epoch: 27. Train Loss: 0.6888707280158997. Validation Accuracy: 51.953125
Epoch: 28. Train Loss: 0.6904106140136719. Validation Accuracy: 51.171875
Epoch: 29. Train Loss: 0.6946496963500977. Validation Accuracy: 48.828125
Epoch: 30. Train Loss: 0.6934255361557007. Validation Accuracy: 53.125
Epoch: 31. Train Loss: 0.6911612153053284. Validation Accuracy: 51.953125
Epoch: 32. Train Loss: 0.6958986520767212. Validation Accuracy: 50.78125
Epoch: 33. Train Loss: 0.6920540928840637. Validation Accuracy: 49.609375
Epoch: 34. Train Loss: 0.6889527440071106. Validation Accuracy: 52.734375
Epoch: 35. Train Loss: 0.6901032328605652. Validation Accuracy: 50.0
Epoch: 36. Train Loss: 0.6915245652198792. Validation Accuracy: 54.296875
Epoch: 37. Train Loss: 0.690345048904419. Validation Accuracy: 53.125
Epoch: 38. Train Loss: 0.6911798119544983. Validation Accuracy: 56.640625
Epoch: 39. Train Loss: 0.6909493207931519. Validation Accuracy: 53.125
Epoch: 40. Train Loss: 0.690887987613678. Validation Accuracy: 52.734375
Epoch: 41. Train Loss: 0.6939929723739624. Validation Accuracy: 53.515625
Epoch: 42. Train Loss: 0.6911274194717407. Validation Accuracy: 58.203125
Epoch: 43. Train Loss: 0.6933571696281433. Validation Accuracy: 49.21875
Epoch: 44. Train Loss: 0.6924529671669006. Validation Accuracy: 50.0
Epoch: 45. Train Loss: 0.6930831670761108. Validation Accuracy: 50.390625
Epoch: 46. Train Loss: 0.6904993653297424. Validation Accuracy: 48.4375
Epoch: 47. Train Loss: 0.6927973628044128. Validation Accuracy: 51.5625
Epoch: 48. Train Loss: 0.6912763714790344. Validation Accuracy: 51.953125
Epoch: 49. Train Loss: 0.6927244067192078. Validation Accuracy: 54.6875
Epoch: 50. Train Loss: 0.689702570438385. Validation Accuracy: 48.046875
Epoch: 51. Train Loss: 0.6908932328224182. Validation Accuracy: 51.5625
Epoch: 52. Train Loss: 0.688690185546875. Validation Accuracy: 53.515625
Epoch: 53. Train Loss: 0.6920692920684814. Validation Accuracy: 53.515625
Epoch: 54. Train Loss: 0.6902260184288025. Validation Accuracy: 50.0

Epoch: 55. Train Loss: 0.6937708258628845. Validation Accuracy: 54.296875
Epoch: 56. Train Loss: 0.6887375116348267. Validation Accuracy: 47.65625
Epoch: 57. Train Loss: 0.6892319321632385. Validation Accuracy: 50.78125
Epoch: 58. Train Loss: 0.6886772513389587. Validation Accuracy: 48.4375
Epoch: 59. Train Loss: 0.6918848752975464. Validation Accuracy: 54.6875
Epoch: 60. Train Loss: 0.6958038210868835. Validation Accuracy: 45.3125
Epoch: 61. Train Loss: 0.6894001364707947. Validation Accuracy: 52.734375
Epoch: 62. Train Loss: 0.6882448196411133. Validation Accuracy: 55.859375
Epoch: 63. Train Loss: 0.6887632608413696. Validation Accuracy: 58.984375
Epoch: 64. Train Loss: 0.6901545524597168. Validation Accuracy: 52.34375
Epoch: 65. Train Loss: 0.6900323033332825. Validation Accuracy: 48.828125
Epoch: 66. Train Loss: 0.6866816878318787. Validation Accuracy: 55.859375
Epoch: 67. Train Loss: 0.6914713382720947. Validation Accuracy: 55.46875
Epoch: 68. Train Loss: 0.691834032535553. Validation Accuracy: 48.046875
Epoch: 69. Train Loss: 0.6903380155563354. Validation Accuracy: 53.125
Epoch: 70. Train Loss: 0.6919645071029663. Validation Accuracy: 52.734375
Epoch: 71. Train Loss: 0.6934596300125122. Validation Accuracy: 49.21875
Epoch: 72. Train Loss: 0.6867311000823975. Validation Accuracy: 57.421875
Epoch: 73. Train Loss: 0.6902612447738647. Validation Accuracy: 48.4375
Epoch: 74. Train Loss: 0.6883017420768738. Validation Accuracy: 53.125
Epoch: 75. Train Loss: 0.6923486590385437. Validation Accuracy: 49.21875
Epoch: 76. Train Loss: 0.6883265972137451. Validation Accuracy: 53.90625
Epoch: 77. Train Loss: 0.6887136697769165. Validation Accuracy: 50.0
Epoch: 78. Train Loss: 0.6891350150108337. Validation Accuracy: 49.609375
Epoch: 79. Train Loss: 0.6924615502357483. Validation Accuracy: 58.59375
Epoch: 80. Train Loss: 0.691348135471344. Validation Accuracy: 52.734375
Epoch: 81. Train Loss: 0.6978548169136047. Validation Accuracy: 53.90625
Epoch: 82. Train Loss: 0.688410222530365. Validation Accuracy: 52.34375
Epoch: 83. Train Loss: 0.6865341067314148. Validation Accuracy: 49.609375
Epoch: 84. Train Loss: 0.6894990801811218. Validation Accuracy: 54.6875
Epoch: 85. Train Loss: 0.6894785761833191. Validation Accuracy: 53.90625
Epoch: 86. Train Loss: 0.6886096596717834. Validation Accuracy: 54.6875
Epoch: 87. Train Loss: 0.6891940236091614. Validation Accuracy: 59.375
Epoch: 88. Train Loss: 0.6940231323242188. Validation Accuracy: 57.8125
Epoch: 89. Train Loss: 0.6845344305038452. Validation Accuracy: 56.25
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Epoch: 91. Train Loss: 0.6878715753555298. Validation Accuracy: 53.90625
Epoch: 92. Train Loss: 0.688497006893158. Validation Accuracy: 48.046875
Epoch: 93. Train Loss: 0.6911697387695312. Validation Accuracy: 56.25
Epoch: 94. Train Loss: 0.6903278827667236. Validation Accuracy: 54.6875
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Epoch: 101. Train Loss: 0.6939659118652344. Validation Accuracy: 54.6875
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Epoch: 103. Train Loss: 0.6899731159210205. Validation Accuracy: 52.734375
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Epoch: 371. Train Loss: 0.6938015222549438. Validation Accuracy: 55.46875
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Epoch: 374. Train Loss: 0.7014772295951843. Validation Accuracy: 50.78125
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Epoch: 377. Train Loss: 0.6881225109100342. Validation Accuracy: 53.515625
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Epoch: 381. Train Loss: 0.6840537786483765. Validation Accuracy: 57.8125
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Epoch: 383. Train Loss: 0.6782901883125305. Validation Accuracy: 51.171875
Epoch: 384. Train Loss: 0.6847668886184692. Validation Accuracy: 56.25
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Epoch: 390. Train Loss: 0.6913143992424011. Validation Accuracy: 50.390625

Epoch: 391. Train Loss: 0.6862275004386902. Validation Accuracy: 54.296875
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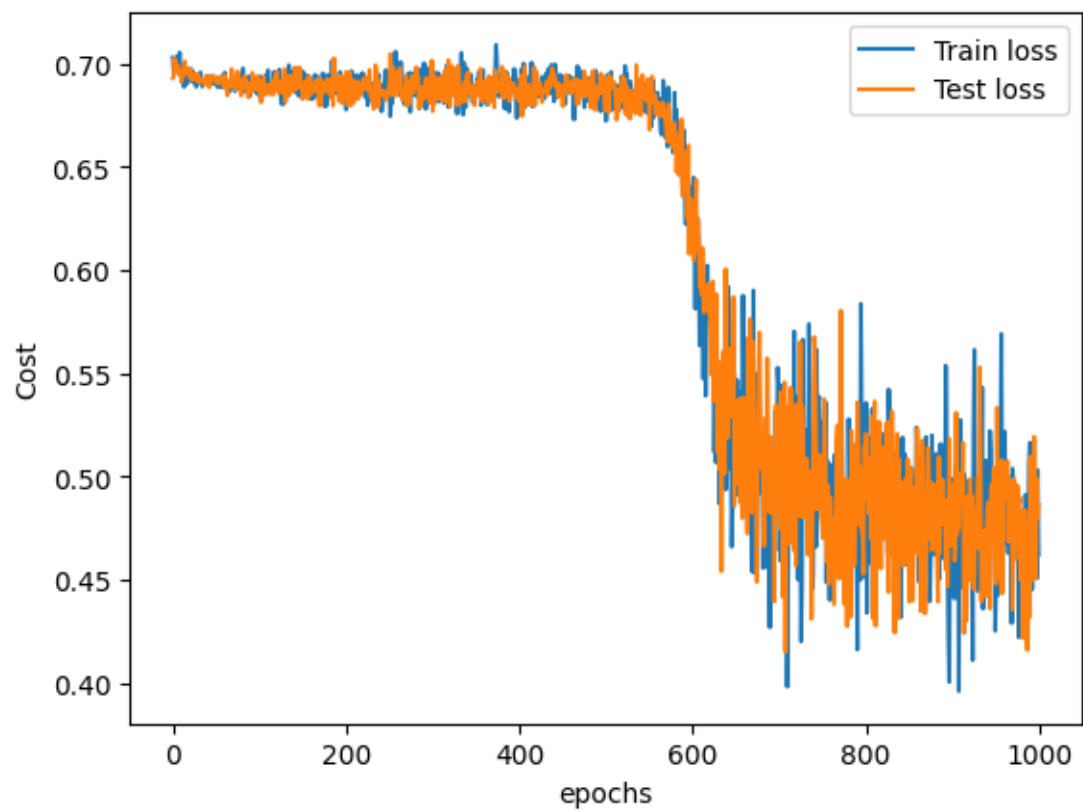
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Epoch: 934. Train Loss: 0.5431839823722839. Validation Accuracy: 77.734375
Epoch: 935. Train Loss: 0.4358411133289337. Validation Accuracy: 75.78125
Epoch: 936. Train Loss: 0.4817984700202942. Validation Accuracy: 76.171875
Epoch: 937. Train Loss: 0.463749498128891. Validation Accuracy: 75.0
Epoch: 938. Train Loss: 0.5077810883522034. Validation Accuracy: 78.125
Epoch: 939. Train Loss: 0.4438604712486267. Validation Accuracy: 75.78125
Epoch: 940. Train Loss: 0.4636611342430115. Validation Accuracy: 73.828125
Epoch: 941. Train Loss: 0.4710577130317688. Validation Accuracy: 75.390625
Epoch: 942. Train Loss: 0.47334855794906616. Validation Accuracy: 76.5625
Epoch: 943. Train Loss: 0.5220667123794556. Validation Accuracy: 82.03125
Epoch: 944. Train Loss: 0.5116295218467712. Validation Accuracy: 73.046875
Epoch: 945. Train Loss: 0.46994829177856445. Validation Accuracy: 71.875
Epoch: 946. Train Loss: 0.47669804096221924. Validation Accuracy: 72.65625
Epoch: 947. Train Loss: 0.47113555669784546. Validation Accuracy: 69.921875
Epoch: 948. Train Loss: 0.4940199851989746. Validation Accuracy: 72.65625
Epoch: 949. Train Loss: 0.4251622259616852. Validation Accuracy: 78.125
Epoch: 950. Train Loss: 0.4481726884841919. Validation Accuracy: 77.734375
Epoch: 951. Train Loss: 0.4501204490661621. Validation Accuracy: 68.359375
Epoch: 952. Train Loss: 0.44242754578590393. Validation Accuracy: 70.703125
Epoch: 953. Train Loss: 0.480108380317688. Validation Accuracy: 71.875
Epoch: 954. Train Loss: 0.46388715505599976. Validation Accuracy: 75.390625
Epoch: 955. Train Loss: 0.5090034604072571. Validation Accuracy: 76.953125
Epoch: 956. Train Loss: 0.5691502094268799. Validation Accuracy: 72.265625
Epoch: 957. Train Loss: 0.48842453956604004. Validation Accuracy: 77.734375
Epoch: 958. Train Loss: 0.5037320256233215. Validation Accuracy: 68.359375
Epoch: 959. Train Loss: 0.520124614238739. Validation Accuracy: 70.703125
Epoch: 960. Train Loss: 0.5217675566673279. Validation Accuracy: 71.484375
Epoch: 961. Train Loss: 0.4811778962612152. Validation Accuracy: 71.484375
Epoch: 962. Train Loss: 0.46819329261779785. Validation Accuracy: 74.21875
Epoch: 963. Train Loss: 0.5009710788726807. Validation Accuracy: 71.875
Epoch: 964. Train Loss: 0.462781697511673. Validation Accuracy: 74.609375
Epoch: 965. Train Loss: 0.48923221230506897. Validation Accuracy: 72.265625
Epoch: 966. Train Loss: 0.4936286211013794. Validation Accuracy: 74.21875

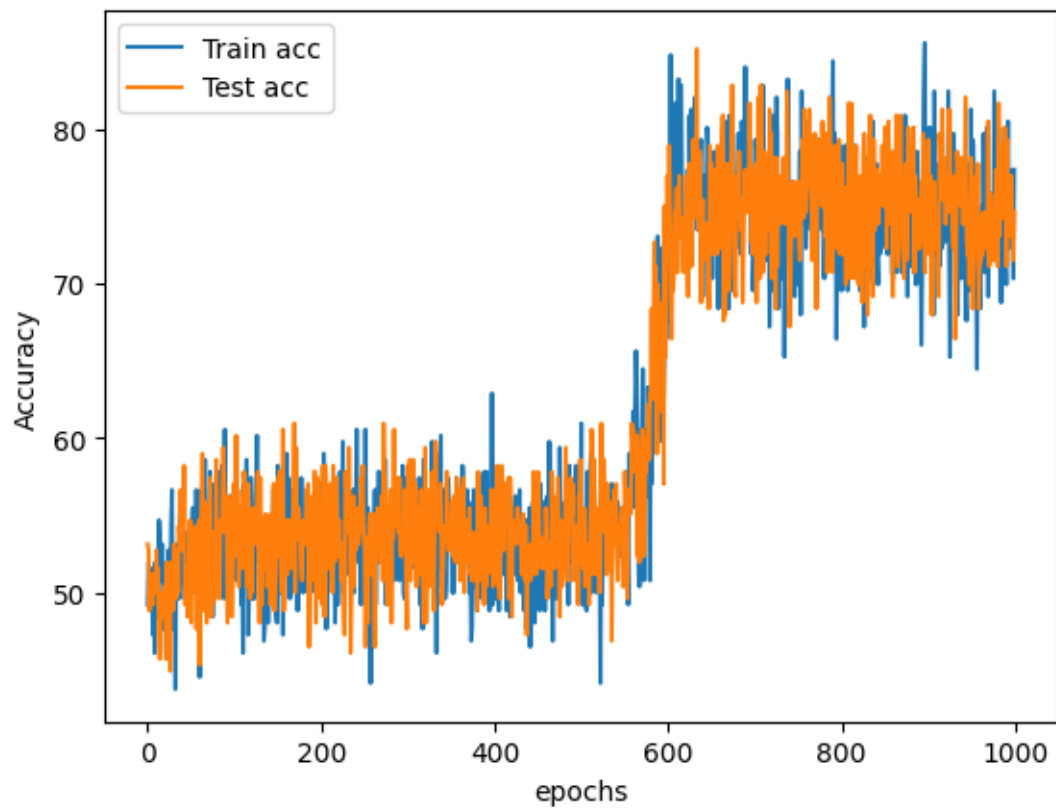
Epoch: 967. Train Loss: 0.49766767024993896. Validation Accuracy: 72.65625
Epoch: 968. Train Loss: 0.4289204478263855. Validation Accuracy: 72.65625
Epoch: 969. Train Loss: 0.50382000207901. Validation Accuracy: 80.46875
Epoch: 970. Train Loss: 0.49713706970214844. Validation Accuracy: 71.09375
Epoch: 971. Train Loss: 0.48805081844329834. Validation Accuracy: 71.484375
Epoch: 972. Train Loss: 0.476641446352005. Validation Accuracy: 75.78125
Epoch: 973. Train Loss: 0.4949665069580078. Validation Accuracy: 73.4375
Epoch: 974. Train Loss: 0.49288538098335266. Validation Accuracy: 72.65625
Epoch: 975. Train Loss: 0.48948147892951965. Validation Accuracy: 71.484375
Epoch: 976. Train Loss: 0.42203858494758606. Validation Accuracy: 73.828125
Epoch: 977. Train Loss: 0.44493430852890015. Validation Accuracy: 73.046875
Epoch: 978. Train Loss: 0.4553658068180084. Validation Accuracy: 77.34375
Epoch: 979. Train Loss: 0.4566234052181244. Validation Accuracy: 76.5625
Epoch: 980. Train Loss: 0.461380273103714. Validation Accuracy: 71.09375
Epoch: 981. Train Loss: 0.45285049080848694. Validation Accuracy: 81.640625
Epoch: 982. Train Loss: 0.47321900725364685. Validation Accuracy: 73.046875
Epoch: 983. Train Loss: 0.46351000666618347. Validation Accuracy: 74.21875
Epoch: 984. Train Loss: 0.4911949932575226. Validation Accuracy: 74.21875
Epoch: 985. Train Loss: 0.4740675687789917. Validation Accuracy: 74.21875
Epoch: 986. Train Loss: 0.4760964512825012. Validation Accuracy: 78.90625
Epoch: 987. Train Loss: 0.4602356255054474. Validation Accuracy: 75.390625
Epoch: 988. Train Loss: 0.5064626932144165. Validation Accuracy: 80.078125
Epoch: 989. Train Loss: 0.5164129734039307. Validation Accuracy: 78.125
Epoch: 990. Train Loss: 0.4930473566055298. Validation Accuracy: 71.09375
Epoch: 991. Train Loss: 0.44507724046707153. Validation Accuracy: 79.296875
Epoch: 992. Train Loss: 0.44592350721359253. Validation Accuracy: 75.390625
Epoch: 993. Train Loss: 0.5050908923149109. Validation Accuracy: 76.953125
Epoch: 994. Train Loss: 0.4758492410182953. Validation Accuracy: 73.046875
Epoch: 995. Train Loss: 0.4679371416568756. Validation Accuracy: 73.828125
Epoch: 996. Train Loss: 0.4626196622848511. Validation Accuracy: 76.953125
Epoch: 997. Train Loss: 0.45058348774909973. Validation Accuracy: 73.046875
Epoch: 998. Train Loss: 0.5030899047851562. Validation Accuracy: 71.484375
Epoch: 999. Train Loss: 0.4619201421737671. Validation Accuracy: 74.609375

Train and test plots

```
[111]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



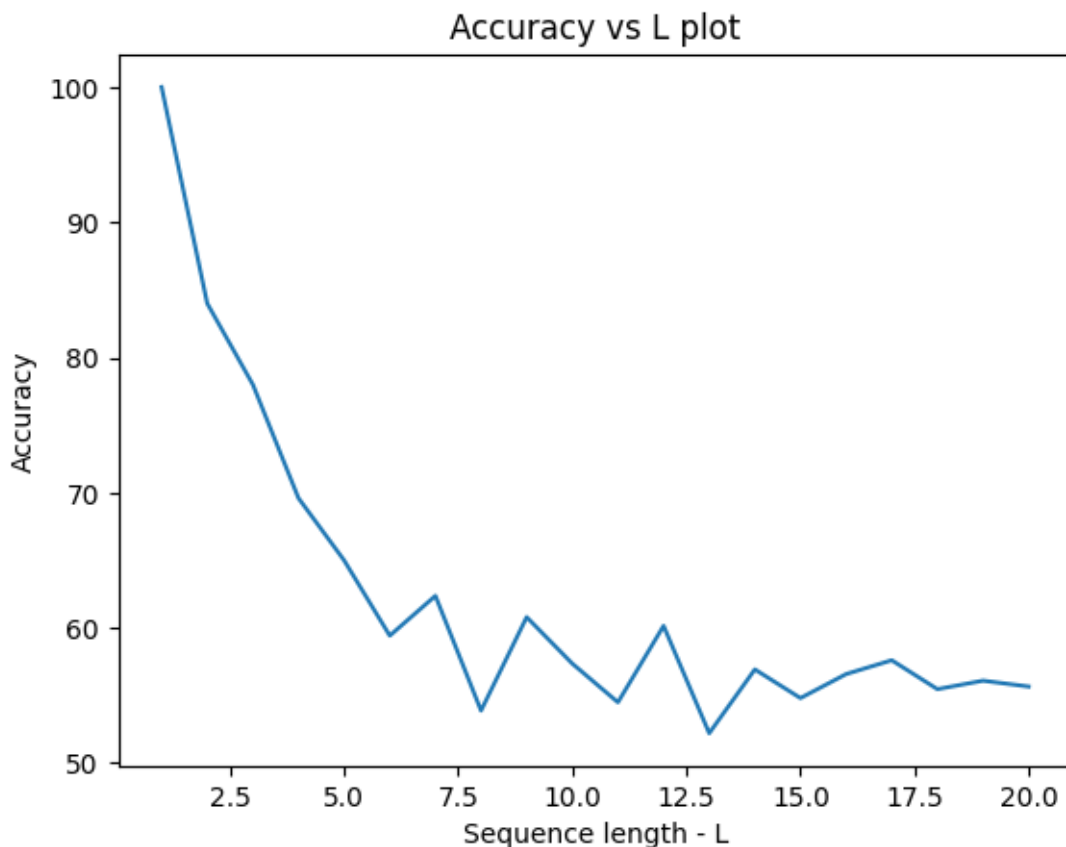
Train loss value after 1000 epochs: 0.4619201421737671
Vaildation loss value after 1000 epochs: 0.48619815707206726



Best Test Accuracy: 85.15625%

Bitwise Accuracy vs Length

```
[112]: plot_accuracy_vs_length(model)
```



9.7.4 Summary of Results

Sequence length = 3

Epochs for training = 1000

| State Size | Train loss | Validation Loss | Bitwise Accuracy |
|------------|------------|-----------------|------------------|
| 2 | 0.5504 | 0.5584 | 83.59375% |
| 5 | 0.5359 | 0.4874 | 86.71875% |
| 10 | 0.4619 | 0.4861 | 85.15625% |

The performance is comparable but it seems like a hidden state size of 5 or 10 is more ideal. We might discover a trend when we try with other binary string lengths.

Analyzing the relationship between sequence lengths and bitwise accuracy from the plots, there's a noticeable decline in performance with increasing sequence lengths.

A noteworthy observation is that our training has been limited to sequences of lengths 3 and 5. In both instances, the bitwise accuracy drops to below 60% around sequence lengths of 5-6. This suggests that models trained on shorter sequences can generalize as effectively as those trained on

longer sequences when tasked with processing extended strings, provided the architecture remains consistent and sufficient training epochs are utilized.

9.8 Length of Input Sequence = 10

```
[131]: L = 10
```

9.8.1 Hidden State Size = 2

```
[132]: HIDDEN_DIM = 2
```

```
[133]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
        criterion = nn.CrossEntropyLoss()
        optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[134]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
        ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.7343868017196655. Validation Accuracy: 50.71022727272727
Epoch: 1. Train Loss: 0.7355112433433533. Validation Accuracy: 48.57954545454545
Epoch: 2. Train Loss: 0.7161359190940857. Validation Accuracy: 50.28409090909091
Epoch: 3. Train Loss: 0.7154760360717773. Validation Accuracy: 48.86363636363637
Epoch: 4. Train Loss: 0.7339316010475159. Validation Accuracy: 49.43181818181818
Epoch: 5. Train Loss: 0.744961142539978. Validation Accuracy: 47.72727272727273
Epoch: 6. Train Loss: 0.7304225564002991. Validation Accuracy: 47.86931818181818
Epoch: 7. Train Loss: 0.7311573028564453. Validation Accuracy: 50.42613636363637
Epoch: 8. Train Loss: 0.7293918132781982. Validation Accuracy: 47.86931818181818
Epoch: 9. Train Loss: 0.7251937389373779. Validation Accuracy: 48.15340909090909
Epoch: 10. Train Loss: 0.7048021554946899. Validation Accuracy: 50.0
Epoch: 11. Train Loss: 0.7375755310058594. Validation Accuracy:
50.56818181818182
Epoch: 12. Train Loss: 0.7069677114486694. Validation Accuracy:
47.86931818181818
Epoch: 13. Train Loss: 0.7162860631942749. Validation Accuracy:
50.28409090909091
Epoch: 14. Train Loss: 0.7180618643760681. Validation Accuracy:
52.69886363636363
Epoch: 15. Train Loss: 0.7244124412536621. Validation Accuracy:
49.57386363636363
Epoch: 16. Train Loss: 0.7247167229652405. Validation Accuracy:
47.30113636363637
Epoch: 17. Train Loss: 0.7162495851516724. Validation Accuracy:
47.86931818181818
Epoch: 18. Train Loss: 0.7205092906951904. Validation Accuracy:
50.28409090909091
Epoch: 19. Train Loss: 0.7214780449867249. Validation Accuracy:
```

51.42045454545455
 Epoch: 20. Train Loss: 0.7295337915420532. Validation Accuracy:
 53.26704545454545
 Epoch: 21. Train Loss: 0.7303701639175415. Validation Accuracy:
 51.13636363636363
 Epoch: 22. Train Loss: 0.7227830290794373. Validation Accuracy:
 51.42045454545455
 Epoch: 23. Train Loss: 0.7158876657485962. Validation Accuracy:
 48.72159090909091
 Epoch: 24. Train Loss: 0.711769163608551. Validation Accuracy: 50.42613636363637
 Epoch: 25. Train Loss: 0.7258408069610596. Validation Accuracy:
 48.57954545454545
 Epoch: 26. Train Loss: 0.7223153710365295. Validation Accuracy: 48.4375
 Epoch: 27. Train Loss: 0.7267144322395325. Validation Accuracy:
 51.98863636363637
 Epoch: 28. Train Loss: 0.7103777527809143. Validation Accuracy: 46.875
 Epoch: 29. Train Loss: 0.724713146686554. Validation Accuracy: 51.98863636363637
 Epoch: 30. Train Loss: 0.7175453901290894. Validation Accuracy:
 49.71590909090909
 Epoch: 31. Train Loss: 0.7207996845245361. Validation Accuracy:
 50.28409090909091
 Epoch: 32. Train Loss: 0.7214910387992859. Validation Accuracy: 51.5625
 Epoch: 33. Train Loss: 0.7229933142662048. Validation Accuracy:
 48.86363636363637
 Epoch: 34. Train Loss: 0.7043231725692749. Validation Accuracy:
 50.85227272727273
 Epoch: 35. Train Loss: 0.7180598974227905. Validation Accuracy: 48.4375
 Epoch: 36. Train Loss: 0.7142110466957092. Validation Accuracy:
 49.43181818181818
 Epoch: 37. Train Loss: 0.7099554538726807. Validation Accuracy: 45.3125
 Epoch: 38. Train Loss: 0.718932569026947. Validation Accuracy: 49.28977272727273
 Epoch: 39. Train Loss: 0.7142155766487122. Validation Accuracy:
 46.30681818181818
 Epoch: 40. Train Loss: 0.7122219204902649. Validation Accuracy:
 51.42045454545455
 Epoch: 41. Train Loss: 0.7089871168136597. Validation Accuracy:
 49.71590909090909
 Epoch: 42. Train Loss: 0.7134328484535217. Validation Accuracy: 50.0
 Epoch: 43. Train Loss: 0.6998595595359802. Validation Accuracy:
 49.57386363636363
 Epoch: 44. Train Loss: 0.7122673392295837. Validation Accuracy:
 50.71022727272727
 Epoch: 45. Train Loss: 0.7126872539520264. Validation Accuracy:
 50.85227272727273
 Epoch: 46. Train Loss: 0.7143450379371643. Validation Accuracy:
 50.14204545454545
 Epoch: 47. Train Loss: 0.7178571224212646. Validation Accuracy:
 52.55681818181818

Epoch: 48. Train Loss: 0.7055233716964722. Validation Accuracy: 49.28977272727273

Epoch: 49. Train Loss: 0.7187389731407166. Validation Accuracy: 49.71590909090909

Epoch: 50. Train Loss: 0.7106661200523376. Validation Accuracy: 48.15340909090909

Epoch: 51. Train Loss: 0.7044285535812378. Validation Accuracy: 50.99431818181818

Epoch: 52. Train Loss: 0.7120078206062317. Validation Accuracy: 52.27272727272727

Epoch: 53. Train Loss: 0.7121255397796631. Validation Accuracy: 51.98863636363637

Epoch: 54. Train Loss: 0.7181755304336548. Validation Accuracy: 49.85795454545455

Epoch: 55. Train Loss: 0.6991395354270935. Validation Accuracy: 49.71590909090909

Epoch: 56. Train Loss: 0.6962584853172302. Validation Accuracy: 50.28409090909091

Epoch: 57. Train Loss: 0.7081544399261475. Validation Accuracy: 48.4375

Epoch: 58. Train Loss: 0.7072560787200928. Validation Accuracy: 49.57386363636363

Epoch: 59. Train Loss: 0.7092142701148987. Validation Accuracy: 48.29545454545455

Epoch: 60. Train Loss: 0.7078102827072144. Validation Accuracy: 49.28977272727273

Epoch: 61. Train Loss: 0.7059784531593323. Validation Accuracy: 50.0

Epoch: 62. Train Loss: 0.7035247087478638. Validation Accuracy: 49.00568181818182

Epoch: 63. Train Loss: 0.7036113142967224. Validation Accuracy: 47.01704545454545

Epoch: 64. Train Loss: 0.7159034013748169. Validation Accuracy: 51.27840909090909

Epoch: 65. Train Loss: 0.7028083801269531. Validation Accuracy: 49.14772727272727

Epoch: 66. Train Loss: 0.7062060832977295. Validation Accuracy: 50.28409090909091

Epoch: 67. Train Loss: 0.696921169757843. Validation Accuracy: 53.55113636363637

Epoch: 68. Train Loss: 0.7052759528160095. Validation Accuracy: 48.57954545454545

Epoch: 69. Train Loss: 0.7118101716041565. Validation Accuracy: 53.26704545454545

Epoch: 70. Train Loss: 0.6994228959083557. Validation Accuracy: 47.72727272727273

Epoch: 71. Train Loss: 0.7061874866485596. Validation Accuracy: 49.57386363636363

Epoch: 72. Train Loss: 0.6958469748497009. Validation Accuracy: 50.0

Epoch: 73. Train Loss: 0.711652398109436. Validation Accuracy: 45.3125

Epoch: 74. Train Loss: 0.7079252600669861. Validation Accuracy:

49.57386363636363
Epoch: 75. Train Loss: 0.6971015930175781. Validation Accuracy: 47.44318181818182
Epoch: 76. Train Loss: 0.7132484912872314. Validation Accuracy: 55.25568181818182
Epoch: 77. Train Loss: 0.711066484451294. Validation Accuracy: 51.5625
Epoch: 78. Train Loss: 0.7074437737464905. Validation Accuracy: 51.70454545454545
Epoch: 79. Train Loss: 0.704353928565979. Validation Accuracy: 52.84090909090909
Epoch: 80. Train Loss: 0.7057529091835022. Validation Accuracy: 50.28409090909091
Epoch: 81. Train Loss: 0.7112152576446533. Validation Accuracy: 49.28977272727273
Epoch: 82. Train Loss: 0.7032250761985779. Validation Accuracy: 45.59659090909091
Epoch: 83. Train Loss: 0.6996570825576782. Validation Accuracy: 49.71590909090909
Epoch: 84. Train Loss: 0.7033886313438416. Validation Accuracy: 50.42613636363637
Epoch: 85. Train Loss: 0.708824872970581. Validation Accuracy: 52.13068181818182
Epoch: 86. Train Loss: 0.695547342300415. Validation Accuracy: 50.99431818181818
Epoch: 87. Train Loss: 0.7046791911125183. Validation Accuracy: 50.99431818181818
Epoch: 88. Train Loss: 0.7016875743865967. Validation Accuracy: 49.28977272727273
Epoch: 89. Train Loss: 0.7006240487098694. Validation Accuracy: 49.43181818181818
Epoch: 90. Train Loss: 0.6978048086166382. Validation Accuracy: 50.56818181818182
Epoch: 91. Train Loss: 0.696208655834198. Validation Accuracy: 52.55681818181818
Epoch: 92. Train Loss: 0.699117124080658. Validation Accuracy: 50.56818181818182
Epoch: 93. Train Loss: 0.6992533206939697. Validation Accuracy: 53.55113636363637
Epoch: 94. Train Loss: 0.7050087451934814. Validation Accuracy: 49.57386363636363
Epoch: 95. Train Loss: 0.70609450340271. Validation Accuracy: 50.85227272727273
Epoch: 96. Train Loss: 0.7012172937393188. Validation Accuracy: 49.43181818181818
Epoch: 97. Train Loss: 0.6990178227424622. Validation Accuracy: 51.42045454545455
Epoch: 98. Train Loss: 0.694700300693512. Validation Accuracy: 50.14204545454545
Epoch: 99. Train Loss: 0.6998775005340576. Validation Accuracy: 45.88068181818182
Epoch: 100. Train Loss: 0.7025880813598633. Validation Accuracy: 52.13068181818182
Epoch: 101. Train Loss: 0.6985968947410583. Validation Accuracy: 49.71590909090909
Epoch: 102. Train Loss: 0.6972082853317261. Validation Accuracy:

48.29545454545455
Epoch: 103. Train Loss: 0.6995523571968079. Validation Accuracy: 50.0
Epoch: 104. Train Loss: 0.6967194080352783. Validation Accuracy:
47.58522727272727
Epoch: 105. Train Loss: 0.6935174465179443. Validation Accuracy:
53.40909090909091
Epoch: 106. Train Loss: 0.7002465724945068. Validation Accuracy:
51.84659090909091
Epoch: 107. Train Loss: 0.6948390603065491. Validation Accuracy:
47.58522727272727
Epoch: 108. Train Loss: 0.6934017539024353. Validation Accuracy:
51.27840909090909
Epoch: 109. Train Loss: 0.6980059742927551. Validation Accuracy:
48.01136363636363
Epoch: 110. Train Loss: 0.6957184672355652. Validation Accuracy:
52.69886363636363
Epoch: 111. Train Loss: 0.6955142617225647. Validation Accuracy:
48.29545454545455
Epoch: 112. Train Loss: 0.6974599361419678. Validation Accuracy:
49.28977272727273
Epoch: 113. Train Loss: 0.6952977776527405. Validation Accuracy:
47.72727272727273
Epoch: 114. Train Loss: 0.6955477595329285. Validation Accuracy:
47.86931818181818
Epoch: 115. Train Loss: 0.6963066458702087. Validation Accuracy:
49.71590909090909
Epoch: 116. Train Loss: 0.7020847201347351. Validation Accuracy:
50.99431818181818
Epoch: 117. Train Loss: 0.6971765756607056. Validation Accuracy: 50.0
Epoch: 118. Train Loss: 0.6952390074729919. Validation Accuracy:
48.15340909090909
Epoch: 119. Train Loss: 0.6922529339790344. Validation Accuracy:
49.85795454545455
Epoch: 120. Train Loss: 0.6969843506813049. Validation Accuracy:
52.69886363636363
Epoch: 121. Train Loss: 0.6946682333946228. Validation Accuracy:
48.72159090909091
Epoch: 122. Train Loss: 0.7008515000343323. Validation Accuracy: 50.0
Epoch: 123. Train Loss: 0.6966074109077454. Validation Accuracy:
49.28977272727273
Epoch: 124. Train Loss: 0.6978676319122314. Validation Accuracy:
49.85795454545455
Epoch: 125. Train Loss: 0.6962079405784607. Validation Accuracy:
47.15909090909091
Epoch: 126. Train Loss: 0.695965588092804. Validation Accuracy:
47.58522727272727
Epoch: 127. Train Loss: 0.6954548954963684. Validation Accuracy:
52.55681818181818

Epoch: 128. Train Loss: 0.6935343146324158. Validation Accuracy: 53.55113636363637
 Epoch: 129. Train Loss: 0.6945850849151611. Validation Accuracy: 49.14772727272727
 Epoch: 130. Train Loss: 0.6950610280036926. Validation Accuracy: 52.55681818181818
 Epoch: 131. Train Loss: 0.6962167620658875. Validation Accuracy: 48.57954545454545
 Epoch: 132. Train Loss: 0.696436882019043. Validation Accuracy: 51.70454545454545
 Epoch: 133. Train Loss: 0.6930485367774963. Validation Accuracy: 50.99431818181818
 Epoch: 134. Train Loss: 0.6965017914772034. Validation Accuracy: 49.28977272727273
 Epoch: 135. Train Loss: 0.6962562799453735. Validation Accuracy: 48.57954545454545
 Epoch: 136. Train Loss: 0.6954061985015869. Validation Accuracy: 49.71590909090909
 Epoch: 137. Train Loss: 0.6921806931495667. Validation Accuracy: 50.56818181818182
 Epoch: 138. Train Loss: 0.6958491206169128. Validation Accuracy: 49.28977272727273
 Epoch: 139. Train Loss: 0.6973679065704346. Validation Accuracy: 46.30681818181818
 Epoch: 140. Train Loss: 0.6935645937919617. Validation Accuracy: 47.58522727272727
 Epoch: 141. Train Loss: 0.6942393779754639. Validation Accuracy: 48.29545454545455
 Epoch: 142. Train Loss: 0.696642279624939. Validation Accuracy: 49.85795454545455
 Epoch: 143. Train Loss: 0.6954975128173828. Validation Accuracy: 50.42613636363637
 Epoch: 144. Train Loss: 0.6938380002975464. Validation Accuracy: 50.28409090909091
 Epoch: 145. Train Loss: 0.6900444030761719. Validation Accuracy: 50.28409090909091
 Epoch: 146. Train Loss: 0.6940368413925171. Validation Accuracy: 46.875
 Epoch: 147. Train Loss: 0.69333815574646. Validation Accuracy: 49.71590909090909
 Epoch: 148. Train Loss: 0.694929659366077. Validation Accuracy: 49.85795454545455
 Epoch: 149. Train Loss: 0.6906428933143616. Validation Accuracy: 49.85795454545455
 Epoch: 150. Train Loss: 0.6945533156394958. Validation Accuracy: 48.29545454545455
 Epoch: 151. Train Loss: 0.6941810250282288. Validation Accuracy: 48.15340909090909
 Epoch: 152. Train Loss: 0.6955317258834839. Validation Accuracy: 47.58522727272727

Epoch: 153. Train Loss: 0.6957364678382874. Validation Accuracy: 47.72727272727273
Epoch: 154. Train Loss: 0.6936907172203064. Validation Accuracy: 48.57954545454545
Epoch: 155. Train Loss: 0.6972473859786987. Validation Accuracy: 51.84659090909091
Epoch: 156. Train Loss: 0.695231556892395. Validation Accuracy: 49.71590909090909
Epoch: 157. Train Loss: 0.695231020450592. Validation Accuracy: 48.4375
Epoch: 158. Train Loss: 0.692141592502594. Validation Accuracy: 51.13636363636363
Epoch: 159. Train Loss: 0.6942518949508667. Validation Accuracy: 50.42613636363637
Epoch: 160. Train Loss: 0.6928735375404358. Validation Accuracy: 49.57386363636363
Epoch: 161. Train Loss: 0.6946044564247131. Validation Accuracy: 48.4375
Epoch: 162. Train Loss: 0.6966868042945862. Validation Accuracy: 53.69318181818182
Epoch: 163. Train Loss: 0.6950095295906067. Validation Accuracy: 51.70454545454545
Epoch: 164. Train Loss: 0.6913905739784241. Validation Accuracy: 49.57386363636363
Epoch: 165. Train Loss: 0.6954883933067322. Validation Accuracy: 47.44318181818182
Epoch: 166. Train Loss: 0.69417804479599. Validation Accuracy: 48.4375
Epoch: 167. Train Loss: 0.6944699287414551. Validation Accuracy: 51.70454545454545
Epoch: 168. Train Loss: 0.6948156356811523. Validation Accuracy: 52.27272727272727
Epoch: 169. Train Loss: 0.6958662271499634. Validation Accuracy: 51.98863636363637
Epoch: 170. Train Loss: 0.6922934651374817. Validation Accuracy: 48.01136363636363
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Epoch: 679. Train Loss: 0.6934283375740051. Validation Accuracy:
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Epoch: 913. Train Loss: 0.692542552947998. Validation Accuracy: 50.28409090909091
Epoch: 914. Train Loss: 0.6923519372940063. Validation Accuracy: 46.875
Epoch: 915. Train Loss: 0.6929484009742737. Validation Accuracy: 54.54545454545455
Epoch: 916. Train Loss: 0.6928238272666931. Validation Accuracy: 49.14772727272727
Epoch: 917. Train Loss: 0.6933521628379822. Validation Accuracy: 50.99431818181818
Epoch: 918. Train Loss: 0.6944809556007385. Validation Accuracy: 50.71022727272727
Epoch: 919. Train Loss: 0.6920403838157654. Validation Accuracy: 49.00568181818182
Epoch: 920. Train Loss: 0.6929450631141663. Validation Accuracy: 52.41477272727273
Epoch: 921. Train Loss: 0.6931023597717285. Validation Accuracy: 48.72159090909091
Epoch: 922. Train Loss: 0.6926791667938232. Validation Accuracy: 49.14772727272727
Epoch: 923. Train Loss: 0.6932559609413147. Validation Accuracy: 49.57386363636363
Epoch: 924. Train Loss: 0.6936500072479248. Validation Accuracy: 49.28977272727273
Epoch: 925. Train Loss: 0.6926555037498474. Validation Accuracy: 48.29545454545455
Epoch: 926. Train Loss: 0.6934509873390198. Validation Accuracy: 49.85795454545455
Epoch: 927. Train Loss: 0.6936315894126892. Validation Accuracy: 49.14772727272727
Epoch: 928. Train Loss: 0.6927807331085205. Validation Accuracy:

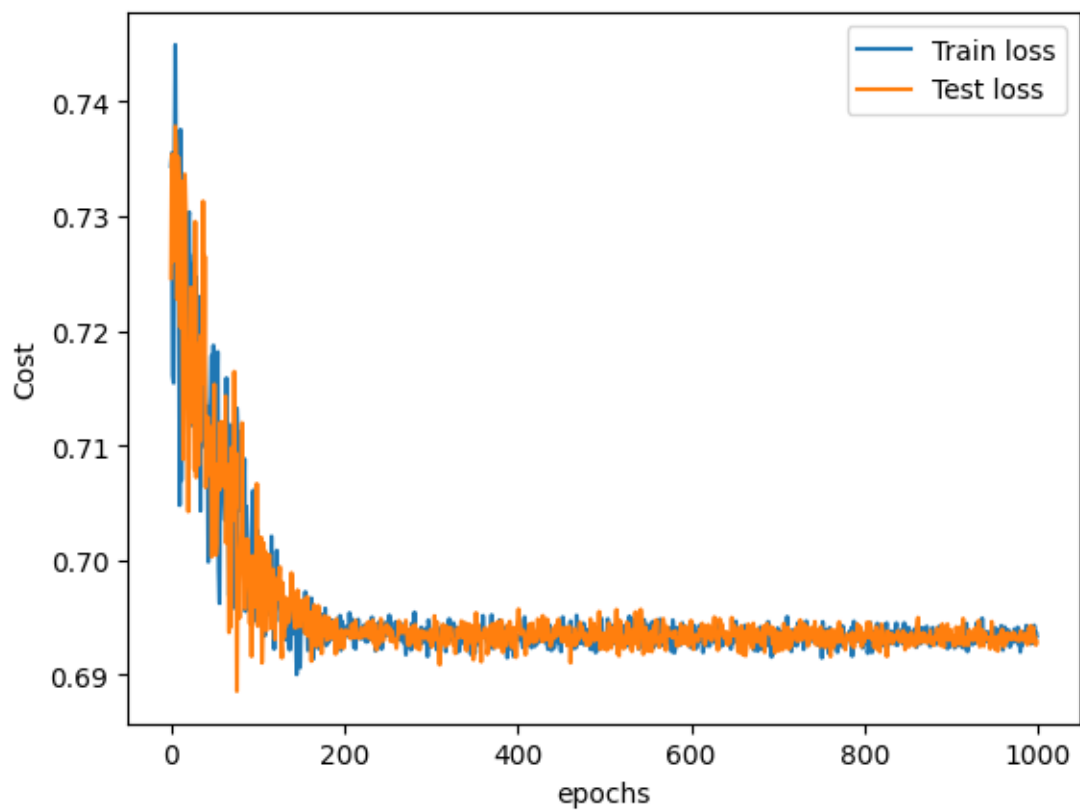
48.72159090909091
Epoch: 929. Train Loss: 0.6933372020721436. Validation Accuracy: 48.29545454545455
Epoch: 930. Train Loss: 0.6945566534996033. Validation Accuracy: 50.14204545454545
Epoch: 931. Train Loss: 0.6934497952461243. Validation Accuracy: 50.99431818181818
Epoch: 932. Train Loss: 0.6932624578475952. Validation Accuracy: 47.44318181818182
Epoch: 933. Train Loss: 0.6928838491439819. Validation Accuracy: 49.57386363636363
Epoch: 934. Train Loss: 0.6937074065208435. Validation Accuracy: 51.70454545454545
Epoch: 935. Train Loss: 0.6936047077178955. Validation Accuracy: 50.56818181818182
Epoch: 936. Train Loss: 0.6949495673179626. Validation Accuracy: 47.72727272727273
Epoch: 937. Train Loss: 0.6935991644859314. Validation Accuracy: 52.98295454545455
Epoch: 938. Train Loss: 0.6928662061691284. Validation Accuracy: 51.27840909090909
Epoch: 939. Train Loss: 0.6935524344444275. Validation Accuracy: 48.15340909090909
Epoch: 940. Train Loss: 0.6930443048477173. Validation Accuracy: 49.14772727272727
Epoch: 941. Train Loss: 0.692908763885498. Validation Accuracy: 51.70454545454545
Epoch: 942. Train Loss: 0.6937784552574158. Validation Accuracy: 49.14772727272727
Epoch: 943. Train Loss: 0.6931748986244202. Validation Accuracy: 51.13636363636363
Epoch: 944. Train Loss: 0.6929702758789062. Validation Accuracy: 48.57954545454545
Epoch: 945. Train Loss: 0.6934708952903748. Validation Accuracy: 51.42045454545455
Epoch: 946. Train Loss: 0.6929508447647095. Validation Accuracy: 52.13068181818182
Epoch: 947. Train Loss: 0.692780613899231. Validation Accuracy: 46.875
Epoch: 948. Train Loss: 0.693107008934021. Validation Accuracy: 49.14772727272727
Epoch: 949. Train Loss: 0.6934316158294678. Validation Accuracy: 50.28409090909091
Epoch: 950. Train Loss: 0.6939987540245056. Validation Accuracy: 53.125
Epoch: 951. Train Loss: 0.6941099166870117. Validation Accuracy: 52.41477272727273
Epoch: 952. Train Loss: 0.6933441758155823. Validation Accuracy: 49.85795454545455
Epoch: 953. Train Loss: 0.6935864090919495. Validation Accuracy:

50.42613636363637
Epoch: 954. Train Loss: 0.6938920617103577. Validation Accuracy: 50.85227272727273
Epoch: 955. Train Loss: 0.6932039856910706. Validation Accuracy: 51.84659090909091
Epoch: 956. Train Loss: 0.6931649446487427. Validation Accuracy: 48.57954545454545
Epoch: 957. Train Loss: 0.6939990520477295. Validation Accuracy: 48.86363636363637
Epoch: 958. Train Loss: 0.6942897439002991. Validation Accuracy: 50.85227272727273
Epoch: 959. Train Loss: 0.6929402947425842. Validation Accuracy: 47.01704545454545
Epoch: 960. Train Loss: 0.6921705603599548. Validation Accuracy: 52.69886363636363
Epoch: 961. Train Loss: 0.6934759020805359. Validation Accuracy: 50.14204545454545
Epoch: 962. Train Loss: 0.6941826343536377. Validation Accuracy: 49.85795454545455
Epoch: 963. Train Loss: 0.6938916444778442. Validation Accuracy: 49.28977272727273
Epoch: 964. Train Loss: 0.6937430500984192. Validation Accuracy: 51.5625
Epoch: 965. Train Loss: 0.6935502290725708. Validation Accuracy: 49.57386363636363
Epoch: 966. Train Loss: 0.6939324736595154. Validation Accuracy: 47.86931818181818
Epoch: 967. Train Loss: 0.6931589245796204. Validation Accuracy: 51.27840909090909
Epoch: 968. Train Loss: 0.6924329996109009. Validation Accuracy: 50.56818181818182
Epoch: 969. Train Loss: 0.6928820013999939. Validation Accuracy: 50.71022727272727
Epoch: 970. Train Loss: 0.6934195160865784. Validation Accuracy: 50.99431818181818
Epoch: 971. Train Loss: 0.6928216814994812. Validation Accuracy: 48.15340909090909
Epoch: 972. Train Loss: 0.6934971213340759. Validation Accuracy: 47.30113636363637
Epoch: 973. Train Loss: 0.6939877271652222. Validation Accuracy: 49.57386363636363
Epoch: 974. Train Loss: 0.6934500336647034. Validation Accuracy: 47.58522727272727
Epoch: 975. Train Loss: 0.6933631300926208. Validation Accuracy: 50.42613636363637
Epoch: 976. Train Loss: 0.6928431987762451. Validation Accuracy: 50.99431818181818
Epoch: 977. Train Loss: 0.6941540241241455. Validation Accuracy: 49.43181818181818

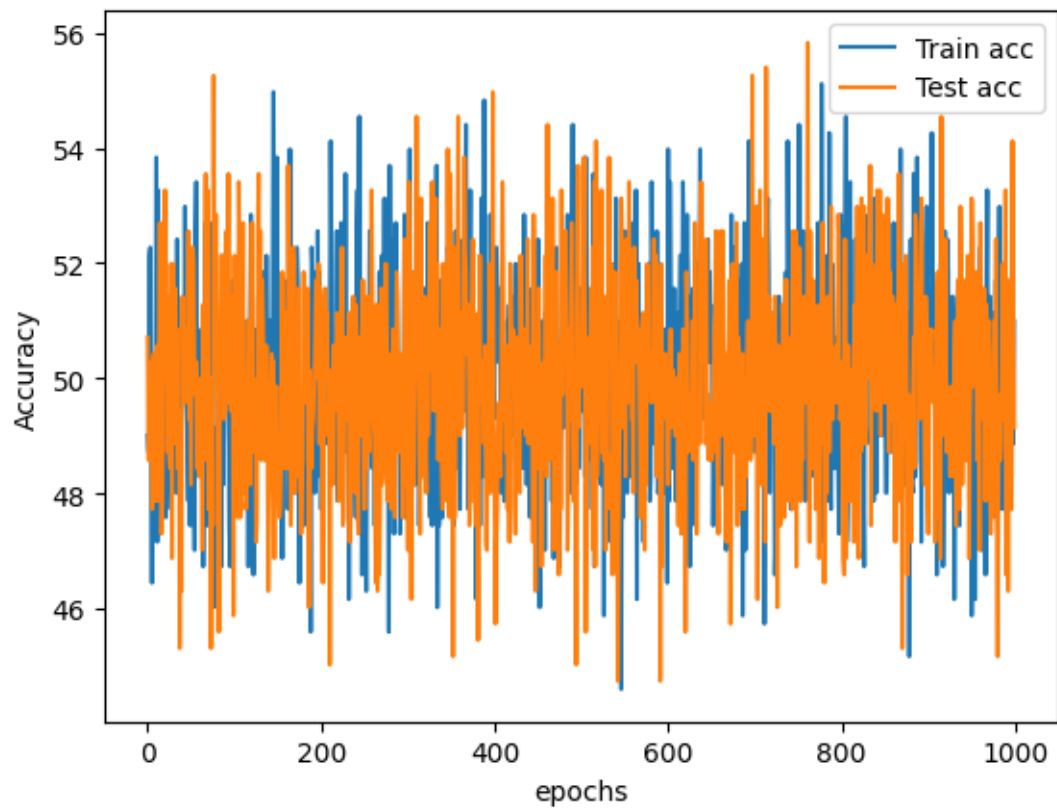
Epoch: 978. Train Loss: 0.6926520466804504. Validation Accuracy: 52.41477272727273
Epoch: 979. Train Loss: 0.6933629512786865. Validation Accuracy: 47.58522727272727
Epoch: 980. Train Loss: 0.6920061707496643. Validation Accuracy: 45.17045454545455
Epoch: 981. Train Loss: 0.6929616928100586. Validation Accuracy: 48.72159090909091
Epoch: 982. Train Loss: 0.6925426721572876. Validation Accuracy: 49.71590909090909
Epoch: 983. Train Loss: 0.6937451958656311. Validation Accuracy: 48.57954545454545
Epoch: 984. Train Loss: 0.693391740322113. Validation Accuracy: 48.86363636363637
Epoch: 985. Train Loss: 0.6938278675079346. Validation Accuracy: 50.42613636363637
Epoch: 986. Train Loss: 0.6929863691329956. Validation Accuracy: 51.98863636363637
Epoch: 987. Train Loss: 0.6943035125732422. Validation Accuracy: 49.28977272727273
Epoch: 988. Train Loss: 0.6930055022239685. Validation Accuracy: 50.42613636363637
Epoch: 989. Train Loss: 0.6930152773857117. Validation Accuracy: 53.26704545454545
Epoch: 990. Train Loss: 0.6932572722434998. Validation Accuracy: 46.59090909090909
Epoch: 991. Train Loss: 0.6933452486991882. Validation Accuracy: 50.71022727272727
Epoch: 992. Train Loss: 0.6927114725112915. Validation Accuracy: 46.30681818181818
Epoch: 993. Train Loss: 0.6934881806373596. Validation Accuracy: 51.70454545454545
Epoch: 994. Train Loss: 0.6932351589202881. Validation Accuracy: 49.28977272727273
Epoch: 995. Train Loss: 0.6928358674049377. Validation Accuracy: 50.0
Epoch: 996. Train Loss: 0.6943183541297913. Validation Accuracy: 47.72727272727273
Epoch: 997. Train Loss: 0.6933150887489319. Validation Accuracy: 54.11931818181818
Epoch: 998. Train Loss: 0.693767249584198. Validation Accuracy: 51.13636363636363
Epoch: 999. Train Loss: 0.6933560967445374. Validation Accuracy: 49.14772727272727

Train and test plots

```
[135]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



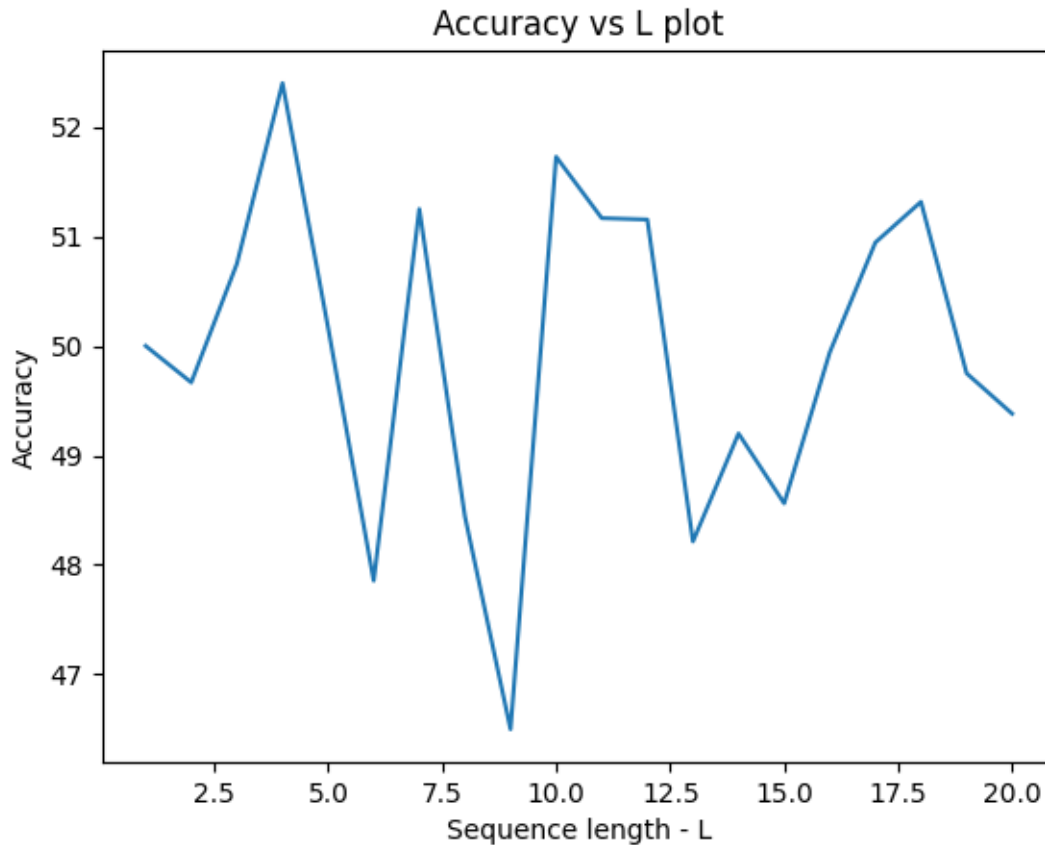
Train loss value after 1000 epochs: 0.6933560967445374
Vaildation loss value after 1000 epochs: 0.6928938031196594



Best Test Accuracy: 55.82386363636363%

Bitwise Accuracy vs Length

```
[136]: plot_accuracy_vs_length(model)
```



9.8.2 Hidden State Size = 5

```
[137]: HIDDEN_DIM = 5
```

```
[138]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
        criterion = nn.CrossEntropyLoss()
        optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[139]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
        ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.697051465511322. Validation Accuracy: 51.27840909090909
Epoch: 1. Train Loss: 0.6988427639007568. Validation Accuracy: 50.0
Epoch: 2. Train Loss: 0.6985238790512085. Validation Accuracy: 46.875
Epoch: 3. Train Loss: 0.6989428997039795. Validation Accuracy: 50.0
Epoch: 4. Train Loss: 0.6962623000144958. Validation Accuracy: 49.57386363636363
Epoch: 5. Train Loss: 0.6904205083847046. Validation Accuracy: 50.14204545454545
Epoch: 6. Train Loss: 0.6965134143829346. Validation Accuracy: 47.86931818181818
```


Epoch: 7. Train Loss: 0.6944434642791748. Validation Accuracy: 51.42045454545455
 Epoch: 8. Train Loss: 0.6952310800552368. Validation Accuracy: 50.71022727272727
 Epoch: 9. Train Loss: 0.697242796421051. Validation Accuracy: 54.26136363636363
 Epoch: 10. Train Loss: 0.6957153677940369. Validation Accuracy:
 51.27840909090909
 Epoch: 11. Train Loss: 0.6966599822044373. Validation Accuracy:
 50.28409090909091
 Epoch: 12. Train Loss: 0.6960803866386414. Validation Accuracy:
 50.14204545454545
 Epoch: 13. Train Loss: 0.6937339305877686. Validation Accuracy:
 50.42613636363637
 Epoch: 14. Train Loss: 0.6933836340904236. Validation Accuracy:
 49.43181818181818
 Epoch: 15. Train Loss: 0.6939554214477539. Validation Accuracy:
 48.01136363636363
 Epoch: 16. Train Loss: 0.6936795711517334. Validation Accuracy:
 48.57954545454545
 Epoch: 17. Train Loss: 0.6930455565452576. Validation Accuracy:
 50.14204545454545
 Epoch: 18. Train Loss: 0.6956533789634705. Validation Accuracy:
 52.69886363636363
 Epoch: 19. Train Loss: 0.6939404606819153. Validation Accuracy:
 50.71022727272727
 Epoch: 20. Train Loss: 0.6932603716850281. Validation Accuracy:
 47.15909090909091
 Epoch: 21. Train Loss: 0.6938026547431946. Validation Accuracy:
 52.55681818181818
 Epoch: 22. Train Loss: 0.6934421062469482. Validation Accuracy:
 49.57386363636363
 Epoch: 23. Train Loss: 0.694248378276825. Validation Accuracy: 49.28977272727273
 Epoch: 24. Train Loss: 0.6940188407897949. Validation Accuracy:
 49.85795454545455
 Epoch: 25. Train Loss: 0.6930805444717407. Validation Accuracy:
 51.84659090909091
 Epoch: 26. Train Loss: 0.6946388483047485. Validation Accuracy:
 50.99431818181818
 Epoch: 27. Train Loss: 0.6950274109840393. Validation Accuracy:
 51.98863636363637
 Epoch: 28. Train Loss: 0.6927909255027771. Validation Accuracy:
 50.14204545454545
 Epoch: 29. Train Loss: 0.6939578652381897. Validation Accuracy:
 50.14204545454545
 Epoch: 30. Train Loss: 0.6939519047737122. Validation Accuracy:
 50.71022727272727
 Epoch: 31. Train Loss: 0.6944156289100647. Validation Accuracy:
 48.01136363636363
 Epoch: 32. Train Loss: 0.6930623650550842. Validation Accuracy: 48.4375
 Epoch: 33. Train Loss: 0.6927012205123901. Validation Accuracy:

52.69886363636363
Epoch: 34. Train Loss: 0.6923609972000122. Validation Accuracy: 51.84659090909091
Epoch: 35. Train Loss: 0.6936681270599365. Validation Accuracy: 49.28977272727273
Epoch: 36. Train Loss: 0.693416953086853. Validation Accuracy: 50.0
Epoch: 37. Train Loss: 0.6927103400230408. Validation Accuracy: 50.85227272727273
Epoch: 38. Train Loss: 0.6940860748291016. Validation Accuracy: 50.28409090909091
Epoch: 39. Train Loss: 0.6940851211547852. Validation Accuracy: 47.44318181818182
Epoch: 40. Train Loss: 0.6935476660728455. Validation Accuracy: 50.28409090909091
Epoch: 41. Train Loss: 0.693120539188385. Validation Accuracy: 52.69886363636363
Epoch: 42. Train Loss: 0.6938526034355164. Validation Accuracy: 46.44886363636363
Epoch: 43. Train Loss: 0.6934909224510193. Validation Accuracy: 50.71022727272727
Epoch: 44. Train Loss: 0.6939195394515991. Validation Accuracy: 51.70454545454545
Epoch: 45. Train Loss: 0.6937617659568787. Validation Accuracy: 48.4375
Epoch: 46. Train Loss: 0.6941914558410645. Validation Accuracy: 51.70454545454545
Epoch: 47. Train Loss: 0.6930637955665588. Validation Accuracy: 51.27840909090909
Epoch: 48. Train Loss: 0.69342440366745. Validation Accuracy: 48.4375
Epoch: 49. Train Loss: 0.693065881729126. Validation Accuracy: 48.29545454545455
Epoch: 50. Train Loss: 0.6929153800010681. Validation Accuracy: 48.57954545454545
Epoch: 51. Train Loss: 0.6918900012969971. Validation Accuracy: 47.72727272727273
Epoch: 52. Train Loss: 0.693030059337616. Validation Accuracy: 51.98863636363637
Epoch: 53. Train Loss: 0.6938028931617737. Validation Accuracy: 48.86363636363637
Epoch: 54. Train Loss: 0.6929566860198975. Validation Accuracy: 47.01704545454545
Epoch: 55. Train Loss: 0.6938173770904541. Validation Accuracy: 48.15340909090909
Epoch: 56. Train Loss: 0.6937127709388733. Validation Accuracy: 49.57386363636363
Epoch: 57. Train Loss: 0.6926116347312927. Validation Accuracy: 49.00568181818182
Epoch: 58. Train Loss: 0.6934221386909485. Validation Accuracy: 48.4375
Epoch: 59. Train Loss: 0.6954655051231384. Validation Accuracy: 50.28409090909091
Epoch: 60. Train Loss: 0.6932839751243591. Validation Accuracy: 50.14204545454545

Epoch: 61. Train Loss: 0.6923590898513794. Validation Accuracy: 49.57386363636363
Epoch: 62. Train Loss: 0.6926732063293457. Validation Accuracy: 50.28409090909091
Epoch: 63. Train Loss: 0.6941060423851013. Validation Accuracy: 51.13636363636363
Epoch: 64. Train Loss: 0.6946371793746948. Validation Accuracy: 55.96590909090909
Epoch: 65. Train Loss: 0.6937093138694763. Validation Accuracy: 49.14772727272727
Epoch: 66. Train Loss: 0.6944192051887512. Validation Accuracy: 49.00568181818182
Epoch: 67. Train Loss: 0.6932437419891357. Validation Accuracy: 49.71590909090909
Epoch: 68. Train Loss: 0.6936097741127014. Validation Accuracy: 50.99431818181818
Epoch: 69. Train Loss: 0.6927849650382996. Validation Accuracy: 49.14772727272727
Epoch: 70. Train Loss: 0.6921250820159912. Validation Accuracy: 48.4375
Epoch: 71. Train Loss: 0.6939184069633484. Validation Accuracy: 51.42045454545455
Epoch: 72. Train Loss: 0.693899393081665. Validation Accuracy: 55.39772727272727
Epoch: 73. Train Loss: 0.693949282169342. Validation Accuracy: 49.28977272727273
Epoch: 74. Train Loss: 0.6924176812171936. Validation Accuracy: 48.72159090909091
Epoch: 75. Train Loss: 0.6941484212875366. Validation Accuracy: 53.125
Epoch: 76. Train Loss: 0.6941812038421631. Validation Accuracy: 52.69886363636363
Epoch: 77. Train Loss: 0.6930866837501526. Validation Accuracy: 53.125
Epoch: 78. Train Loss: 0.69381183385849. Validation Accuracy: 49.85795454545455
Epoch: 79. Train Loss: 0.6926383376121521. Validation Accuracy: 48.57954545454545
Epoch: 80. Train Loss: 0.6924622654914856. Validation Accuracy: 51.70454545454545
Epoch: 81. Train Loss: 0.6935980916023254. Validation Accuracy: 47.58522727272727
Epoch: 82. Train Loss: 0.6926490068435669. Validation Accuracy: 48.72159090909091
Epoch: 83. Train Loss: 0.6936069130897522. Validation Accuracy: 51.5625
Epoch: 84. Train Loss: 0.6935811638832092. Validation Accuracy: 51.70454545454545
Epoch: 85. Train Loss: 0.6926153302192688. Validation Accuracy: 50.42613636363637
Epoch: 86. Train Loss: 0.6937516331672668. Validation Accuracy: 51.98863636363637
Epoch: 87. Train Loss: 0.693385899066925. Validation Accuracy: 50.0
Epoch: 88. Train Loss: 0.6933627724647522. Validation Accuracy: 48.86363636363637

Epoch: 89. Train Loss: 0.6931475400924683. Validation Accuracy: 45.73863636363637
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Epoch: 92. Train Loss: 0.6937700510025024. Validation Accuracy: 49.71590909090909
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Epoch: 94. Train Loss: 0.6937599778175354. Validation Accuracy: 50.85227272727273
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Epoch: 96. Train Loss: 0.692797839641571. Validation Accuracy: 49.28977272727273
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Epoch: 109. Train Loss: 0.6937887072563171. Validation Accuracy: 52.41477272727273
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Epoch: 111. Train Loss: 0.6928724646568298. Validation Accuracy: 50.85227272727273
Epoch: 112. Train Loss: 0.693696916103363. Validation Accuracy: 51.27840909090909
Epoch: 113. Train Loss: 0.6943886280059814. Validation Accuracy: 48.29545454545455
Epoch: 114. Train Loss: 0.6940397620201111. Validation Accuracy: 52.98295454545455

Epoch: 115. Train Loss: 0.6934499740600586. Validation Accuracy: 50.14204545454545
Epoch: 116. Train Loss: 0.693662703037262. Validation Accuracy: 50.85227272727273
Epoch: 117. Train Loss: 0.69346022605896. Validation Accuracy: 52.41477272727273
Epoch: 118. Train Loss: 0.6928682327270508. Validation Accuracy: 50.99431818181818
Epoch: 119. Train Loss: 0.6929520964622498. Validation Accuracy: 47.58522727272727
Epoch: 120. Train Loss: 0.693482518196106. Validation Accuracy: 47.72727272727273
Epoch: 121. Train Loss: 0.6926937699317932. Validation Accuracy: 51.13636363636363
Epoch: 122. Train Loss: 0.6938932538032532. Validation Accuracy: 50.0
Epoch: 123. Train Loss: 0.6931575536727905. Validation Accuracy: 51.84659090909091
Epoch: 124. Train Loss: 0.6940143704414368. Validation Accuracy: 51.42045454545455
Epoch: 125. Train Loss: 0.6934214234352112. Validation Accuracy: 49.71590909090909
Epoch: 126. Train Loss: 0.6937339305877686. Validation Accuracy: 49.85795454545455
Epoch: 127. Train Loss: 0.6935603022575378. Validation Accuracy: 51.27840909090909
Epoch: 128. Train Loss: 0.6924914121627808. Validation Accuracy: 49.14772727272727
Epoch: 129. Train Loss: 0.6938488483428955. Validation Accuracy: 49.57386363636363
Epoch: 130. Train Loss: 0.692919135093689. Validation Accuracy: 49.14772727272727
Epoch: 131. Train Loss: 0.6942617893218994. Validation Accuracy: 48.4375
Epoch: 132. Train Loss: 0.6923505067825317. Validation Accuracy: 50.0
Epoch: 133. Train Loss: 0.6931814551353455. Validation Accuracy: 48.72159090909091
Epoch: 134. Train Loss: 0.6924062371253967. Validation Accuracy: 51.13636363636363
Epoch: 135. Train Loss: 0.692974328994751. Validation Accuracy: 50.56818181818182
Epoch: 136. Train Loss: 0.6929847002029419. Validation Accuracy: 51.27840909090909
Epoch: 137. Train Loss: 0.6941913962364197. Validation Accuracy: 50.14204545454545
Epoch: 138. Train Loss: 0.6937656998634338. Validation Accuracy: 48.57954545454545
Epoch: 139. Train Loss: 0.6922712922096252. Validation Accuracy: 50.14204545454545
Epoch: 140. Train Loss: 0.6932693123817444. Validation Accuracy: 48.4375
Epoch: 141. Train Loss: 0.6919180750846863. Validation Accuracy:

50.14204545454545

Epoch: 142. Train Loss: 0.6937415599822998. Validation Accuracy: 48.72159090909091

Epoch: 143. Train Loss: 0.6939546465873718. Validation Accuracy: 48.72159090909091

Epoch: 144. Train Loss: 0.6926716566085815. Validation Accuracy: 50.99431818181818

Epoch: 145. Train Loss: 0.6933982968330383. Validation Accuracy: 48.01136363636363

Epoch: 146. Train Loss: 0.6933677196502686. Validation Accuracy: 46.73295454545455

Epoch: 147. Train Loss: 0.6930791139602661. Validation Accuracy: 51.13636363636363

Epoch: 148. Train Loss: 0.6935558915138245. Validation Accuracy: 48.4375

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Epoch: 891. Train Loss: 0.6424866318702698. Validation Accuracy: 57.67045454545455
Epoch: 892. Train Loss: 0.640249490737915. Validation Accuracy: 61.22159090909091
Epoch: 893. Train Loss: 0.6413068771362305. Validation Accuracy: 58.52272727272727
Epoch: 894. Train Loss: 0.6743436455726624. Validation Accuracy: 60.08522727272727
Epoch: 895. Train Loss: 0.6322433352470398. Validation Accuracy: 53.69318181818182
Epoch: 896. Train Loss: 0.6631336212158203. Validation Accuracy: 57.67045454545455
Epoch: 897. Train Loss: 0.6718321442604065. Validation Accuracy: 57.67045454545455
Epoch: 898. Train Loss: 0.647570788860321. Validation Accuracy: 56.96022727272727
Epoch: 899. Train Loss: 0.6294440031051636. Validation Accuracy: 54.6875
Epoch: 900. Train Loss: 0.6393928527832031. Validation Accuracy: 57.95454545454545
Epoch: 901. Train Loss: 0.651932954788208. Validation Accuracy:

57.10227272727273
Epoch: 902. Train Loss: 0.6476355195045471. Validation Accuracy: 61.07954545454545
Epoch: 903. Train Loss: 0.6471745371818542. Validation Accuracy: 59.375
Epoch: 904. Train Loss: 0.6550003886222839. Validation Accuracy: 57.24431818181818
Epoch: 905. Train Loss: 0.644183337688446. Validation Accuracy: 59.80113636363637
Epoch: 906. Train Loss: 0.6357904076576233. Validation Accuracy: 61.78977272727273
Epoch: 907. Train Loss: 0.6354402303695679. Validation Accuracy: 57.95454545454545
Epoch: 908. Train Loss: 0.6550748348236084. Validation Accuracy: 61.36363636363637
Epoch: 909. Train Loss: 0.6399365067481995. Validation Accuracy: 59.80113636363637
Epoch: 910. Train Loss: 0.6622227430343628. Validation Accuracy: 53.55113636363637
Epoch: 911. Train Loss: 0.6429121494293213. Validation Accuracy: 63.49431818181818
Epoch: 912. Train Loss: 0.6533958911895752. Validation Accuracy: 61.50568181818182
Epoch: 913. Train Loss: 0.6412460803985596. Validation Accuracy: 56.81818181818182
Epoch: 914. Train Loss: 0.6483232975006104. Validation Accuracy: 58.38068181818182
Epoch: 915. Train Loss: 0.6667830944061279. Validation Accuracy: 60.9375
Epoch: 916. Train Loss: 0.6624738574028015. Validation Accuracy: 60.36931818181818
Epoch: 917. Train Loss: 0.6421598196029663. Validation Accuracy: 61.50568181818182
Epoch: 918. Train Loss: 0.6268872618675232. Validation Accuracy: 58.09659090909091
Epoch: 919. Train Loss: 0.6343379020690918. Validation Accuracy: 60.36931818181818
Epoch: 920. Train Loss: 0.642676591873169. Validation Accuracy: 60.08522727272727
Epoch: 921. Train Loss: 0.6574555039405823. Validation Accuracy: 52.13068181818182
Epoch: 922. Train Loss: 0.6320095658302307. Validation Accuracy: 58.80681818181818
Epoch: 923. Train Loss: 0.6502439975738525. Validation Accuracy: 58.23863636363637
Epoch: 924. Train Loss: 0.6360551118850708. Validation Accuracy: 56.81818181818182
Epoch: 925. Train Loss: 0.6479931473731995. Validation Accuracy: 62.35795454545455
Epoch: 926. Train Loss: 0.6582065224647522. Validation Accuracy:

59.80113636363637
 Epoch: 927. Train Loss: 0.6503811478614807. Validation Accuracy: 66.47727272727273
 Epoch: 928. Train Loss: 0.6642743945121765. Validation Accuracy: 59.51704545454545
 Epoch: 929. Train Loss: 0.6519793272018433. Validation Accuracy: 59.80113636363637
 Epoch: 930. Train Loss: 0.650039553642273. Validation Accuracy: 62.35795454545455
 Epoch: 931. Train Loss: 0.6589887738227844. Validation Accuracy: 60.51136363636363
 Epoch: 932. Train Loss: 0.657493531703949. Validation Accuracy: 57.8125
 Epoch: 933. Train Loss: 0.6612719893455505. Validation Accuracy: 54.40340909090909
 Epoch: 934. Train Loss: 0.63985276222229. Validation Accuracy: 63.63636363636363
 Epoch: 935. Train Loss: 0.6574063897132874. Validation Accuracy: 57.67045454545455
 Epoch: 936. Train Loss: 0.6557117104530334. Validation Accuracy: 64.0625
 Epoch: 937. Train Loss: 0.6424187421798706. Validation Accuracy: 60.08522727272727
 Epoch: 938. Train Loss: 0.6477146744728088. Validation Accuracy: 57.8125
 Epoch: 939. Train Loss: 0.6385692954063416. Validation Accuracy: 62.07386363636363
 Epoch: 940. Train Loss: 0.6591641902923584. Validation Accuracy: 60.08522727272727
 Epoch: 941. Train Loss: 0.6430745720863342. Validation Accuracy: 60.08522727272727
 Epoch: 942. Train Loss: 0.644138753414154. Validation Accuracy: 58.38068181818182
 Epoch: 943. Train Loss: 0.6546721458435059. Validation Accuracy: 54.40340909090909
 Epoch: 944. Train Loss: 0.6444145441055298. Validation Accuracy: 58.09659090909091
 Epoch: 945. Train Loss: 0.6604434847831726. Validation Accuracy: 58.94886363636363
 Epoch: 946. Train Loss: 0.6412667632102966. Validation Accuracy: 54.6875
 Epoch: 947. Train Loss: 0.6469948887825012. Validation Accuracy: 60.65340909090909
 Epoch: 948. Train Loss: 0.6557676792144775. Validation Accuracy: 55.68181818181818
 Epoch: 949. Train Loss: 0.6406044363975525. Validation Accuracy: 57.95454545454545
 Epoch: 950. Train Loss: 0.662384569644928. Validation Accuracy: 49.85795454545455
 Epoch: 951. Train Loss: 0.6590890884399414. Validation Accuracy: 60.51136363636363
 Epoch: 952. Train Loss: 0.6325158476829529. Validation Accuracy: 61.50568181818182

Epoch: 953. Train Loss: 0.6460112929344177. Validation Accuracy: 58.94886363636363
 Epoch: 954. Train Loss: 0.6356080174446106. Validation Accuracy: 59.94318181818182
 Epoch: 955. Train Loss: 0.6517667174339294. Validation Accuracy: 57.24431818181818
 Epoch: 956. Train Loss: 0.6191156506538391. Validation Accuracy: 62.07386363636363
 Epoch: 957. Train Loss: 0.6498979330062866. Validation Accuracy: 62.21590909090909
 Epoch: 958. Train Loss: 0.6288056969642639. Validation Accuracy: 57.38636363636363
 Epoch: 959. Train Loss: 0.6569774746894836. Validation Accuracy: 59.375
 Epoch: 960. Train Loss: 0.6396335363388062. Validation Accuracy: 54.54545454545455
 Epoch: 961. Train Loss: 0.6528494954109192. Validation Accuracy: 60.08522727272727
 Epoch: 962. Train Loss: 0.6439390182495117. Validation Accuracy: 62.07386363636363
 Epoch: 963. Train Loss: 0.6484196782112122. Validation Accuracy: 59.94318181818182
 Epoch: 964. Train Loss: 0.6500038504600525. Validation Accuracy: 59.65909090909091
 Epoch: 965. Train Loss: 0.6259400844573975. Validation Accuracy: 60.51136363636363
 Epoch: 966. Train Loss: 0.6394951343536377. Validation Accuracy: 61.50568181818182
 Epoch: 967. Train Loss: 0.6273958683013916. Validation Accuracy: 59.23295454545455
 Epoch: 968. Train Loss: 0.6585280895233154. Validation Accuracy: 58.23863636363637
 Epoch: 969. Train Loss: 0.663367509841919. Validation Accuracy: 55.96590909090909
 Epoch: 970. Train Loss: 0.6263039112091064. Validation Accuracy: 59.23295454545455
 Epoch: 971. Train Loss: 0.6598561406135559. Validation Accuracy: 60.36931818181818
 Epoch: 972. Train Loss: 0.6414509415626526. Validation Accuracy: 57.95454545454545
 Epoch: 973. Train Loss: 0.6355224847793579. Validation Accuracy: 59.23295454545455
 Epoch: 974. Train Loss: 0.6516833901405334. Validation Accuracy: 59.51704545454545
 Epoch: 975. Train Loss: 0.6431472897529602. Validation Accuracy: 61.64772727272727
 Epoch: 976. Train Loss: 0.6290598511695862. Validation Accuracy: 60.22727272727273
 Epoch: 977. Train Loss: 0.6308821439743042. Validation Accuracy:

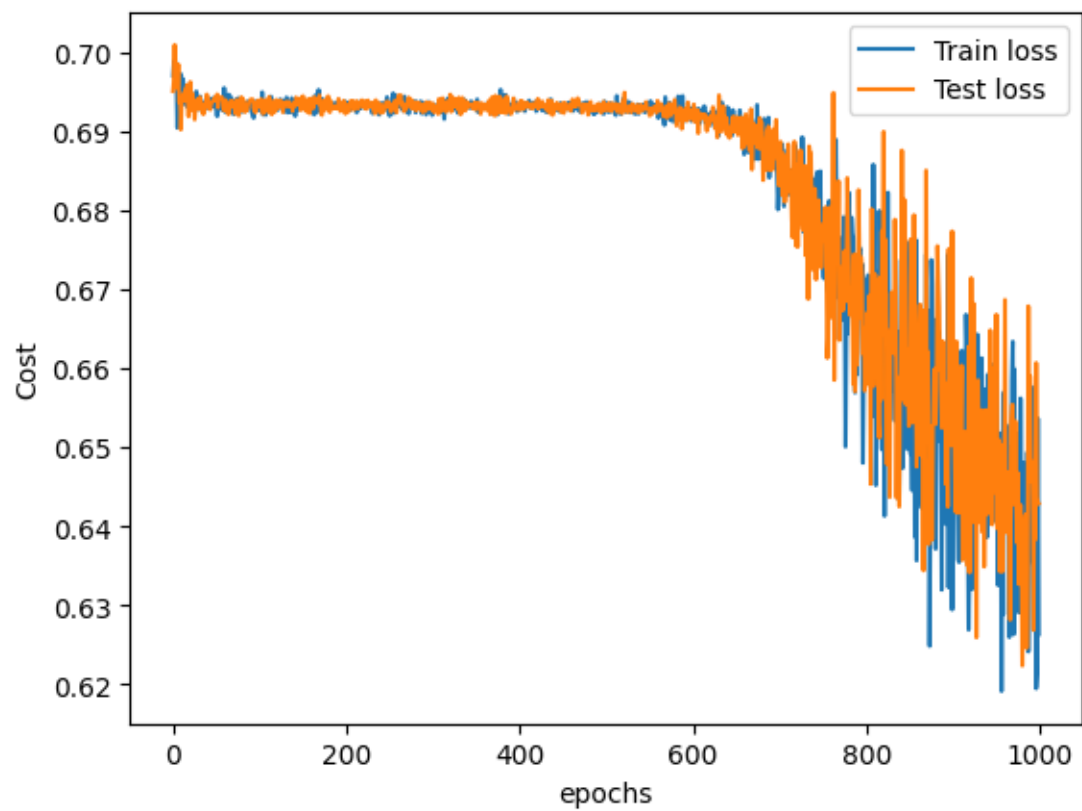
```

59.51704545454545
Epoch: 978. Train Loss: 0.6561816334724426. Validation Accuracy:
61.22159090909091
Epoch: 979. Train Loss: 0.640133798122406. Validation Accuracy:
60.65340909090909
Epoch: 980. Train Loss: 0.640014111995697. Validation Accuracy:
61.64772727272727
Epoch: 981. Train Loss: 0.6480739116668701. Validation Accuracy:
60.65340909090909
Epoch: 982. Train Loss: 0.6331648230552673. Validation Accuracy:
61.22159090909091
Epoch: 983. Train Loss: 0.645537793636322. Validation Accuracy: 57.8125
Epoch: 984. Train Loss: 0.6459864377975464. Validation Accuracy:
59.80113636363637
Epoch: 985. Train Loss: 0.6271516680717468. Validation Accuracy:
61.64772727272727
Epoch: 986. Train Loss: 0.6493683457374573. Validation Accuracy:
59.51704545454545
Epoch: 987. Train Loss: 0.6241340637207031. Validation Accuracy:
53.69318181818182
Epoch: 988. Train Loss: 0.6349605917930603. Validation Accuracy:
61.50568181818182
Epoch: 989. Train Loss: 0.6358267068862915. Validation Accuracy: 56.25
Epoch: 990. Train Loss: 0.6576883792877197. Validation Accuracy:
55.82386363636363
Epoch: 991. Train Loss: 0.6410276293754578. Validation Accuracy:
58.94886363636363
Epoch: 992. Train Loss: 0.6469109654426575. Validation Accuracy:
59.65909090909091
Epoch: 993. Train Loss: 0.6461268663406372. Validation Accuracy:
61.36363636363637
Epoch: 994. Train Loss: 0.6376612186431885. Validation Accuracy:
55.82386363636363
Epoch: 995. Train Loss: 0.6393596529960632. Validation Accuracy:
58.94886363636363
Epoch: 996. Train Loss: 0.619468629360199. Validation Accuracy:
54.26136363636363
Epoch: 997. Train Loss: 0.6213112473487854. Validation Accuracy:
58.94886363636363
Epoch: 998. Train Loss: 0.6536335349082947. Validation Accuracy:
57.24431818181818
Epoch: 999. Train Loss: 0.6263185143470764. Validation Accuracy:
61.07954545454545

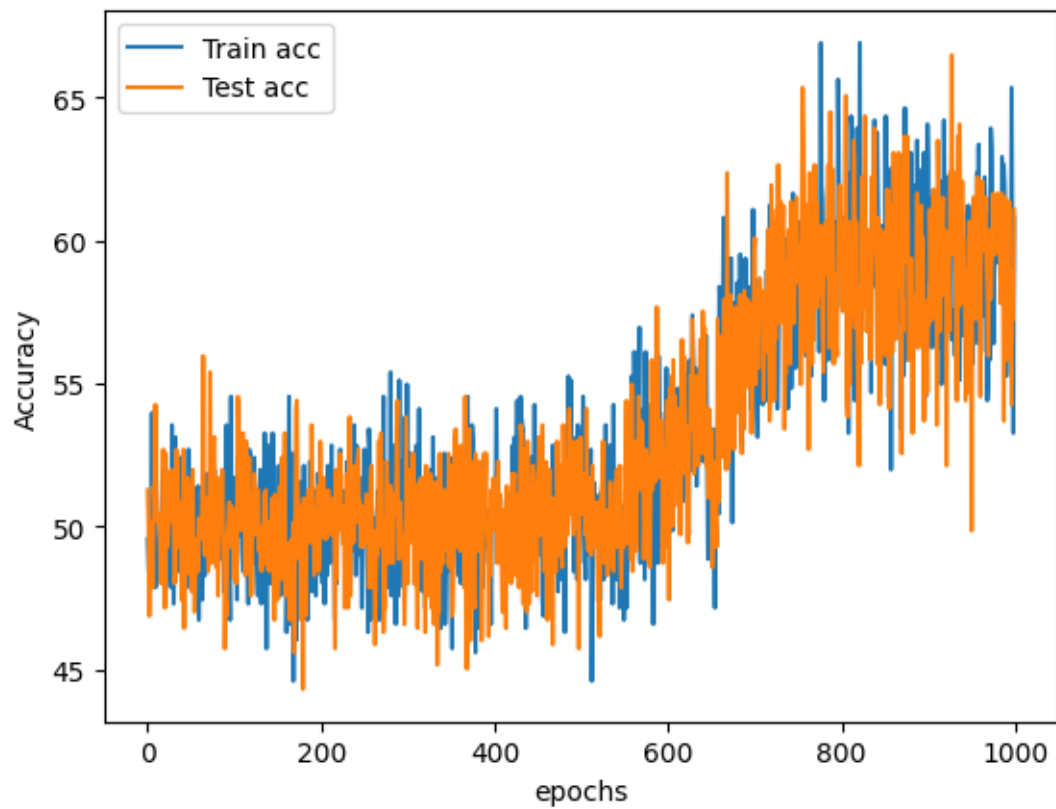
```

Train and test plots

```
[140]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



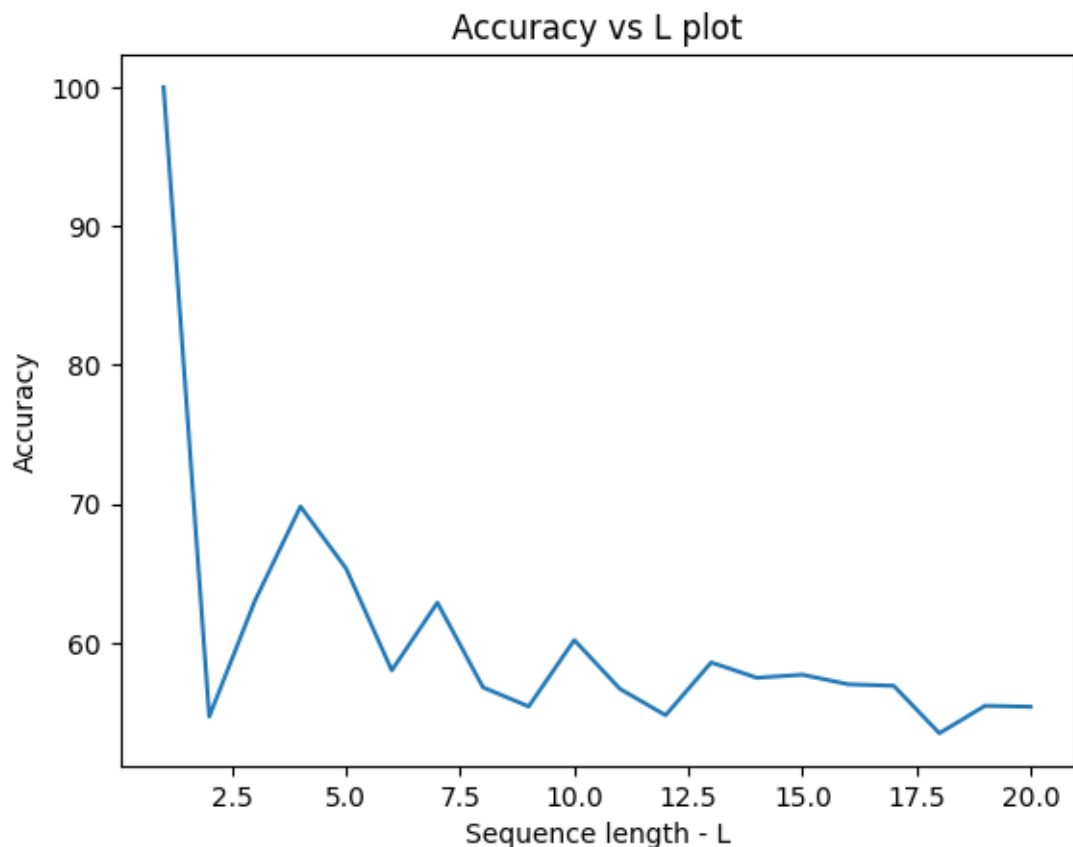
Train loss value after 1000 epochs: 0.6263185143470764
Vaildation loss value after 1000 epochs: 0.6428563594818115



Best Test Accuracy: 66.477272727273%

Bitwise Accuracy vs Length

```
[141]: plot_accuracy_vs_length(model)
```



9.8.3 Hidden State Size = 10

```
[142]: HIDDEN_DIM = 10
```

```
[143]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
        criterion = nn.CrossEntropyLoss()
        optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[144]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
        ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.6963188648223877. Validation Accuracy: 50.71022727272727
Epoch: 1. Train Loss: 0.6934484839439392. Validation Accuracy: 48.72159090909091
Epoch: 2. Train Loss: 0.6949735283851624. Validation Accuracy: 50.42613636363637
Epoch: 3. Train Loss: 0.6926169991493225. Validation Accuracy: 49.71590909090909
Epoch: 4. Train Loss: 0.6951655149459839. Validation Accuracy: 47.72727272727273
Epoch: 5. Train Loss: 0.6935188174247742. Validation Accuracy: 52.69886363636363
Epoch: 6. Train Loss: 0.6924707293510437. Validation Accuracy: 48.72159090909091
```

Epoch: 7. Train Loss: 0.6929764151573181. Validation Accuracy: 52.41477272727273
Epoch: 8. Train Loss: 0.6924092769622803. Validation Accuracy: 51.42045454545455
Epoch: 9. Train Loss: 0.6931347250938416. Validation Accuracy: 49.71590909090909
Epoch: 10. Train Loss: 0.6938812732696533. Validation Accuracy:
53.55113636363637
Epoch: 11. Train Loss: 0.6930593252182007. Validation Accuracy:
50.56818181818182
Epoch: 12. Train Loss: 0.6930811405181885. Validation Accuracy:
49.57386363636363
Epoch: 13. Train Loss: 0.6935039162635803. Validation Accuracy:
47.58522727272727
Epoch: 14. Train Loss: 0.6924905180931091. Validation Accuracy: 50.0
Epoch: 15. Train Loss: 0.693342387676239. Validation Accuracy: 52.55681818181818
Epoch: 16. Train Loss: 0.6930426359176636. Validation Accuracy:
47.44318181818182
Epoch: 17. Train Loss: 0.6933049559593201. Validation Accuracy: 53.125
Epoch: 18. Train Loss: 0.6931660771369934. Validation Accuracy:
49.57386363636363
Epoch: 19. Train Loss: 0.6931734085083008. Validation Accuracy:
52.13068181818182
Epoch: 20. Train Loss: 0.6932666301727295. Validation Accuracy:
51.42045454545455
Epoch: 21. Train Loss: 0.6932321786880493. Validation Accuracy:
50.42613636363637
Epoch: 22. Train Loss: 0.6931489109992981. Validation Accuracy:
50.28409090909091
Epoch: 23. Train Loss: 0.693105936050415. Validation Accuracy: 48.15340909090909
Epoch: 24. Train Loss: 0.6931804418563843. Validation Accuracy:
49.57386363636363
Epoch: 25. Train Loss: 0.6933560967445374. Validation Accuracy:
49.00568181818182
Epoch: 26. Train Loss: 0.6931856274604797. Validation Accuracy:
49.00568181818182
Epoch: 27. Train Loss: 0.6931050419807434. Validation Accuracy:
51.13636363636363
Epoch: 28. Train Loss: 0.6929448843002319. Validation Accuracy:
49.28977272727273
Epoch: 29. Train Loss: 0.6928566694259644. Validation Accuracy:
48.72159090909091
Epoch: 30. Train Loss: 0.6930693984031677. Validation Accuracy:
52.69886363636363
Epoch: 31. Train Loss: 0.6936048865318298. Validation Accuracy: 51.5625
Epoch: 32. Train Loss: 0.6928601861000061. Validation Accuracy:
49.85795454545455
Epoch: 33. Train Loss: 0.6937487125396729. Validation Accuracy:
47.86931818181818
Epoch: 34. Train Loss: 0.6935480237007141. Validation Accuracy:
47.15909090909091

Epoch: 35. Train Loss: 0.6933923959732056. Validation Accuracy: 48.4375
Epoch: 36. Train Loss: 0.6934836506843567. Validation Accuracy:
47.44318181818182
Epoch: 37. Train Loss: 0.6924412250518799. Validation Accuracy:
50.85227272727273
Epoch: 38. Train Loss: 0.6939101219177246. Validation Accuracy: 51.5625
Epoch: 39. Train Loss: 0.692769467830658. Validation Accuracy: 50.99431818181818
Epoch: 40. Train Loss: 0.693235456943512. Validation Accuracy: 49.43181818181818
Epoch: 41. Train Loss: 0.6933170557022095. Validation Accuracy:
51.13636363636363
Epoch: 42. Train Loss: 0.6929779648780823. Validation Accuracy:
51.84659090909091
Epoch: 43. Train Loss: 0.6933610439300537. Validation Accuracy:
51.27840909090909
Epoch: 44. Train Loss: 0.6932168006896973. Validation Accuracy:
51.70454545454545
Epoch: 45. Train Loss: 0.6932551860809326. Validation Accuracy:
49.43181818181818
Epoch: 46. Train Loss: 0.6932207942008972. Validation Accuracy: 50.0
Epoch: 47. Train Loss: 0.6932926774024963. Validation Accuracy:
52.13068181818182
Epoch: 48. Train Loss: 0.6930655837059021. Validation Accuracy:
47.72727272727273
Epoch: 49. Train Loss: 0.6931998133659363. Validation Accuracy:
47.86931818181818
Epoch: 50. Train Loss: 0.6932308673858643. Validation Accuracy:
50.71022727272727
Epoch: 51. Train Loss: 0.6932001709938049. Validation Accuracy:
49.14772727272727
Epoch: 52. Train Loss: 0.6930021643638611. Validation Accuracy:
49.71590909090909
Epoch: 53. Train Loss: 0.6931859850883484. Validation Accuracy:
47.15909090909091
Epoch: 54. Train Loss: 0.6931068897247314. Validation Accuracy:
51.27840909090909
Epoch: 55. Train Loss: 0.6933740377426147. Validation Accuracy: 48.4375
Epoch: 56. Train Loss: 0.6928935050964355. Validation Accuracy:
50.71022727272727
Epoch: 57. Train Loss: 0.6932545900344849. Validation Accuracy:
50.42613636363637
Epoch: 58. Train Loss: 0.6934618949890137. Validation Accuracy:
50.85227272727273
Epoch: 59. Train Loss: 0.693412721157074. Validation Accuracy: 51.42045454545455
Epoch: 60. Train Loss: 0.693242609500885. Validation Accuracy: 49.85795454545455
Epoch: 61. Train Loss: 0.6930493712425232. Validation Accuracy:
52.98295454545455
Epoch: 62. Train Loss: 0.6933422088623047. Validation Accuracy:
50.85227272727273

Epoch: 63. Train Loss: 0.693129301071167. Validation Accuracy: 46.73295454545455
Epoch: 64. Train Loss: 0.6930766105651855. Validation Accuracy:
50.85227272727273
Epoch: 65. Train Loss: 0.6929452419281006. Validation Accuracy:
50.71022727272727
Epoch: 66. Train Loss: 0.6932001113891602. Validation Accuracy:
50.42613636363637
Epoch: 67. Train Loss: 0.6933251619338989. Validation Accuracy:
50.99431818181818
Epoch: 68. Train Loss: 0.6933405995368958. Validation Accuracy:
49.85795454545455
Epoch: 69. Train Loss: 0.6930601000785828. Validation Accuracy:
48.57954545454545
Epoch: 70. Train Loss: 0.6932972073554993. Validation Accuracy:
50.99431818181818
Epoch: 71. Train Loss: 0.6930447220802307. Validation Accuracy:
49.85795454545455
Epoch: 72. Train Loss: 0.6931657791137695. Validation Accuracy:
50.42613636363637
Epoch: 73. Train Loss: 0.6931402087211609. Validation Accuracy:
50.85227272727273
Epoch: 74. Train Loss: 0.6932399272918701. Validation Accuracy:
50.42613636363637
Epoch: 75. Train Loss: 0.6928668022155762. Validation Accuracy:
49.43181818181818
Epoch: 76. Train Loss: 0.693344235420227. Validation Accuracy: 53.97727272727273
Epoch: 77. Train Loss: 0.6930765509605408. Validation Accuracy: 50.0
Epoch: 78. Train Loss: 0.6933856010437012. Validation Accuracy:
48.01136363636363
Epoch: 79. Train Loss: 0.6930931210517883. Validation Accuracy:
52.84090909090909
Epoch: 80. Train Loss: 0.6932410597801208. Validation Accuracy:
47.44318181818182
Epoch: 81. Train Loss: 0.6930703520774841. Validation Accuracy:
50.14204545454545
Epoch: 82. Train Loss: 0.6931502819061279. Validation Accuracy:
50.14204545454545
Epoch: 83. Train Loss: 0.6933352947235107. Validation Accuracy:
51.13636363636363
Epoch: 84. Train Loss: 0.6931223273277283. Validation Accuracy:
50.14204545454545
Epoch: 85. Train Loss: 0.6932685375213623. Validation Accuracy:
50.28409090909091
Epoch: 86. Train Loss: 0.6932992339134216. Validation Accuracy:
50.99431818181818
Epoch: 87. Train Loss: 0.6931002140045166. Validation Accuracy:
49.85795454545455
Epoch: 88. Train Loss: 0.6930912137031555. Validation Accuracy: 50.0

Epoch: 89. Train Loss: 0.6931545734405518. Validation Accuracy: 50.56818181818182

Epoch: 90. Train Loss: 0.6932179927825928. Validation Accuracy: 47.86931818181818

Epoch: 91. Train Loss: 0.6935202479362488. Validation Accuracy: 50.14204545454545

Epoch: 92. Train Loss: 0.6929458975791931. Validation Accuracy: 46.73295454545455

Epoch: 93. Train Loss: 0.6928182244300842. Validation Accuracy: 49.85795454545455

Epoch: 94. Train Loss: 0.6930211186408997. Validation Accuracy: 50.42613636363637

Epoch: 95. Train Loss: 0.6932205557823181. Validation Accuracy: 50.56818181818182

Epoch: 96. Train Loss: 0.6928439736366272. Validation Accuracy: 49.28977272727273

Epoch: 97. Train Loss: 0.693189799785614. Validation Accuracy: 54.97159090909091

Epoch: 98. Train Loss: 0.6928800940513611. Validation Accuracy: 51.70454545454545

Epoch: 99. Train Loss: 0.6930689811706543. Validation Accuracy: 50.42613636363637

Epoch: 100. Train Loss: 0.6932518482208252. Validation Accuracy: 53.55113636363637

Epoch: 101. Train Loss: 0.6932991743087769. Validation Accuracy: 52.84090909090909

Epoch: 102. Train Loss: 0.6931207180023193. Validation Accuracy: 48.57954545454545

Epoch: 103. Train Loss: 0.6935322284698486. Validation Accuracy: 50.99431818181818

Epoch: 104. Train Loss: 0.6933230757713318. Validation Accuracy: 50.28409090909091

Epoch: 105. Train Loss: 0.693351149559021. Validation Accuracy: 50.56818181818182

Epoch: 106. Train Loss: 0.6930214166641235. Validation Accuracy: 50.28409090909091

Epoch: 107. Train Loss: 0.6928063035011292. Validation Accuracy: 51.42045454545455

Epoch: 108. Train Loss: 0.692990779876709. Validation Accuracy: 53.83522727272727

Epoch: 109. Train Loss: 0.6928539276123047. Validation Accuracy: 49.43181818181818

Epoch: 110. Train Loss: 0.693422257900238. Validation Accuracy: 51.70454545454545

Epoch: 111. Train Loss: 0.6931934952735901. Validation Accuracy: 48.4375

Epoch: 112. Train Loss: 0.6933220624923706. Validation Accuracy: 49.43181818181818

Epoch: 113. Train Loss: 0.6936405301094055. Validation Accuracy: 49.57386363636363

Epoch: 114. Train Loss: 0.6927800178527832. Validation Accuracy: 49.14772727272727
Epoch: 115. Train Loss: 0.6927928328514099. Validation Accuracy: 50.42613636363637
Epoch: 116. Train Loss: 0.6931957006454468. Validation Accuracy: 48.4375
Epoch: 117. Train Loss: 0.6934888362884521. Validation Accuracy: 49.57386363636363
Epoch: 118. Train Loss: 0.6929931640625. Validation Accuracy: 48.15340909090909
Epoch: 119. Train Loss: 0.693091869354248. Validation Accuracy: 49.57386363636363
Epoch: 120. Train Loss: 0.6931073665618896. Validation Accuracy: 49.57386363636363
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Epoch: 122. Train Loss: 0.6928403377532959. Validation Accuracy: 48.57954545454545
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Epoch: 872. Train Loss: 0.6573436260223389. Validation Accuracy: 53.55113636363637
Epoch: 873. Train Loss: 0.6827641129493713. Validation Accuracy: 60.22727272727273
Epoch: 874. Train Loss: 0.6805581450462341. Validation Accuracy: 63.63636363636363
Epoch: 875. Train Loss: 0.6749529242515564. Validation Accuracy: 61.78977272727273
Epoch: 876. Train Loss: 0.6696873903274536. Validation Accuracy: 60.08522727272727
Epoch: 877. Train Loss: 0.6455297470092773. Validation Accuracy: 57.10227272727273
Epoch: 878. Train Loss: 0.6752310395240784. Validation Accuracy: 59.375

Epoch: 879. Train Loss: 0.6421251893043518. Validation Accuracy: 61.07954545454545
Epoch: 880. Train Loss: 0.6686772704124451. Validation Accuracy: 50.42613636363637
Epoch: 881. Train Loss: 0.658207356929779. Validation Accuracy: 62.07386363636363
Epoch: 882. Train Loss: 0.654228687286377. Validation Accuracy: 62.92613636363637
Epoch: 883. Train Loss: 0.6576324701309204. Validation Accuracy: 58.23863636363637
Epoch: 884. Train Loss: 0.6563605070114136. Validation Accuracy: 58.66477272727273
Epoch: 885. Train Loss: 0.6589788794517517. Validation Accuracy: 61.64772727272727
Epoch: 886. Train Loss: 0.6568042039871216. Validation Accuracy: 59.375
Epoch: 887. Train Loss: 0.6579260230064392. Validation Accuracy: 62.35795454545455
Epoch: 888. Train Loss: 0.6726728081703186. Validation Accuracy: 60.51136363636363
Epoch: 889. Train Loss: 0.6422207355499268. Validation Accuracy: 54.40340909090909
Epoch: 890. Train Loss: 0.6788767576217651. Validation Accuracy: 54.40340909090909
Epoch: 891. Train Loss: 0.648676335811615. Validation Accuracy: 55.53977272727273
Epoch: 892. Train Loss: 0.65653395652771. Validation Accuracy: 60.51136363636363
Epoch: 893. Train Loss: 0.6598590612411499. Validation Accuracy: 55.11363636363637
Epoch: 894. Train Loss: 0.6494654417037964. Validation Accuracy: 58.80681818181818
Epoch: 895. Train Loss: 0.6598548889160156. Validation Accuracy: 57.10227272727273
Epoch: 896. Train Loss: 0.6742924451828003. Validation Accuracy: 60.9375
Epoch: 897. Train Loss: 0.6486029028892517. Validation Accuracy: 61.07954545454545
Epoch: 898. Train Loss: 0.6481974124908447. Validation Accuracy: 62.35795454545455
Epoch: 899. Train Loss: 0.6430982947349548. Validation Accuracy: 57.67045454545455
Epoch: 900. Train Loss: 0.6509843468666077. Validation Accuracy: 57.10227272727273
Epoch: 901. Train Loss: 0.650892972946167. Validation Accuracy: 53.83522727272727
Epoch: 902. Train Loss: 0.6600404381752014. Validation Accuracy: 61.36363636363637
Epoch: 903. Train Loss: 0.6426113247871399. Validation Accuracy: 57.52840909090909
Epoch: 904. Train Loss: 0.6763087511062622. Validation Accuracy:

55.25568181818182
Epoch: 905. Train Loss: 0.6465256810188293. Validation Accuracy: 63.06818181818182
Epoch: 906. Train Loss: 0.6577433943748474. Validation Accuracy: 57.52840909090909
Epoch: 907. Train Loss: 0.6539765000343323. Validation Accuracy: 55.53977272727273
Epoch: 908. Train Loss: 0.6490762233734131. Validation Accuracy: 55.82386363636363
Epoch: 909. Train Loss: 0.6695700287818909. Validation Accuracy: 57.52840909090909
Epoch: 910. Train Loss: 0.6419402360916138. Validation Accuracy: 59.375
Epoch: 911. Train Loss: 0.6456890106201172. Validation Accuracy: 55.53977272727273
Epoch: 912. Train Loss: 0.6621668338775635. Validation Accuracy: 58.52272727272727
Epoch: 913. Train Loss: 0.6471383571624756. Validation Accuracy: 59.94318181818182
Epoch: 914. Train Loss: 0.6450442671775818. Validation Accuracy: 57.38636363636363
Epoch: 915. Train Loss: 0.6539326310157776. Validation Accuracy: 57.8125
Epoch: 916. Train Loss: 0.6488004922866821. Validation Accuracy: 59.51704545454545
Epoch: 917. Train Loss: 0.6552886366844177. Validation Accuracy: 58.09659090909091
Epoch: 918. Train Loss: 0.6209061145782471. Validation Accuracy: 53.97727272727273
Epoch: 919. Train Loss: 0.654171884059906. Validation Accuracy: 60.79545454545455
Epoch: 920. Train Loss: 0.6616000533103943. Validation Accuracy: 61.50568181818182
Epoch: 921. Train Loss: 0.6506743431091309. Validation Accuracy: 57.24431818181818
Epoch: 922. Train Loss: 0.6605381369590759. Validation Accuracy: 62.64204545454545
Epoch: 923. Train Loss: 0.6504140496253967. Validation Accuracy: 60.65340909090909
Epoch: 924. Train Loss: 0.6666948795318604. Validation Accuracy: 57.52840909090909
Epoch: 925. Train Loss: 0.6420990824699402. Validation Accuracy: 54.11931818181818
Epoch: 926. Train Loss: 0.6383899450302124. Validation Accuracy: 62.35795454545455
Epoch: 927. Train Loss: 0.6427149772644043. Validation Accuracy: 56.96022727272727
Epoch: 928. Train Loss: 0.6457594037055969. Validation Accuracy: 57.24431818181818
Epoch: 929. Train Loss: 0.6336016058921814. Validation Accuracy:

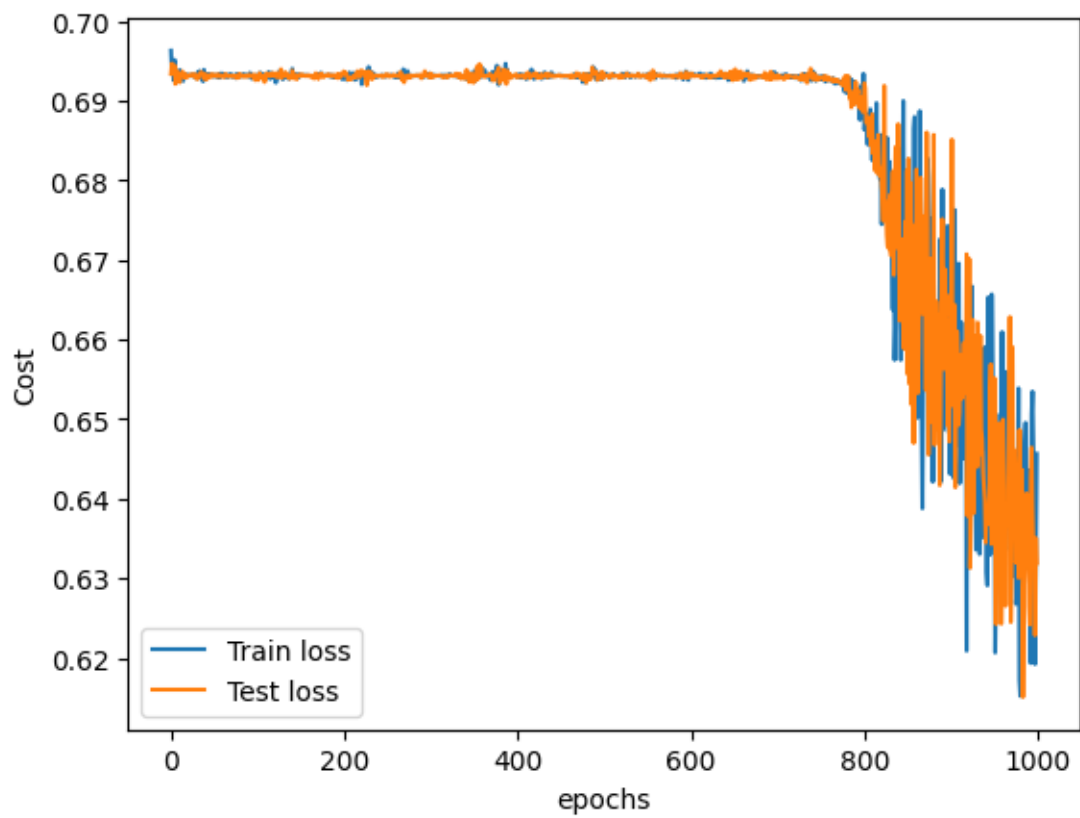
57.38636363636363
Epoch: 930. Train Loss: 0.6582934260368347. Validation Accuracy: 59.23295454545455
Epoch: 931. Train Loss: 0.6607682108879089. Validation Accuracy: 58.09659090909091
Epoch: 932. Train Loss: 0.6520161628723145. Validation Accuracy: 59.375
Epoch: 933. Train Loss: 0.6330543160438538. Validation Accuracy: 56.10795454545455
Epoch: 934. Train Loss: 0.6406481266021729. Validation Accuracy: 56.96022727272727
Epoch: 935. Train Loss: 0.635063111782074. Validation Accuracy: 57.24431818181818
Epoch: 936. Train Loss: 0.6508328914642334. Validation Accuracy: 56.81818181818182
Epoch: 937. Train Loss: 0.6589239239692688. Validation Accuracy: 60.51136363636363
Epoch: 938. Train Loss: 0.6501747965812683. Validation Accuracy: 59.65909090909091
Epoch: 939. Train Loss: 0.6464303731918335. Validation Accuracy: 62.35795454545455
Epoch: 940. Train Loss: 0.6590662598609924. Validation Accuracy: 62.92613636363637
Epoch: 941. Train Loss: 0.6307804584503174. Validation Accuracy: 61.07954545454545
Epoch: 942. Train Loss: 0.6291078925132751. Validation Accuracy: 60.65340909090909
Epoch: 943. Train Loss: 0.6653386354446411. Validation Accuracy: 59.65909090909091
Epoch: 944. Train Loss: 0.6511287093162537. Validation Accuracy: 60.08522727272727
Epoch: 945. Train Loss: 0.6329502463340759. Validation Accuracy: 56.81818181818182
Epoch: 946. Train Loss: 0.6369349360466003. Validation Accuracy: 57.52840909090909
Epoch: 947. Train Loss: 0.6656882762908936. Validation Accuracy: 64.20454545454545
Epoch: 948. Train Loss: 0.6554364562034607. Validation Accuracy: 55.53977272727273
Epoch: 949. Train Loss: 0.647405207157135. Validation Accuracy: 59.65909090909091
Epoch: 950. Train Loss: 0.6437287330627441. Validation Accuracy: 57.38636363636363
Epoch: 951. Train Loss: 0.6206715106964111. Validation Accuracy: 57.38636363636363
Epoch: 952. Train Loss: 0.630169153213501. Validation Accuracy: 62.92613636363637
Epoch: 953. Train Loss: 0.6450389623641968. Validation Accuracy: 60.51136363636363

Epoch: 954. Train Loss: 0.643036961555481. Validation Accuracy:
63.35227272727273
Epoch: 955. Train Loss: 0.6367797255516052. Validation Accuracy:
58.52272727272727
Epoch: 956. Train Loss: 0.6394131183624268. Validation Accuracy:
56.81818181818182
Epoch: 957. Train Loss: 0.650667130947113. Validation Accuracy:
58.80681818181818
Epoch: 958. Train Loss: 0.6358370184898376. Validation Accuracy:
62.92613636363637
Epoch: 959. Train Loss: 0.6609590649604797. Validation Accuracy:
61.78977272727273
Epoch: 960. Train Loss: 0.6290645003318787. Validation Accuracy:
58.38068181818182
Epoch: 961. Train Loss: 0.6299736499786377. Validation Accuracy:
60.51136363636363
Epoch: 962. Train Loss: 0.6468328833580017. Validation Accuracy: 59.375
Epoch: 963. Train Loss: 0.6559463143348694. Validation Accuracy:
62.07386363636363
Epoch: 964. Train Loss: 0.6470951437950134. Validation Accuracy:
58.80681818181818
Epoch: 965. Train Loss: 0.6389038562774658. Validation Accuracy:
58.52272727272727
Epoch: 966. Train Loss: 0.6380543112754822. Validation Accuracy: 59.375
Epoch: 967. Train Loss: 0.6449596881866455. Validation Accuracy: 59.375
Epoch: 968. Train Loss: 0.6336449384689331. Validation Accuracy:
55.11363636363637
Epoch: 969. Train Loss: 0.6338990330696106. Validation Accuracy:
58.80681818181818
Epoch: 970. Train Loss: 0.6428136229515076. Validation Accuracy:
59.65909090909091
Epoch: 971. Train Loss: 0.640078604221344. Validation Accuracy:
56.81818181818182
Epoch: 972. Train Loss: 0.6302762031555176. Validation Accuracy:
59.65909090909091
Epoch: 973. Train Loss: 0.6326699256896973. Validation Accuracy:
56.39204545454545
Epoch: 974. Train Loss: 0.6414758563041687. Validation Accuracy:
58.38068181818182
Epoch: 975. Train Loss: 0.6267874240875244. Validation Accuracy:
58.23863636363637
Epoch: 976. Train Loss: 0.6279987692832947. Validation Accuracy:
58.80681818181818
Epoch: 977. Train Loss: 0.6368580460548401. Validation Accuracy:
59.51704545454545
Epoch: 978. Train Loss: 0.6538820862770081. Validation Accuracy:
62.07386363636363
Epoch: 979. Train Loss: 0.6172208189964294. Validation Accuracy:

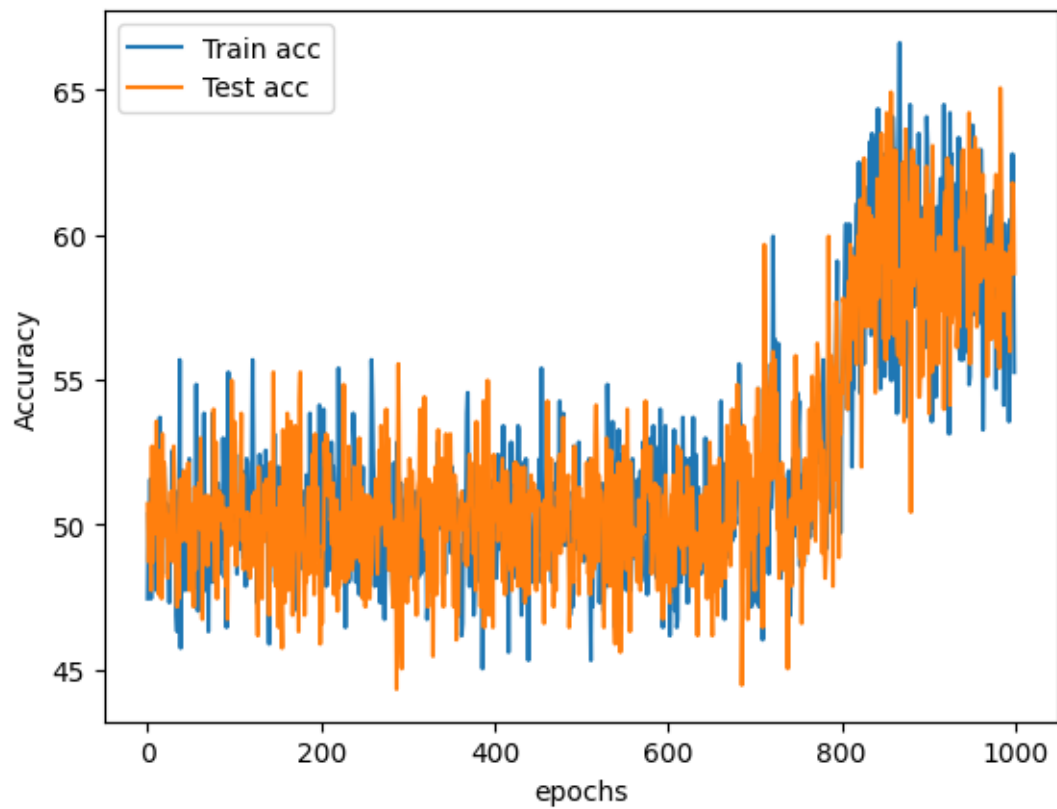
56.10795454545455
Epoch: 980. Train Loss: 0.6152255535125732. Validation Accuracy: 57.52840909090909
Epoch: 981. Train Loss: 0.6269383430480957. Validation Accuracy: 58.52272727272727
Epoch: 982. Train Loss: 0.6382453441619873. Validation Accuracy: 55.39772727272727
Epoch: 983. Train Loss: 0.6382091045379639. Validation Accuracy: 65.05681818181819
Epoch: 984. Train Loss: 0.641191303730011. Validation Accuracy: 61.78977272727273
Epoch: 985. Train Loss: 0.6471529603004456. Validation Accuracy: 59.09090909090909
Epoch: 986. Train Loss: 0.6495463848114014. Validation Accuracy: 58.23863636363637
Epoch: 987. Train Loss: 0.6382776498794556. Validation Accuracy: 57.38636363636363
Epoch: 988. Train Loss: 0.6357240080833435. Validation Accuracy: 59.375
Epoch: 989. Train Loss: 0.643562912940979. Validation Accuracy: 58.80681818181818
Epoch: 990. Train Loss: 0.6411321759223938. Validation Accuracy: 57.67045454545455
Epoch: 991. Train Loss: 0.6326187252998352. Validation Accuracy: 57.67045454545455
Epoch: 992. Train Loss: 0.6193451285362244. Validation Accuracy: 56.53409090909091
Epoch: 993. Train Loss: 0.6506094336509705. Validation Accuracy: 59.375
Epoch: 994. Train Loss: 0.6534850597381592. Validation Accuracy: 55.96590909090909
Epoch: 995. Train Loss: 0.646260142326355. Validation Accuracy: 59.65909090909091
Epoch: 996. Train Loss: 0.6413739919662476. Validation Accuracy: 59.09090909090909
Epoch: 997. Train Loss: 0.6192197799682617. Validation Accuracy: 61.78977272727273
Epoch: 998. Train Loss: 0.6341944336891174. Validation Accuracy: 61.64772727272727
Epoch: 999. Train Loss: 0.645656943321228. Validation Accuracy: 58.66477272727273

Train and test plots

```
[145]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



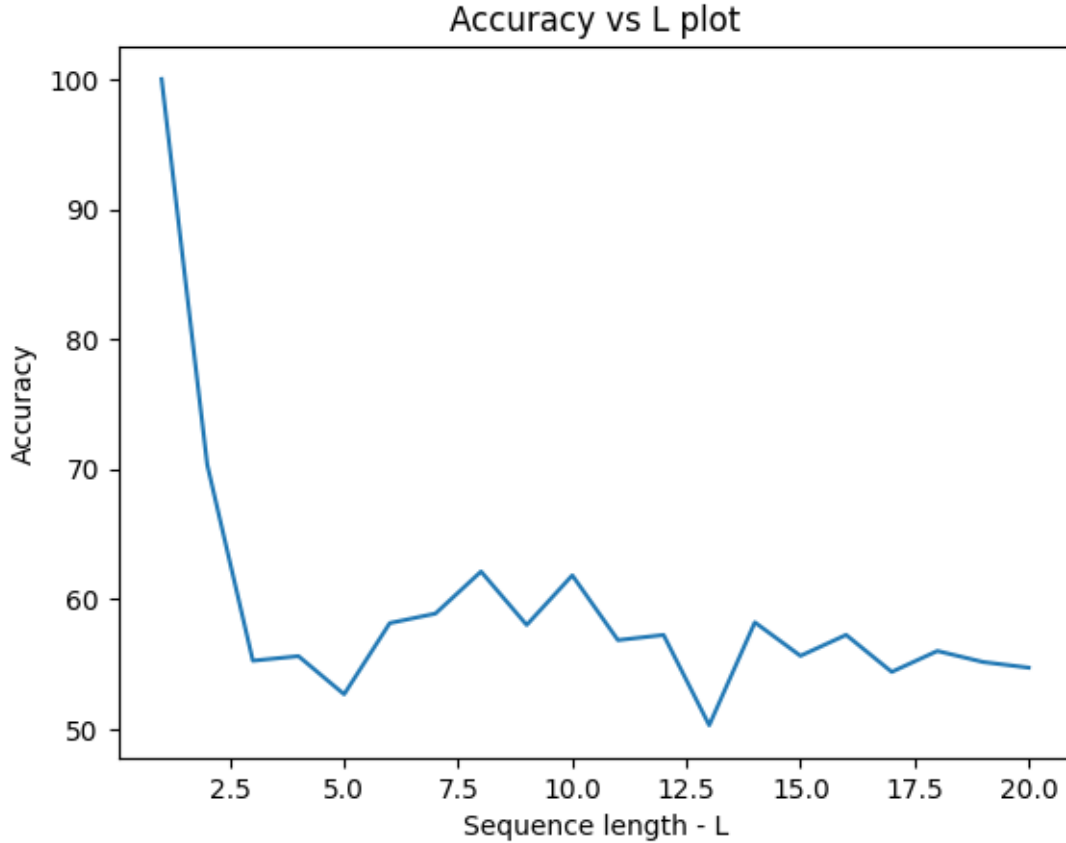
Train loss value after 1000 epochs: 0.645656943321228
Vaildation loss value after 1000 epochs: 0.631892204284668



Best Test Accuracy: 65.05681818181819%

Bitwise Accuracy vs Length

```
[146]: plot_accuracy_vs_length(model)
```



9.8.4 Summary of Results

Sequence length = 10

Epochs for training = 1000

Train loss value after 1000 epochs: 0.645656943321228 Vaildation loss value after 1000 epochs: 0.631892204284668

| State Size | Train loss | Validation Loss | Bitwise Accuracy |
|------------|------------|-----------------|------------------|
| 2 | 0.6933 | 0.6928 | 55.8238% |
| 5 | 0.6263 | 0.6428 | 66.4772% |
| 10 | 0.6456 | 0.6319 | 65.0568% |

In our previous experiments, we observed that the model struggles with learning the task for longer strings. For this study, we specifically trained and tested it on sequences of length 10. I think this problem arises due to issues other than the choice of arhcitecture (like vanishing gradients), hyperparameters or the amount of data. The inherent complexity of the task becomes evident when considering the “carry” context in numerical operations. For instance, the sum of 1+1 can result in either 0 or 1 depending on the carry from a previous position. Similarly, 0+0 and 0+1 can also

produce varying results based on the carry. This contextual understanding of the carry appears to be the primary challenge for the model.

9.9 Overall Summary

| Sequence Length | State Size | Bitwise Accuracy |
|-----------------|------------|------------------|
| 3 | 2 | 83.59375% |
| 3 | 5 | 86.71875% |
| 3 | 10 | 85.15625% |
| 5 | 2 | 75.26% |
| 5 | 5 | 76.56% |
| 5 | 10 | 75.78% |
| 10 | 2 | 55.88238% |
| 10 | 5 | 66.4772% |
| 10 | 10 | 65.0568% |

Here are some key observations and inferences:

- A hidden state size of 5 seems to be ideal, as seen from all the experiments.
- The performance of the model decreases with increase in the length of the string.
- This decrease is apparent in all experiments and is almost agnostic of length of the sequences on which the model was trained.
- The model finds it tricky to interpret the concept of carry as the length of the string increases.

9.10 Comparison with MSE

We test on an architecture with 3 LSTM layers and hidden state size of 5.

```
[19]: class BinaryAdder(nn.Module):
    def __init__(self, input_dim, hidden_dim, output_dim, layers = 1):
        super().__init__()
        self.layers = layers
        self.hidden_dim = hidden_dim
        self.rnn = nn.LSTM(input_dim, hidden_dim, num_layers = layers,
        ↪ batch_first = True)
        self.fc = nn.Linear(hidden_dim, output_dim)

    def forward(self, text):
        output, (hidden, cell) = self.rnn(text)
        return F.softmax(self.fc(output), dim = -1)
```

```
[20]: def one_hot_encode(labels, num_classes=2):
    # Convert labels to one-hot encoded tensor
    return F.one_hot(labels, num_classes=num_classes).float()

def evaluate(model, criterion, K, L):
```

```

inputs, labels = get_batch(K, L)
labels = one_hot_encode(labels.flatten())
inputs, labels = inputs.to(device), labels.to(device)
with torch.no_grad():
    outputs = model(inputs)
    if criterion:
        loss = criterion(outputs.view(-1, 2), labels)
        correct = (torch.argmax(outputs, dim=-1).flatten() == torch.
↪argmax(labels, dim=-1)).sum().item()
        accuracy = 100 * correct / len(labels)

    if criterion:
        return loss.item(), accuracy
    else:
        return None, accuracy

def train_model(model, criterion, optimizer, K, L, epochs=1000):
    train_costs = []
    val_costs = []
    train_acc = []
    val_acc = []

    for epoch in range(epochs):
        inputs, labels = get_batch(K, L)
        labels = one_hot_encode(labels.flatten())
        inputs, labels = inputs.to(device), labels.to(device)

        optimizer.zero_grad()

        outputs = model(inputs)
        loss = criterion(outputs.view(-1, 2), labels)
        loss.backward()
        optimizer.step()

        train_costs.append(loss.item())

        correct = (torch.argmax(outputs, dim=-1).flatten() == torch.
↪argmax(labels, dim=-1)).sum().item()
        accuracy = 100 * correct / len(labels)
        train_acc.append(accuracy)

        val_cost, val_accuracy = evaluate(model, criterion, K, L)
        val_costs.append(val_cost)
        val_acc.append(val_accuracy)

        print(f'Epoch: {epoch}. Train Loss: {loss.item()}. Validation Accuracy:
↪{val_accuracy}')

```

```
return train_costs, train_acc, val_costs, val_acc
```

```
[21]: INPUT_DIM = 2
      HIDDEN_DIM = 5
      OUTPUT_DIM = 2
      NUM_LAYERS = 3
      LR = 0.001
      K = 64
```

9.10.1 Length of Input Sequence = 3

```
[22]: L = 3
```

```
[23]: model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)
      criterion = nn.MSELoss()
      optimizer = optim.Adam(model.parameters(), lr=LR)
```

Training

```
[24]: train_costs, train_acc, val_costs, val_acc = train_model(model, criterion,
      ↪optimizer, K, L)
```

```
Epoch: 0. Train Loss: 0.25609806180000305. Validation Accuracy: 51.171875
Epoch: 1. Train Loss: 0.2593976557254791. Validation Accuracy: 51.171875
Epoch: 2. Train Loss: 0.25050657987594604. Validation Accuracy: 49.21875
Epoch: 3. Train Loss: 0.2590530514717102. Validation Accuracy: 50.390625
Epoch: 4. Train Loss: 0.25318413972854614. Validation Accuracy: 49.21875
Epoch: 5. Train Loss: 0.25615525245666504. Validation Accuracy: 49.21875
Epoch: 6. Train Loss: 0.25584712624549866. Validation Accuracy: 51.5625
Epoch: 7. Train Loss: 0.2531619369983673. Validation Accuracy: 51.5625
Epoch: 8. Train Loss: 0.2529607117176056. Validation Accuracy: 51.953125
Epoch: 9. Train Loss: 0.2572353482246399. Validation Accuracy: 48.828125
Epoch: 10. Train Loss: 0.25438541173934937. Validation Accuracy: 45.3125
Epoch: 11. Train Loss: 0.25404059886932373. Validation Accuracy: 44.140625
Epoch: 12. Train Loss: 0.24854308366775513. Validation Accuracy: 50.0
Epoch: 13. Train Loss: 0.2503030598163605. Validation Accuracy: 48.046875
Epoch: 14. Train Loss: 0.25041571259498596. Validation Accuracy: 47.65625
Epoch: 15. Train Loss: 0.25437599420547485. Validation Accuracy: 51.953125
Epoch: 16. Train Loss: 0.25312405824661255. Validation Accuracy: 46.09375
Epoch: 17. Train Loss: 0.25348344445228577. Validation Accuracy: 51.953125
Epoch: 18. Train Loss: 0.2517150044441223. Validation Accuracy: 53.515625
Epoch: 19. Train Loss: 0.2527941167354584. Validation Accuracy: 49.609375
Epoch: 20. Train Loss: 0.25155556201934814. Validation Accuracy: 50.0
Epoch: 21. Train Loss: 0.25310614705085754. Validation Accuracy: 49.609375
Epoch: 22. Train Loss: 0.24793365597724915. Validation Accuracy: 48.046875
Epoch: 23. Train Loss: 0.25038373470306396. Validation Accuracy: 50.0
Epoch: 24. Train Loss: 0.25167930126190186. Validation Accuracy: 45.703125
```

Epoch: 25. Train Loss: 0.25397467613220215. Validation Accuracy: 50.390625
Epoch: 26. Train Loss: 0.2495799958705902. Validation Accuracy: 49.609375
Epoch: 27. Train Loss: 0.25134968757629395. Validation Accuracy: 52.34375
Epoch: 28. Train Loss: 0.2513611912727356. Validation Accuracy: 48.4375
Epoch: 29. Train Loss: 0.24946178495883942. Validation Accuracy: 48.4375
Epoch: 30. Train Loss: 0.2513033449649811. Validation Accuracy: 49.21875
Epoch: 31. Train Loss: 0.25198230147361755. Validation Accuracy: 50.390625
Epoch: 32. Train Loss: 0.2505931854248047. Validation Accuracy: 50.0
Epoch: 33. Train Loss: 0.25057658553123474. Validation Accuracy: 46.484375
Epoch: 34. Train Loss: 0.24894526600837708. Validation Accuracy: 47.265625
Epoch: 35. Train Loss: 0.24894744157791138. Validation Accuracy: 49.21875
Epoch: 36. Train Loss: 0.2501922845840454. Validation Accuracy: 52.34375
Epoch: 37. Train Loss: 0.25067806243896484. Validation Accuracy: 47.65625
Epoch: 38. Train Loss: 0.2512308359146118. Validation Accuracy: 51.171875
Epoch: 39. Train Loss: 0.24947723746299744. Validation Accuracy: 50.0
Epoch: 40. Train Loss: 0.24729090929031372. Validation Accuracy: 46.484375
Epoch: 41. Train Loss: 0.24797579646110535. Validation Accuracy: 51.5625
Epoch: 42. Train Loss: 0.24911530315876007. Validation Accuracy: 50.390625
Epoch: 43. Train Loss: 0.24934199452400208. Validation Accuracy: 50.78125
Epoch: 44. Train Loss: 0.248750239610672. Validation Accuracy: 46.484375
Epoch: 45. Train Loss: 0.24743139743804932. Validation Accuracy: 51.171875
Epoch: 46. Train Loss: 0.2480991929769516. Validation Accuracy: 51.5625
Epoch: 47. Train Loss: 0.24894919991493225. Validation Accuracy: 51.5625
Epoch: 48. Train Loss: 0.2485378086566925. Validation Accuracy: 58.984375
Epoch: 49. Train Loss: 0.2494838535785675. Validation Accuracy: 57.8125
Epoch: 50. Train Loss: 0.2514256536960602. Validation Accuracy: 52.734375
Epoch: 51. Train Loss: 0.249406635761261. Validation Accuracy: 55.859375
Epoch: 52. Train Loss: 0.24871820211410522. Validation Accuracy: 54.6875
Epoch: 53. Train Loss: 0.24866080284118652. Validation Accuracy: 55.078125
Epoch: 54. Train Loss: 0.24743510782718658. Validation Accuracy: 51.171875
Epoch: 55. Train Loss: 0.25042611360549927. Validation Accuracy: 52.34375
Epoch: 56. Train Loss: 0.25000661611557007. Validation Accuracy: 53.90625
Epoch: 57. Train Loss: 0.2479427456855774. Validation Accuracy: 50.0
Epoch: 58. Train Loss: 0.24703261256217957. Validation Accuracy: 51.5625
Epoch: 59. Train Loss: 0.24882522225379944. Validation Accuracy: 51.953125
Epoch: 60. Train Loss: 0.24686336517333984. Validation Accuracy: 55.078125
Epoch: 61. Train Loss: 0.24882802367210388. Validation Accuracy: 55.859375
Epoch: 62. Train Loss: 0.2503467798233032. Validation Accuracy: 51.171875
Epoch: 63. Train Loss: 0.24687698483467102. Validation Accuracy: 58.203125
Epoch: 64. Train Loss: 0.24967631697654724. Validation Accuracy: 47.265625
Epoch: 65. Train Loss: 0.24984101951122284. Validation Accuracy: 55.078125
Epoch: 66. Train Loss: 0.24504566192626953. Validation Accuracy: 59.375
Epoch: 67. Train Loss: 0.2496335208415985. Validation Accuracy: 50.0
Epoch: 68. Train Loss: 0.24866583943367004. Validation Accuracy: 55.859375
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Epoch: 73. Train Loss: 0.24841131269931793. Validation Accuracy: 55.078125
Epoch: 74. Train Loss: 0.2516103684902191. Validation Accuracy: 55.078125
Epoch: 75. Train Loss: 0.24842225015163422. Validation Accuracy: 57.421875
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Epoch: 356. Train Loss: 0.24474531412124634. Validation Accuracy: 46.09375
Epoch: 357. Train Loss: 0.24830645322799683. Validation Accuracy: 54.6875
Epoch: 358. Train Loss: 0.24239645898342133. Validation Accuracy: 53.125
Epoch: 359. Train Loss: 0.24093246459960938. Validation Accuracy: 57.03125
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Epoch: 361. Train Loss: 0.2503452003002167. Validation Accuracy: 50.78125
Epoch: 362. Train Loss: 0.2429831624031067. Validation Accuracy: 53.90625
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Epoch: 365. Train Loss: 0.24603129923343658. Validation Accuracy: 49.21875
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Epoch: 369. Train Loss: 0.2430732250213623. Validation Accuracy: 52.734375
Epoch: 370. Train Loss: 0.24771367013454437. Validation Accuracy: 55.859375
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Epoch: 383. Train Loss: 0.24566873908042908. Validation Accuracy: 56.25
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Epoch: 385. Train Loss: 0.2480798214673996. Validation Accuracy: 51.5625
Epoch: 386. Train Loss: 0.251007080078125. Validation Accuracy: 57.421875
Epoch: 387. Train Loss: 0.24826326966285706. Validation Accuracy: 55.078125
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Epoch: 466. Train Loss: 0.24171483516693115. Validation Accuracy: 51.171875
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Epoch: 554. Train Loss: 0.21233980357646942. Validation Accuracy: 70.3125
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Epoch: 583. Train Loss: 0.18273700773715973. Validation Accuracy: 74.609375
Epoch: 584. Train Loss: 0.21091333031654358. Validation Accuracy: 73.046875
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Epoch: 586. Train Loss: 0.21066708862781525. Validation Accuracy: 69.921875
Epoch: 587. Train Loss: 0.2136659473180771. Validation Accuracy: 73.828125
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Epoch: 589. Train Loss: 0.18898840248584747. Validation Accuracy: 81.640625
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Epoch: 613. Train Loss: 0.19077017903327942. Validation Accuracy: 71.484375
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Epoch: 615. Train Loss: 0.19068433344364166. Validation Accuracy: 73.046875
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Epoch: 624. Train Loss: 0.1937888115644455. Validation Accuracy: 75.0
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Epoch: 637. Train Loss: 0.17817065119743347. Validation Accuracy: 70.703125
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Epoch: 648. Train Loss: 0.17338868975639343. Validation Accuracy: 73.046875

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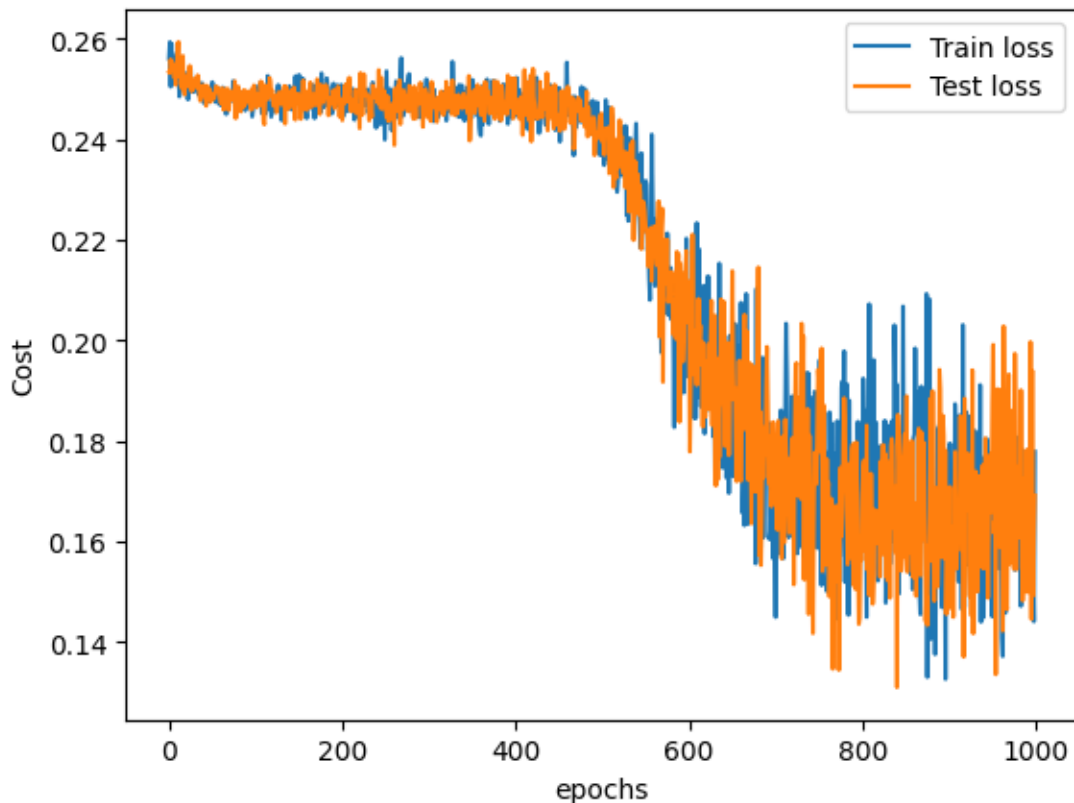
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Epoch: 914. Train Loss: 0.17512613534927368. Validation Accuracy: 73.4375
Epoch: 915. Train Loss: 0.14645853638648987. Validation Accuracy: 76.953125
Epoch: 916. Train Loss: 0.2031027227640152. Validation Accuracy: 73.828125
Epoch: 917. Train Loss: 0.16257336735725403. Validation Accuracy: 83.984375
Epoch: 918. Train Loss: 0.1468755155801773. Validation Accuracy: 70.703125
Epoch: 919. Train Loss: 0.16889174282550812. Validation Accuracy: 76.171875
Epoch: 920. Train Loss: 0.18572455644607544. Validation Accuracy: 78.515625
Epoch: 921. Train Loss: 0.17153170704841614. Validation Accuracy: 75.78125
Epoch: 922. Train Loss: 0.15542329847812653. Validation Accuracy: 73.046875
Epoch: 923. Train Loss: 0.18492375314235687. Validation Accuracy: 80.078125
Epoch: 924. Train Loss: 0.15621832013130188. Validation Accuracy: 78.515625
Epoch: 925. Train Loss: 0.15359258651733398. Validation Accuracy: 73.828125
Epoch: 926. Train Loss: 0.18342317640781403. Validation Accuracy: 79.296875
Epoch: 927. Train Loss: 0.17333880066871643. Validation Accuracy: 70.3125
Epoch: 928. Train Loss: 0.1715407818555832. Validation Accuracy: 80.46875
Epoch: 929. Train Loss: 0.15548861026763916. Validation Accuracy: 78.515625
Epoch: 930. Train Loss: 0.18201372027397156. Validation Accuracy: 75.0
Epoch: 931. Train Loss: 0.1535625457763672. Validation Accuracy: 73.828125
Epoch: 932. Train Loss: 0.15892621874809265. Validation Accuracy: 75.390625
Epoch: 933. Train Loss: 0.1629563719034195. Validation Accuracy: 78.90625
Epoch: 934. Train Loss: 0.1537538766860962. Validation Accuracy: 75.0
Epoch: 935. Train Loss: 0.1591769903898239. Validation Accuracy: 76.953125
Epoch: 936. Train Loss: 0.19112473726272583. Validation Accuracy: 76.953125

Epoch: 937. Train Loss: 0.14397230744361877. Validation Accuracy: 75.78125
Epoch: 938. Train Loss: 0.17310677468776703. Validation Accuracy: 78.125
Epoch: 939. Train Loss: 0.16899189352989197. Validation Accuracy: 71.484375
Epoch: 940. Train Loss: 0.14490139484405518. Validation Accuracy: 79.296875
Epoch: 941. Train Loss: 0.17675665020942688. Validation Accuracy: 75.390625
Epoch: 942. Train Loss: 0.16025489568710327. Validation Accuracy: 73.046875
Epoch: 943. Train Loss: 0.18013155460357666. Validation Accuracy: 76.953125
Epoch: 944. Train Loss: 0.18037915229797363. Validation Accuracy: 79.296875
Epoch: 945. Train Loss: 0.17549988627433777. Validation Accuracy: 80.46875
Epoch: 946. Train Loss: 0.16742362082004547. Validation Accuracy: 74.609375
Epoch: 947. Train Loss: 0.17626547813415527. Validation Accuracy: 73.4375
Epoch: 948. Train Loss: 0.15779423713684082. Validation Accuracy: 72.65625
Epoch: 949. Train Loss: 0.16281887888908386. Validation Accuracy: 73.4375
Epoch: 950. Train Loss: 0.14502662420272827. Validation Accuracy: 71.875
Epoch: 951. Train Loss: 0.16702589392662048. Validation Accuracy: 67.578125
Epoch: 952. Train Loss: 0.16113850474357605. Validation Accuracy: 76.953125
Epoch: 953. Train Loss: 0.1516866385936737. Validation Accuracy: 76.5625
Epoch: 954. Train Loss: 0.1570238173007965. Validation Accuracy: 82.8125
Epoch: 955. Train Loss: 0.17258045077323914. Validation Accuracy: 73.828125
Epoch: 956. Train Loss: 0.15912885963916779. Validation Accuracy: 69.921875
Epoch: 957. Train Loss: 0.15468230843544006. Validation Accuracy: 76.5625
Epoch: 958. Train Loss: 0.16086241602897644. Validation Accuracy: 72.65625
Epoch: 959. Train Loss: 0.15766948461532593. Validation Accuracy: 76.953125
Epoch: 960. Train Loss: 0.1628229171037674. Validation Accuracy: 78.515625
Epoch: 961. Train Loss: 0.14085716009140015. Validation Accuracy: 72.265625
Epoch: 962. Train Loss: 0.13714134693145752. Validation Accuracy: 82.421875
Epoch: 963. Train Loss: 0.16842132806777954. Validation Accuracy: 70.3125
Epoch: 964. Train Loss: 0.16215556859970093. Validation Accuracy: 71.484375
Epoch: 965. Train Loss: 0.1457499861717224. Validation Accuracy: 77.734375
Epoch: 966. Train Loss: 0.1704081892967224. Validation Accuracy: 80.46875
Epoch: 967. Train Loss: 0.16024565696716309. Validation Accuracy: 78.90625
Epoch: 968. Train Loss: 0.15916132926940918. Validation Accuracy: 74.21875
Epoch: 969. Train Loss: 0.17654046416282654. Validation Accuracy: 69.921875
Epoch: 970. Train Loss: 0.15576717257499695. Validation Accuracy: 78.515625
Epoch: 971. Train Loss: 0.1581488847732544. Validation Accuracy: 71.875
Epoch: 972. Train Loss: 0.17964860796928406. Validation Accuracy: 69.921875
Epoch: 973. Train Loss: 0.1639879196882248. Validation Accuracy: 76.953125
Epoch: 974. Train Loss: 0.16496050357818604. Validation Accuracy: 76.171875
Epoch: 975. Train Loss: 0.16487571597099304. Validation Accuracy: 80.859375
Epoch: 976. Train Loss: 0.15433020889759064. Validation Accuracy: 67.578125
Epoch: 977. Train Loss: 0.17205476760864258. Validation Accuracy: 72.265625
Epoch: 978. Train Loss: 0.1638614535331726. Validation Accuracy: 77.34375
Epoch: 979. Train Loss: 0.1806206852197647. Validation Accuracy: 75.390625
Epoch: 980. Train Loss: 0.18072634935379028. Validation Accuracy: 79.6875
Epoch: 981. Train Loss: 0.15992668271064758. Validation Accuracy: 73.828125
Epoch: 982. Train Loss: 0.16470488905906677. Validation Accuracy: 74.609375
Epoch: 983. Train Loss: 0.1471291482448578. Validation Accuracy: 70.3125
Epoch: 984. Train Loss: 0.15708646178245544. Validation Accuracy: 73.828125

Epoch: 985. Train Loss: 0.1781313568353653. Validation Accuracy: 76.5625
Epoch: 986. Train Loss: 0.16395168006420135. Validation Accuracy: 73.046875
Epoch: 987. Train Loss: 0.17227418720722198. Validation Accuracy: 79.6875
Epoch: 988. Train Loss: 0.15870177745819092. Validation Accuracy: 77.734375
Epoch: 989. Train Loss: 0.17617365717887878. Validation Accuracy: 75.78125
Epoch: 990. Train Loss: 0.16222776472568512. Validation Accuracy: 71.09375
Epoch: 991. Train Loss: 0.16638684272766113. Validation Accuracy: 76.953125
Epoch: 992. Train Loss: 0.17081594467163086. Validation Accuracy: 73.4375
Epoch: 993. Train Loss: 0.16419607400894165. Validation Accuracy: 75.390625
Epoch: 994. Train Loss: 0.16201728582382202. Validation Accuracy: 68.359375
Epoch: 995. Train Loss: 0.16146314144134521. Validation Accuracy: 79.6875
Epoch: 996. Train Loss: 0.15268322825431824. Validation Accuracy: 69.53125
Epoch: 997. Train Loss: 0.1536445915699005. Validation Accuracy: 79.296875
Epoch: 998. Train Loss: 0.14407402276992798. Validation Accuracy: 78.90625
Epoch: 999. Train Loss: 0.17787010967731476. Validation Accuracy: 75.0

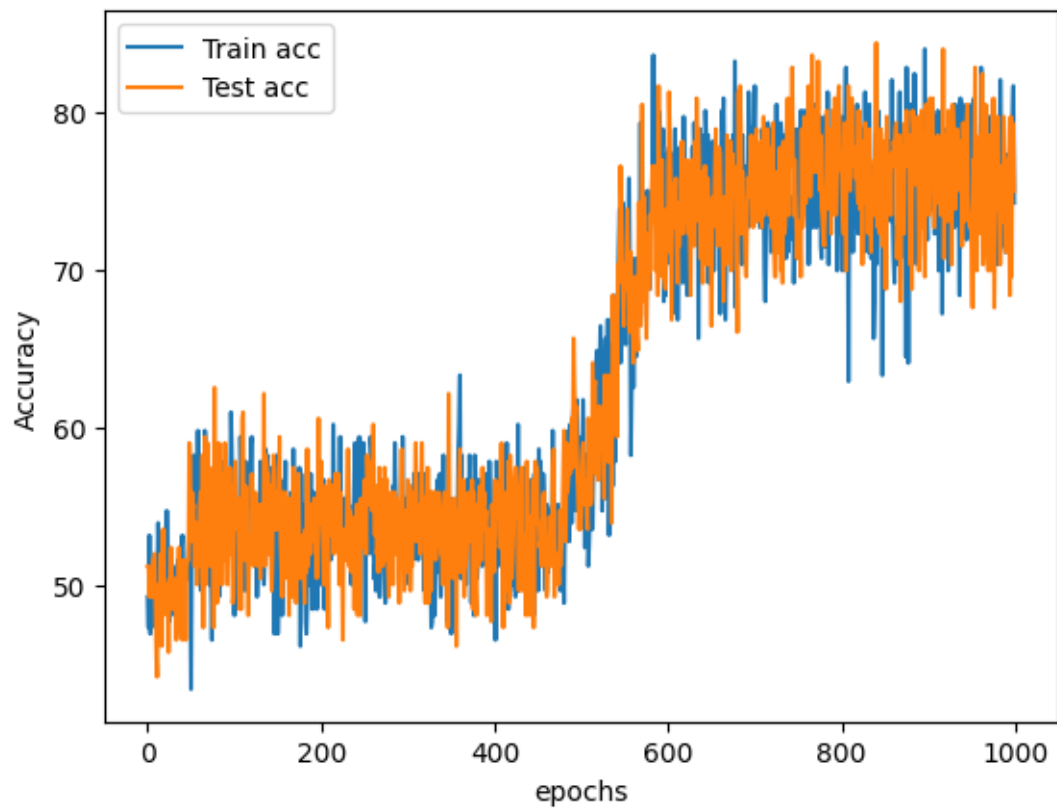
Train and test plots

```
[25]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



Train loss value after 1000 epochs: 0.17787010967731476

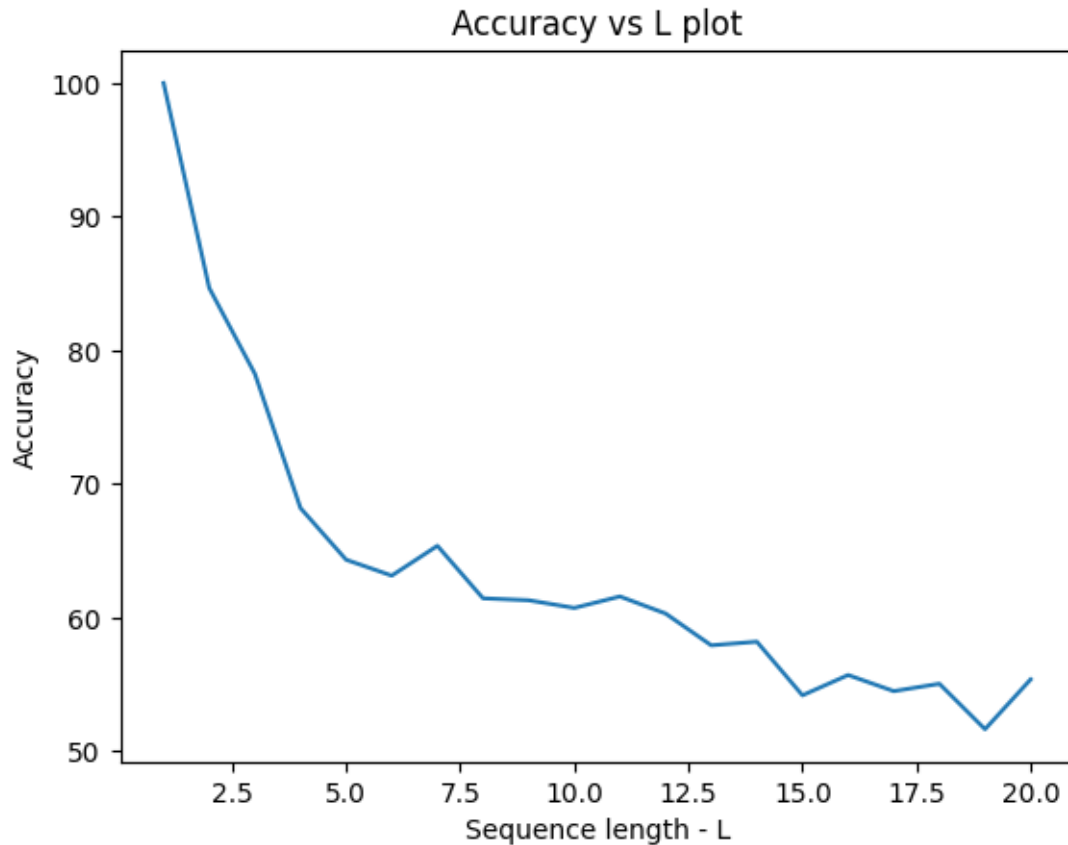
Vaildation loss value after 1000 epochs: 0.1691247522830963



Best Test Accuracy: 84.375%

Bitwise Accuracy vs Length

```
[27]: plot_accuracy_vs_length(model)
```



9.10.2 Length of Input Sequence = 5

[28]: `L = 5`

[29]: `model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)`
`criterion = nn.MSELoss()`
`optimizer = optim.Adam(model.parameters(), lr=LR)`

Training

[33]: `train_costs, train_acc, val_costs, val_acc = train_model(model, criterion, ↵`
`↵optimizer, K, L)`

Epoch: 0. Train Loss: 0.23662230372428894. Validation Accuracy: 59.895833333333336

Epoch: 1. Train Loss: 0.2418895959854126. Validation Accuracy: 58.59375

Epoch: 2. Train Loss: 0.23741045594215393. Validation Accuracy: 55.46875

Epoch: 3. Train Loss: 0.23552116751670837. Validation Accuracy: 63.28125

Epoch: 4. Train Loss: 0.2368830442428589. Validation Accuracy: 59.375

Epoch: 5. Train Loss: 0.2371053695678711. Validation Accuracy: 59.375

Epoch: 6. Train Loss: 0.2377779185771942. Validation Accuracy: 62.760416666666664
Epoch: 7. Train Loss: 0.2394515872001648. Validation Accuracy: 62.5
Epoch: 8. Train Loss: 0.23536905646324158. Validation Accuracy: 67.70833333333333
Epoch: 9. Train Loss: 0.2332640141248703. Validation Accuracy: 65.625
Epoch: 10. Train Loss: 0.23605918884277344. Validation Accuracy: 67.1875
Epoch: 11. Train Loss: 0.2299691140651703. Validation Accuracy: 64.84375
Epoch: 12. Train Loss: 0.23995690047740936. Validation Accuracy: 64.322916666666667
Epoch: 13. Train Loss: 0.23066017031669617. Validation Accuracy: 67.96875
Epoch: 14. Train Loss: 0.2334575355052948. Validation Accuracy: 61.458333333333336
Epoch: 15. Train Loss: 0.22752636671066284. Validation Accuracy: 66.40625
Epoch: 16. Train Loss: 0.22805026173591614. Validation Accuracy: 63.28125
Epoch: 17. Train Loss: 0.22983472049236298. Validation Accuracy: 61.458333333333336
Epoch: 18. Train Loss: 0.2329396903514862. Validation Accuracy: 62.760416666666664
Epoch: 19. Train Loss: 0.22835516929626465. Validation Accuracy: 56.25
Epoch: 20. Train Loss: 0.23949134349822998. Validation Accuracy: 64.0625
Epoch: 21. Train Loss: 0.23163217306137085. Validation Accuracy: 63.802083333333336
Epoch: 22. Train Loss: 0.23139230906963348. Validation Accuracy: 68.75
Epoch: 23. Train Loss: 0.22523526847362518. Validation Accuracy: 61.71875
Epoch: 24. Train Loss: 0.22769615054130554. Validation Accuracy: 65.36458333333333
Epoch: 25. Train Loss: 0.2301129549741745. Validation Accuracy: 63.28125
Epoch: 26. Train Loss: 0.2245427370071411. Validation Accuracy: 66.14583333333333
Epoch: 27. Train Loss: 0.2297523021697998. Validation Accuracy: 71.875
Epoch: 28. Train Loss: 0.23435068130493164. Validation Accuracy: 66.40625
Epoch: 29. Train Loss: 0.22616522014141083. Validation Accuracy: 66.14583333333333
Epoch: 30. Train Loss: 0.22783808410167694. Validation Accuracy: 64.0625
Epoch: 31. Train Loss: 0.23820249736309052. Validation Accuracy: 63.541666666666664
Epoch: 32. Train Loss: 0.2321145385503769. Validation Accuracy: 68.48958333333333
Epoch: 33. Train Loss: 0.22876691818237305. Validation Accuracy: 62.239583333333336
Epoch: 34. Train Loss: 0.22617189586162567. Validation Accuracy: 57.03125
Epoch: 35. Train Loss: 0.22385722398757935. Validation Accuracy: 66.14583333333333
Epoch: 36. Train Loss: 0.2163601815700531. Validation Accuracy: 69.791666666666667
Epoch: 37. Train Loss: 0.22644293308258057. Validation Accuracy: 71.61458333333333

Epoch: 38. Train Loss: 0.2191820591688156. Validation Accuracy: 64.58333333333333

Epoch: 39. Train Loss: 0.21768632531166077. Validation Accuracy: 60.9375

Epoch: 40. Train Loss: 0.21540451049804688. Validation Accuracy: 72.91666666666667

Epoch: 41. Train Loss: 0.22784863412380219. Validation Accuracy: 66.14583333333333

Epoch: 42. Train Loss: 0.23239147663116455. Validation Accuracy: 65.88541666666667

Epoch: 43. Train Loss: 0.22706151008605957. Validation Accuracy: 66.92708333333333

Epoch: 44. Train Loss: 0.22669783234596252. Validation Accuracy: 67.44791666666667

Epoch: 45. Train Loss: 0.22111758589744568. Validation Accuracy: 66.92708333333333

Epoch: 46. Train Loss: 0.2250538468360901. Validation Accuracy: 64.0625

Epoch: 47. Train Loss: 0.21848106384277344. Validation Accuracy: 64.84375

Epoch: 48. Train Loss: 0.213471919298172. Validation Accuracy: 66.66666666666667

Epoch: 49. Train Loss: 0.21773123741149902. Validation Accuracy: 68.75

Epoch: 50. Train Loss: 0.230453222990036. Validation Accuracy: 68.22916666666667

Epoch: 51. Train Loss: 0.21152012050151825. Validation Accuracy: 65.10416666666667

Epoch: 52. Train Loss: 0.21218189597129822. Validation Accuracy: 64.84375

Epoch: 53. Train Loss: 0.21778950095176697. Validation Accuracy: 66.40625

Epoch: 54. Train Loss: 0.2241031527519226. Validation Accuracy: 66.92708333333333

Epoch: 55. Train Loss: 0.22440557181835175. Validation Accuracy: 66.40625

Epoch: 56. Train Loss: 0.2203683853149414. Validation Accuracy: 65.625

Epoch: 57. Train Loss: 0.22590892016887665. Validation Accuracy: 68.22916666666667

Epoch: 58. Train Loss: 0.21164333820343018. Validation Accuracy: 58.854166666666664

Epoch: 59. Train Loss: 0.2115435004234314. Validation Accuracy: 69.27083333333333

Epoch: 60. Train Loss: 0.21113669872283936. Validation Accuracy: 73.95833333333333

Epoch: 61. Train Loss: 0.20869436860084534. Validation Accuracy: 65.10416666666667

Epoch: 62. Train Loss: 0.20053677260875702. Validation Accuracy: 67.44791666666667

Epoch: 63. Train Loss: 0.2205747365951538. Validation Accuracy: 65.10416666666667

Epoch: 64. Train Loss: 0.21375612914562225. Validation Accuracy: 67.1875

Epoch: 65. Train Loss: 0.21261301636695862. Validation Accuracy: 66.40625

Epoch: 66. Train Loss: 0.2215997576713562. Validation Accuracy: 68.75

Epoch: 67. Train Loss: 0.214090034365654. Validation Accuracy: 64.0625

Epoch: 68. Train Loss: 0.2222132384777069. Validation Accuracy: 66.92708333333333

Epoch: 69. Train Loss: 0.23057375848293304. Validation Accuracy: 70.57291666666667
Epoch: 70. Train Loss: 0.21333199739456177. Validation Accuracy: 66.66666666666667
Epoch: 71. Train Loss: 0.2130511850118637. Validation Accuracy: 65.10416666666667
Epoch: 72. Train Loss: 0.20670339465141296. Validation Accuracy: 67.44791666666667
Epoch: 73. Train Loss: 0.20528608560562134. Validation Accuracy: 66.14583333333333
Epoch: 74. Train Loss: 0.19978046417236328. Validation Accuracy: 68.75
Epoch: 75. Train Loss: 0.2187107503414154. Validation Accuracy: 65.10416666666667
Epoch: 76. Train Loss: 0.20049993693828583. Validation Accuracy: 65.36458333333333
Epoch: 77. Train Loss: 0.20084111392498016. Validation Accuracy: 67.1875
Epoch: 78. Train Loss: 0.22068874537944794. Validation Accuracy: 70.3125
Epoch: 79. Train Loss: 0.20359376072883606. Validation Accuracy: 67.70833333333333
Epoch: 80. Train Loss: 0.20888911187648773. Validation Accuracy: 69.27083333333333
Epoch: 81. Train Loss: 0.2104310244321823. Validation Accuracy: 67.1875
Epoch: 82. Train Loss: 0.2014751136302948. Validation Accuracy: 67.70833333333333
Epoch: 83. Train Loss: 0.20326292514801025. Validation Accuracy: 59.895833333333336
Epoch: 84. Train Loss: 0.19921748340129852. Validation Accuracy: 75.0
Epoch: 85. Train Loss: 0.19560407102108002. Validation Accuracy: 68.22916666666667
Epoch: 86. Train Loss: 0.22130471467971802. Validation Accuracy: 70.3125
Epoch: 87. Train Loss: 0.20608864724636078. Validation Accuracy: 65.36458333333333
Epoch: 88. Train Loss: 0.21007156372070312. Validation Accuracy: 66.92708333333333
Epoch: 89. Train Loss: 0.21735000610351562. Validation Accuracy: 65.625
Epoch: 90. Train Loss: 0.21053114533424377. Validation Accuracy: 63.802083333333336
Epoch: 91. Train Loss: 0.17928890883922577. Validation Accuracy: 64.58333333333333
Epoch: 92. Train Loss: 0.20571617782115936. Validation Accuracy: 68.48958333333333
Epoch: 93. Train Loss: 0.19633615016937256. Validation Accuracy: 70.05208333333333
Epoch: 94. Train Loss: 0.21035413444042206. Validation Accuracy: 63.541666666666664
Epoch: 95. Train Loss: 0.20278984308242798. Validation Accuracy: 69.79166666666667
Epoch: 96. Train Loss: 0.20406846702098846. Validation Accuracy:

66.66666666666667
Epoch: 97. Train Loss: 0.20096322894096375. Validation Accuracy: 66.14583333333333
Epoch: 98. Train Loss: 0.2026119828224182. Validation Accuracy: 65.36458333333333
Epoch: 99. Train Loss: 0.2149648368358612. Validation Accuracy: 66.40625
Epoch: 100. Train Loss: 0.18348562717437744. Validation Accuracy: 71.61458333333333
Epoch: 101. Train Loss: 0.20292308926582336. Validation Accuracy: 64.58333333333333
Epoch: 102. Train Loss: 0.22275444865226746. Validation Accuracy: 67.1875
Epoch: 103. Train Loss: 0.2117963433265686. Validation Accuracy: 67.96875
Epoch: 104. Train Loss: 0.20495407283306122. Validation Accuracy: 68.22916666666667
Epoch: 105. Train Loss: 0.19726762175559998. Validation Accuracy: 59.895833333333336
Epoch: 106. Train Loss: 0.20044076442718506. Validation Accuracy: 65.36458333333333
Epoch: 107. Train Loss: 0.21350501477718353. Validation Accuracy: 65.88541666666667
Epoch: 108. Train Loss: 0.21898357570171356. Validation Accuracy: 69.53125
Epoch: 109. Train Loss: 0.2015725076198578. Validation Accuracy: 65.88541666666667
Epoch: 110. Train Loss: 0.20605729520320892. Validation Accuracy: 70.57291666666667
Epoch: 111. Train Loss: 0.21104899048805237. Validation Accuracy: 71.35416666666667
Epoch: 112. Train Loss: 0.20781129598617554. Validation Accuracy: 63.28125
Epoch: 113. Train Loss: 0.21856626868247986. Validation Accuracy: 68.22916666666667
Epoch: 114. Train Loss: 0.20320847630500793. Validation Accuracy: 66.14583333333333
Epoch: 115. Train Loss: 0.19894886016845703. Validation Accuracy: 65.10416666666667
Epoch: 116. Train Loss: 0.215616375207901. Validation Accuracy: 63.802083333333336
Epoch: 117. Train Loss: 0.225830078125. Validation Accuracy: 67.96875
Epoch: 118. Train Loss: 0.21216806769371033. Validation Accuracy: 69.01041666666667
Epoch: 119. Train Loss: 0.21292057633399963. Validation Accuracy: 66.66666666666667
Epoch: 120. Train Loss: 0.19195573031902313. Validation Accuracy: 68.22916666666667
Epoch: 121. Train Loss: 0.2146349400281906. Validation Accuracy: 68.48958333333333
Epoch: 122. Train Loss: 0.20705895125865936. Validation Accuracy: 64.32291666666667
Epoch: 123. Train Loss: 0.20802363753318787. Validation Accuracy:

63.802083333333336
Epoch: 124. Train Loss: 0.21511515974998474. Validation Accuracy: 69.010416666666667
Epoch: 125. Train Loss: 0.19826678931713104. Validation Accuracy: 64.0625
Epoch: 126. Train Loss: 0.22455522418022156. Validation Accuracy: 64.0625
Epoch: 127. Train Loss: 0.1947496384382248. Validation Accuracy: 60.677083333333336
Epoch: 128. Train Loss: 0.19737902283668518. Validation Accuracy: 69.010416666666667
Epoch: 129. Train Loss: 0.21161028742790222. Validation Accuracy: 66.927083333333333
Epoch: 130. Train Loss: 0.19567275047302246. Validation Accuracy: 68.75
Epoch: 131. Train Loss: 0.2178839147090912. Validation Accuracy: 59.375
Epoch: 132. Train Loss: 0.21268758177757263. Validation Accuracy: 65.885416666666667
Epoch: 133. Train Loss: 0.19172291457653046. Validation Accuracy: 70.83333333333333
Epoch: 134. Train Loss: 0.210985466837883. Validation Accuracy: 68.48958333333333
Epoch: 135. Train Loss: 0.1897854059934616. Validation Accuracy: 71.61458333333333
Epoch: 136. Train Loss: 0.20852038264274597. Validation Accuracy: 66.40625
Epoch: 137. Train Loss: 0.2029496431350708. Validation Accuracy: 71.09375
Epoch: 138. Train Loss: 0.21435308456420898. Validation Accuracy: 66.40625
Epoch: 139. Train Loss: 0.21008627116680145. Validation Accuracy: 65.625
Epoch: 140. Train Loss: 0.2387758195400238. Validation Accuracy: 67.1875
Epoch: 141. Train Loss: 0.19092321395874023. Validation Accuracy: 63.802083333333336
Epoch: 142. Train Loss: 0.21656839549541473. Validation Accuracy: 72.39583333333333
Epoch: 143. Train Loss: 0.2130194753408432. Validation Accuracy: 62.5
Epoch: 144. Train Loss: 0.2070411890745163. Validation Accuracy: 68.229166666666667
Epoch: 145. Train Loss: 0.20643703639507294. Validation Accuracy: 63.28125
Epoch: 146. Train Loss: 0.20013445615768433. Validation Accuracy: 59.635416666666664
Epoch: 147. Train Loss: 0.21726159751415253. Validation Accuracy: 64.322916666666667
Epoch: 148. Train Loss: 0.2085849940776825. Validation Accuracy: 70.572916666666667
Epoch: 149. Train Loss: 0.2040124386548996. Validation Accuracy: 70.3125
Epoch: 150. Train Loss: 0.1936936378479004. Validation Accuracy: 68.229166666666667
Epoch: 151. Train Loss: 0.21265068650245667. Validation Accuracy: 64.0625
Epoch: 152. Train Loss: 0.19703981280326843. Validation Accuracy: 68.75
Epoch: 153. Train Loss: 0.21285425126552582. Validation Accuracy: 63.802083333333336
Epoch: 154. Train Loss: 0.20820538699626923. Validation Accuracy:

67.44791666666667
Epoch: 155. Train Loss: 0.19461524486541748. Validation Accuracy: 70.3125
Epoch: 156. Train Loss: 0.20105931162834167. Validation Accuracy: 65.88541666666667
Epoch: 157. Train Loss: 0.20025038719177246. Validation Accuracy: 65.36458333333333
Epoch: 158. Train Loss: 0.1895362138748169. Validation Accuracy: 74.21875
Epoch: 159. Train Loss: 0.20413385331630707. Validation Accuracy: 66.14583333333333
Epoch: 160. Train Loss: 0.199618861079216. Validation Accuracy: 65.10416666666667
Epoch: 161. Train Loss: 0.227578803896904. Validation Accuracy: 65.10416666666667
Epoch: 162. Train Loss: 0.19283269345760345. Validation Accuracy: 66.40625
Epoch: 163. Train Loss: 0.198464035987854. Validation Accuracy: 63.28125
Epoch: 164. Train Loss: 0.1951836198568344. Validation Accuracy: 68.75
Epoch: 165. Train Loss: 0.20497044920921326. Validation Accuracy: 70.57291666666667
Epoch: 166. Train Loss: 0.1969953030347824. Validation Accuracy: 62.239583333333336
Epoch: 167. Train Loss: 0.21405881643295288. Validation Accuracy: 62.239583333333336
Epoch: 168. Train Loss: 0.2072945535182953. Validation Accuracy: 67.96875
Epoch: 169. Train Loss: 0.1884576380252838. Validation Accuracy: 71.875
Epoch: 170. Train Loss: 0.2259722650051117. Validation Accuracy: 66.92708333333333
Epoch: 171. Train Loss: 0.20870858430862427. Validation Accuracy: 69.27083333333333
Epoch: 172. Train Loss: 0.21206727623939514. Validation Accuracy: 66.14583333333333
Epoch: 173. Train Loss: 0.19148236513137817. Validation Accuracy: 63.020833333333336
Epoch: 174. Train Loss: 0.2239382565021515. Validation Accuracy: 63.020833333333336
Epoch: 175. Train Loss: 0.20314514636993408. Validation Accuracy: 65.88541666666667
Epoch: 176. Train Loss: 0.20701217651367188. Validation Accuracy: 70.57291666666667
Epoch: 177. Train Loss: 0.21832506358623505. Validation Accuracy: 61.458333333333336
Epoch: 178. Train Loss: 0.20383334159851074. Validation Accuracy: 65.10416666666667
Epoch: 179. Train Loss: 0.2081339955329895. Validation Accuracy: 69.79166666666667
Epoch: 180. Train Loss: 0.20192226767539978. Validation Accuracy: 66.66666666666667
Epoch: 181. Train Loss: 0.20288340747356415. Validation Accuracy: 67.1875
Epoch: 182. Train Loss: 0.21861664950847626. Validation Accuracy: 67.1875

Epoch: 183. Train Loss: 0.2115648239850998. Validation Accuracy: 68.75
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 Epoch: 185. Train Loss: 0.21477839350700378. Validation Accuracy: 66.92708333333333
 Epoch: 186. Train Loss: 0.2124493420124054. Validation Accuracy: 66.92708333333333
 Epoch: 187. Train Loss: 0.19532524049282074. Validation Accuracy: 63.28125
 Epoch: 188. Train Loss: 0.21447604894638062. Validation Accuracy: 67.1875
 Epoch: 189. Train Loss: 0.2056136429309845. Validation Accuracy: 65.10416666666667
 Epoch: 190. Train Loss: 0.18167459964752197. Validation Accuracy: 66.66666666666667
 Epoch: 191. Train Loss: 0.19940416514873505. Validation Accuracy: 62.760416666666664
 Epoch: 192. Train Loss: 0.21555571258068085. Validation Accuracy: 69.01041666666667
 Epoch: 193. Train Loss: 0.21045678853988647. Validation Accuracy: 61.197916666666664
 Epoch: 194. Train Loss: 0.20445571839809418. Validation Accuracy: 74.47916666666667
 Epoch: 195. Train Loss: 0.19707155227661133. Validation Accuracy: 64.32291666666667
 Epoch: 196. Train Loss: 0.20674024522304535. Validation Accuracy: 70.57291666666667
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 Epoch: 201. Train Loss: 0.21676747500896454. Validation Accuracy: 68.48958333333333
 Epoch: 202. Train Loss: 0.2240924835205078. Validation Accuracy: 70.05208333333333
 Epoch: 203. Train Loss: 0.23828522861003876. Validation Accuracy: 67.44791666666667
 Epoch: 204. Train Loss: 0.21814672648906708. Validation Accuracy: 72.13541666666667
 Epoch: 205. Train Loss: 0.20021581649780273. Validation Accuracy: 62.760416666666664
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Epoch: 212. Train Loss: 0.21424554288387299. Validation Accuracy: 68.22916666666667
Epoch: 213. Train Loss: 0.2138107270002365. Validation Accuracy: 69.27083333333333
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Epoch: 232. Train Loss: 0.19996392726898193. Validation Accuracy: 63.28125
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Epoch: 236. Train Loss: 0.2019515484571457. Validation Accuracy: 67.1875

Epoch: 237. Train Loss: 0.20691826939582825. Validation Accuracy: 68.48958333333333
Epoch: 238. Train Loss: 0.21216344833374023. Validation Accuracy: 63.02083333333336
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Epoch: 240. Train Loss: 0.20357808470726013. Validation Accuracy: 64.0625
Epoch: 241. Train Loss: 0.18708139657974243. Validation Accuracy: 71.35416666666667
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Epoch: 297. Train Loss: 0.19513551890850067. Validation Accuracy: 64.0625

Epoch: 298. Train Loss: 0.22005002200603485. Validation Accuracy: 66.14583333333333

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Epoch: 304. Train Loss: 0.19964870810508728. Validation Accuracy: 65.36458333333333

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Epoch: 306. Train Loss: 0.2115715742111206. Validation Accuracy: 68.75

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Epoch: 318. Train Loss: 0.19619743525981903. Validation Accuracy: 69.01041666666667

Epoch: 319. Train Loss: 0.18981198966503143. Validation Accuracy: 68.48958333333333

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Epoch: 374. Train Loss: 0.19043764472007751. Validation Accuracy: 61.71875

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Epoch: 430. Train Loss: 0.1824132204055786. Validation Accuracy: 74.21875

Epoch: 431. Train Loss: 0.18789032101631165. Validation Accuracy: 64.32291666666667

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Epoch: 438. Train Loss: 0.18690794706344604. Validation Accuracy: 65.625

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Epoch: 440. Train Loss: 0.18881432712078094. Validation Accuracy: 75.78125

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Epoch: 443. Train Loss: 0.22005555033683777. Validation Accuracy: 65.625
Epoch: 444. Train Loss: 0.1940835416316986. Validation Accuracy: 64.0625
Epoch: 445. Train Loss: 0.21109318733215332. Validation Accuracy:
69.010416666666667
Epoch: 446. Train Loss: 0.20441246032714844. Validation Accuracy:
68.229166666666667
Epoch: 447. Train Loss: 0.2113422155380249. Validation Accuracy: 65.625
Epoch: 448. Train Loss: 0.21417348086833954. Validation Accuracy:
60.416666666666664
Epoch: 449. Train Loss: 0.1962738037109375. Validation Accuracy:
61.458333333333336
Epoch: 450. Train Loss: 0.19146977365016937. Validation Accuracy:
71.614583333333333
Epoch: 451. Train Loss: 0.20299217104911804. Validation Accuracy:
66.927083333333333
Epoch: 452. Train Loss: 0.19948488473892212. Validation Accuracy: 65.625
Epoch: 453. Train Loss: 0.19014307856559753. Validation Accuracy:
70.052083333333333
Epoch: 454. Train Loss: 0.19358669221401215. Validation Accuracy:
63.020833333333336
Epoch: 455. Train Loss: 0.20465466380119324. Validation Accuracy:
69.270833333333333
Epoch: 456. Train Loss: 0.18400755524635315. Validation Accuracy:
67.708333333333333
Epoch: 457. Train Loss: 0.1868857592344284. Validation Accuracy:
67.447916666666667
Epoch: 458. Train Loss: 0.18384945392608643. Validation Accuracy:
63.802083333333336
Epoch: 459. Train Loss: 0.18681934475898743. Validation Accuracy:
67.447916666666667
Epoch: 460. Train Loss: 0.1909460723400116. Validation Accuracy:
67.447916666666667
Epoch: 461. Train Loss: 0.183702751994133. Validation Accuracy:
59.895833333333336
Epoch: 462. Train Loss: 0.20131468772888184. Validation Accuracy:
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Epoch: 463. Train Loss: 0.1892530620098114. Validation Accuracy:
72.395833333333333
Epoch: 464. Train Loss: 0.20407359302043915. Validation Accuracy:
67.447916666666667
Epoch: 465. Train Loss: 0.20988935232162476. Validation Accuracy: 69.53125
Epoch: 466. Train Loss: 0.1980668008327484. Validation Accuracy: 66.40625
Epoch: 467. Train Loss: 0.19954094290733337. Validation Accuracy:
68.489583333333333
Epoch: 468. Train Loss: 0.19779178500175476. Validation Accuracy:
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Epoch: 469. Train Loss: 0.18636304140090942. Validation Accuracy:
66.145833333333333

Epoch: 470. Train Loss: 0.19932371377944946. Validation Accuracy: 70.05208333333333

Epoch: 471. Train Loss: 0.21157929301261902. Validation Accuracy: 65.625

Epoch: 472. Train Loss: 0.21086236834526062. Validation Accuracy: 65.625

Epoch: 473. Train Loss: 0.1919758915901184. Validation Accuracy: 67.1875

Epoch: 474. Train Loss: 0.21012040972709656. Validation Accuracy: 67.96875

Epoch: 475. Train Loss: 0.19633488357067108. Validation Accuracy: 66.92708333333333

Epoch: 476. Train Loss: 0.2024521678686142. Validation Accuracy: 64.84375

Epoch: 477. Train Loss: 0.19595281779766083. Validation Accuracy: 66.14583333333333

Epoch: 478. Train Loss: 0.19663584232330322. Validation Accuracy: 70.3125

Epoch: 479. Train Loss: 0.191226527094841. Validation Accuracy: 67.70833333333333

Epoch: 480. Train Loss: 0.20112481713294983. Validation Accuracy: 69.01041666666667

Epoch: 481. Train Loss: 0.19047527015209198. Validation Accuracy: 68.48958333333333

Epoch: 482. Train Loss: 0.20655477046966553. Validation Accuracy: 66.92708333333333

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Epoch: 484. Train Loss: 0.19925051927566528. Validation Accuracy: 62.760416666666664

Epoch: 485. Train Loss: 0.19329217076301575. Validation Accuracy: 65.88541666666667

Epoch: 486. Train Loss: 0.19685930013656616. Validation Accuracy: 62.239583333333336

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Epoch: 490. Train Loss: 0.20416918396949768. Validation Accuracy: 61.71875

Epoch: 491. Train Loss: 0.21090564131736755. Validation Accuracy: 65.36458333333333

Epoch: 492. Train Loss: 0.2035115659236908. Validation Accuracy: 64.58333333333333

Epoch: 493. Train Loss: 0.19895371794700623. Validation Accuracy: 67.96875

Epoch: 494. Train Loss: 0.19476675987243652. Validation Accuracy: 66.66666666666667

Epoch: 495. Train Loss: 0.1935766637325287. Validation Accuracy: 67.70833333333333

Epoch: 496. Train Loss: 0.19698020815849304. Validation Accuracy: 65.10416666666667

Epoch: 497. Train Loss: 0.20544730126857758. Validation Accuracy: 66.92708333333333

Epoch: 498. Train Loss: 0.1842689961194992. Validation Accuracy: 69.53125
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Epoch: 530. Train Loss: 0.21166491508483887. Validation Accuracy: 71.09375
Epoch: 531. Train Loss: 0.19284474849700928. Validation Accuracy:
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Epoch: 532. Train Loss: 0.19201116263866425. Validation Accuracy: 70.3125
Epoch: 533. Train Loss: 0.19420763850212097. Validation Accuracy:
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Epoch: 536. Train Loss: 0.18747878074645996. Validation Accuracy:
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Epoch: 539. Train Loss: 0.1920337677001953. Validation Accuracy: 65.625
Epoch: 540. Train Loss: 0.20368525385856628. Validation Accuracy:
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Epoch: 544. Train Loss: 0.18638107180595398. Validation Accuracy:
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Epoch: 551. Train Loss: 0.18587321043014526. Validation Accuracy:
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Epoch: 556. Train Loss: 0.19455133378505707. Validation Accuracy:
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Epoch: 568. Train Loss: 0.1919572353363037. Validation Accuracy:
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61.197916666666664
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Epoch: 572. Train Loss: 0.18818721175193787. Validation Accuracy:
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69.79166666666667
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61.979166666666664
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63.020833333333336
Epoch: 579. Train Loss: 0.20847421884536743. Validation Accuracy:
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67.70833333333333
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Epoch: 591. Train Loss: 0.19816742837429047. Validation Accuracy: 65.625
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Epoch: 608. Train Loss: 0.1999942660331726. Validation Accuracy: 69.27083333333333
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Epoch: 616. Train Loss: 0.1869196891784668. Validation Accuracy: 61.197916666666664

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Epoch: 632. Train Loss: 0.20459479093551636. Validation Accuracy: 69.01041666666667

Epoch: 633. Train Loss: 0.19829456508159637. Validation Accuracy: 68.75

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Epoch: 635. Train Loss: 0.1910591572523117. Validation Accuracy: 73.69791666666667

Epoch: 636. Train Loss: 0.20324943959712982. Validation Accuracy: 63.020833333333336

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 Epoch: 696. Train Loss: 0.18590711057186127. Validation Accuracy:
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 Epoch: 698. Train Loss: 0.17389535903930664. Validation Accuracy:
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Epoch: 699. Train Loss: 0.19785401225090027. Validation Accuracy: 69.01041666666667
Epoch: 700. Train Loss: 0.19901302456855774. Validation Accuracy: 69.27083333333333
Epoch: 701. Train Loss: 0.1835850179195404. Validation Accuracy: 67.44791666666667
Epoch: 702. Train Loss: 0.19425126910209656. Validation Accuracy: 71.61458333333333
Epoch: 703. Train Loss: 0.19124886393547058. Validation Accuracy: 64.32291666666667
Epoch: 704. Train Loss: 0.21594958007335663. Validation Accuracy: 68.22916666666667
Epoch: 705. Train Loss: 0.1995161771774292. Validation Accuracy: 69.79166666666667
Epoch: 706. Train Loss: 0.205422043800354. Validation Accuracy: 68.22916666666667
Epoch: 707. Train Loss: 0.20003923773765564. Validation Accuracy: 69.27083333333333
Epoch: 708. Train Loss: 0.200691819190979. Validation Accuracy: 68.22916666666667
Epoch: 709. Train Loss: 0.18940973281860352. Validation Accuracy: 64.32291666666667
Epoch: 710. Train Loss: 0.21088062226772308. Validation Accuracy: 66.66666666666667
Epoch: 711. Train Loss: 0.19738751649856567. Validation Accuracy: 65.36458333333333
Epoch: 712. Train Loss: 0.18860255181789398. Validation Accuracy: 71.61458333333333
Epoch: 713. Train Loss: 0.1994626522064209. Validation Accuracy: 64.84375
Epoch: 714. Train Loss: 0.19723747670650482. Validation Accuracy: 67.44791666666667
Epoch: 715. Train Loss: 0.19318896532058716. Validation Accuracy: 72.13541666666667
Epoch: 716. Train Loss: 0.20601408183574677. Validation Accuracy: 63.02083333333333
Epoch: 717. Train Loss: 0.1854419708251953. Validation Accuracy: 70.05208333333333
Epoch: 718. Train Loss: 0.19994917511940002. Validation Accuracy: 62.76041666666664
Epoch: 719. Train Loss: 0.21004848182201385. Validation Accuracy: 67.96875
Epoch: 720. Train Loss: 0.20869684219360352. Validation Accuracy: 61.71875
Epoch: 721. Train Loss: 0.20152918994426727. Validation Accuracy: 62.5
Epoch: 722. Train Loss: 0.1922653615474701. Validation Accuracy: 67.44791666666667
Epoch: 723. Train Loss: 0.18869929015636444. Validation Accuracy: 61.97916666666664
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Epoch: 725. Train Loss: 0.2070339024066925. Validation Accuracy:

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Epoch: 727. Train Loss: 0.18877121806144714. Validation Accuracy:
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Epoch: 732. Train Loss: 0.20589356124401093. Validation Accuracy: 61.71875
Epoch: 733. Train Loss: 0.1945655792951584. Validation Accuracy:
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Epoch: 758. Train Loss: 0.1838853657245636. Validation Accuracy:
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Epoch: 764. Train Loss: 0.20538519322872162. Validation Accuracy:
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Epoch: 779. Train Loss: 0.19420365989208221. Validation Accuracy:
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67.70833333333333

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Epoch: 966. Train Loss: 0.20258426666259766. Validation Accuracy:

69.01041666666667
Epoch: 967. Train Loss: 0.19862744212150574. Validation Accuracy: 63.802083333333336
Epoch: 968. Train Loss: 0.20917360484600067. Validation Accuracy: 70.3125
Epoch: 969. Train Loss: 0.18859168887138367. Validation Accuracy: 63.802083333333336
Epoch: 970. Train Loss: 0.20071479678153992. Validation Accuracy: 59.895833333333336
Epoch: 971. Train Loss: 0.1947612762451172. Validation Accuracy: 59.895833333333336
Epoch: 972. Train Loss: 0.206579327583313. Validation Accuracy: 68.22916666666667
Epoch: 973. Train Loss: 0.1919877976179123. Validation Accuracy: 62.5
Epoch: 974. Train Loss: 0.18370714783668518. Validation Accuracy: 66.92708333333333
Epoch: 975. Train Loss: 0.19532084465026855. Validation Accuracy: 66.66666666666667
Epoch: 976. Train Loss: 0.19815301895141602. Validation Accuracy: 67.44791666666667
Epoch: 977. Train Loss: 0.19745783507823944. Validation Accuracy: 66.14583333333333
Epoch: 978. Train Loss: 0.19455674290657043. Validation Accuracy: 65.625
Epoch: 979. Train Loss: 0.192285418510437. Validation Accuracy: 65.625
Epoch: 980. Train Loss: 0.20516471564769745. Validation Accuracy: 60.677083333333336
Epoch: 981. Train Loss: 0.19214104115962982. Validation Accuracy: 61.71875
Epoch: 982. Train Loss: 0.20455297827720642. Validation Accuracy: 68.48958333333333
Epoch: 983. Train Loss: 0.20763687789440155. Validation Accuracy: 68.75
Epoch: 984. Train Loss: 0.19665467739105225. Validation Accuracy: 65.10416666666667
Epoch: 985. Train Loss: 0.18904797732830048. Validation Accuracy: 66.66666666666667
Epoch: 986. Train Loss: 0.20499777793884277. Validation Accuracy: 63.802083333333336
Epoch: 987. Train Loss: 0.2037287801504135. Validation Accuracy: 70.57291666666667
Epoch: 988. Train Loss: 0.19156257808208466. Validation Accuracy: 65.88541666666667
Epoch: 989. Train Loss: 0.18836236000061035. Validation Accuracy: 64.32291666666667
Epoch: 990. Train Loss: 0.18384751677513123. Validation Accuracy: 65.36458333333333
Epoch: 991. Train Loss: 0.18766002357006073. Validation Accuracy: 67.96875
Epoch: 992. Train Loss: 0.18275634944438934. Validation Accuracy: 67.44791666666667
Epoch: 993. Train Loss: 0.20738282799720764. Validation Accuracy: 67.1875
Epoch: 994. Train Loss: 0.20413903892040253. Validation Accuracy:

63.020833333333336

Epoch: 995. Train Loss: 0.19290141761302948. Validation Accuracy: 61.71875

Epoch: 996. Train Loss: 0.2037944793701172. Validation Accuracy: 62.5

Epoch: 997. Train Loss: 0.2125202864408493. Validation Accuracy:

56.770833333333336

Epoch: 998. Train Loss: 0.2034497857093811. Validation Accuracy:

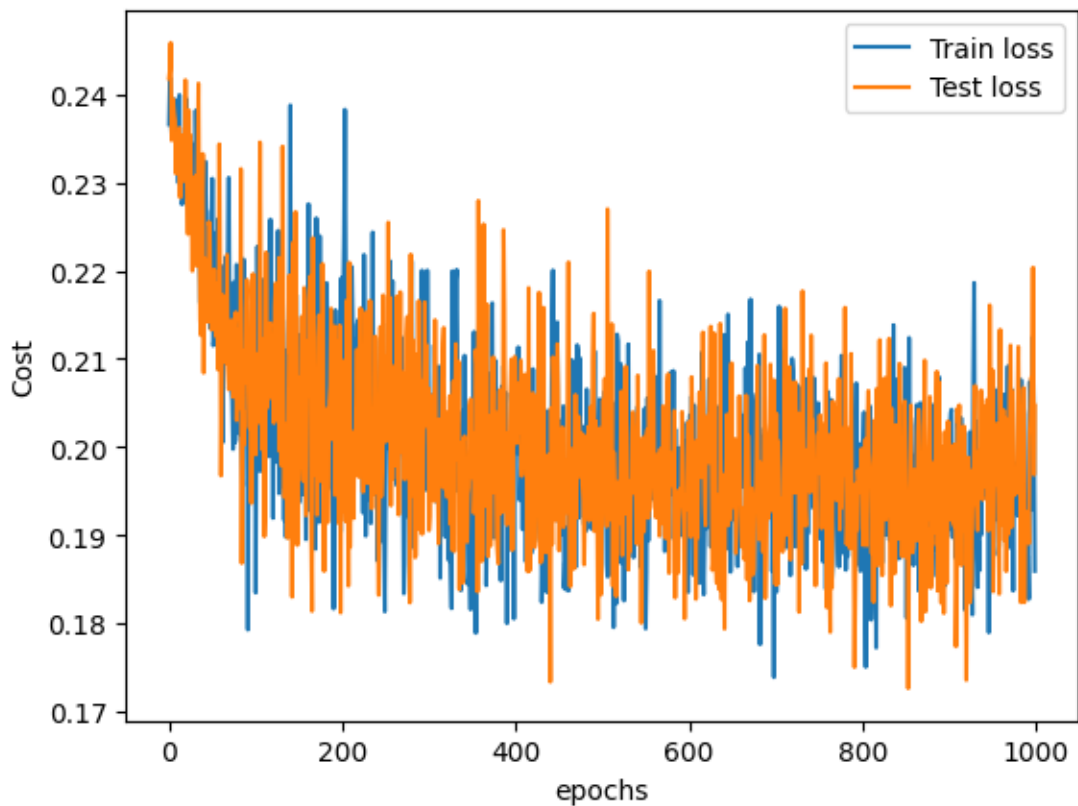
63.802083333333336

Epoch: 999. Train Loss: 0.18594537675380707. Validation Accuracy:

63.541666666666664

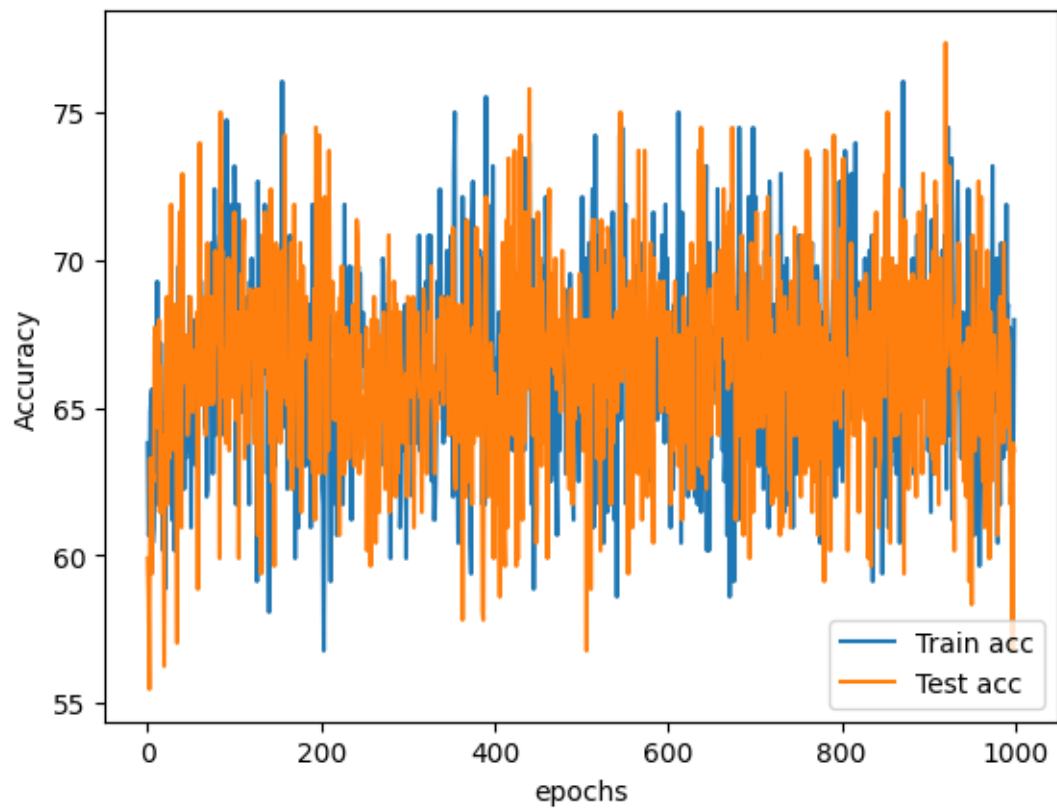
Train and test plots

```
[34]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



Train loss value after 1000 epochs: 0.18594537675380707

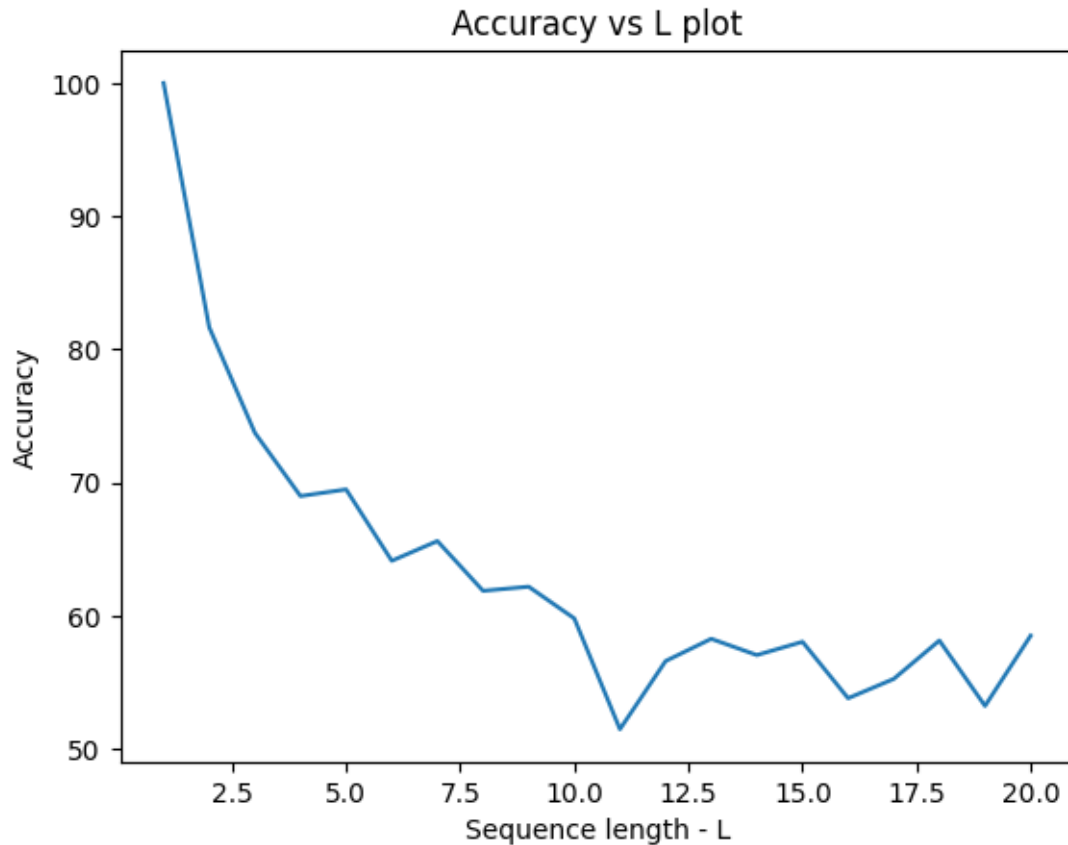
Vaildation loss value after 1000 epochs: 0.20471921563148499



Best Test Accuracy: 77.34375%

Bitwise Accuracy vs Length

```
[35]: plot_accuracy_vs_length(model)
```



9.10.3 Length of Input Sequence = 10

[48]: `L = 10`

[49]: `model = BinaryAdder(INPUT_DIM, HIDDEN_DIM, OUTPUT_DIM, NUM_LAYERS).to(device)`
`criterion = nn.MSELoss()`
`optimizer = optim.Adam(model.parameters(), lr=LR)`

Training

[50]: `train_costs, train_acc, val_costs, val_acc = train_model(model, criterion, ↵`
`↵optimizer, K, L)`

Epoch: 0. Train Loss: 0.25105199217796326. Validation Accuracy:
 47.58522727272727

Epoch: 1. Train Loss: 0.2511880099773407. Validation Accuracy: 48.29545454545455

Epoch: 2. Train Loss: 0.25234901905059814. Validation Accuracy:
 49.14772727272727

Epoch: 3. Train Loss: 0.25248318910598755. Validation Accuracy:
 50.99431818181818

Epoch: 4. Train Loss: 0.252188116312027. Validation Accuracy: 49.85795454545455
Epoch: 5. Train Loss: 0.25078320503234863. Validation Accuracy:
50.56818181818182
Epoch: 6. Train Loss: 0.2493717521429062. Validation Accuracy: 49.28977272727273
Epoch: 7. Train Loss: 0.25042134523391724. Validation Accuracy:
50.85227272727273
Epoch: 8. Train Loss: 0.25227808952331543. Validation Accuracy:
50.85227272727273
Epoch: 9. Train Loss: 0.25061336159706116. Validation Accuracy: 51.5625
Epoch: 10. Train Loss: 0.25310730934143066. Validation Accuracy:
51.70454545454545
Epoch: 11. Train Loss: 0.2512250542640686. Validation Accuracy:
47.72727272727273
Epoch: 12. Train Loss: 0.25167298316955566. Validation Accuracy:
50.85227272727273
Epoch: 13. Train Loss: 0.25059637427330017. Validation Accuracy:
48.15340909090909
Epoch: 14. Train Loss: 0.25061923265457153. Validation Accuracy:
49.00568181818182
Epoch: 15. Train Loss: 0.2503019869327545. Validation Accuracy:
48.01136363636363
Epoch: 16. Train Loss: 0.25204893946647644. Validation Accuracy: 50.0
Epoch: 17. Train Loss: 0.2499876469373703. Validation Accuracy:
52.27272727272727
Epoch: 18. Train Loss: 0.2510847747325897. Validation Accuracy:
48.72159090909091
Epoch: 19. Train Loss: 0.249881774187088. Validation Accuracy: 52.69886363636363
Epoch: 20. Train Loss: 0.2503891587257385. Validation Accuracy:
48.57954545454545
Epoch: 21. Train Loss: 0.25040891766548157. Validation Accuracy:
48.15340909090909
Epoch: 22. Train Loss: 0.25077998638153076. Validation Accuracy:
49.28977272727273
Epoch: 23. Train Loss: 0.2502952516078949. Validation Accuracy:
50.99431818181818
Epoch: 24. Train Loss: 0.2498522251844406. Validation Accuracy:
51.70454545454545
Epoch: 25. Train Loss: 0.25041165947914124. Validation Accuracy:
48.86363636363637
Epoch: 26. Train Loss: 0.25048986077308655. Validation Accuracy: 50.0
Epoch: 27. Train Loss: 0.2505837678909302. Validation Accuracy:
49.57386363636363
Epoch: 28. Train Loss: 0.2507510781288147. Validation Accuracy:
49.14772727272727
Epoch: 29. Train Loss: 0.24996361136436462. Validation Accuracy:
50.56818181818182
Epoch: 30. Train Loss: 0.25037798285484314. Validation Accuracy:
48.72159090909091

Epoch: 31. Train Loss: 0.2501372992992401. Validation Accuracy: 48.86363636363637

Epoch: 32. Train Loss: 0.25021064281463623. Validation Accuracy: 49.71590909090909

Epoch: 33. Train Loss: 0.24977295100688934. Validation Accuracy: 50.0

Epoch: 34. Train Loss: 0.25013503432273865. Validation Accuracy: 48.57954545454545

Epoch: 35. Train Loss: 0.2505275309085846. Validation Accuracy: 50.28409090909091

Epoch: 36. Train Loss: 0.2501909136772156. Validation Accuracy: 47.58522727272727

Epoch: 37. Train Loss: 0.2499866485595703. Validation Accuracy: 49.57386363636363

Epoch: 38. Train Loss: 0.24954983592033386. Validation Accuracy: 50.0

Epoch: 39. Train Loss: 0.2502005696296692. Validation Accuracy: 52.69886363636363

Epoch: 40. Train Loss: 0.24966062605381012. Validation Accuracy: 51.70454545454545

Epoch: 41. Train Loss: 0.25042322278022766. Validation Accuracy: 52.84090909090909

Epoch: 42. Train Loss: 0.2504165768623352. Validation Accuracy: 51.70454545454545

Epoch: 43. Train Loss: 0.25019776821136475. Validation Accuracy: 48.29545454545455

Epoch: 44. Train Loss: 0.25085169076919556. Validation Accuracy: 50.56818181818182

Epoch: 45. Train Loss: 0.24954602122306824. Validation Accuracy: 51.42045454545455

Epoch: 46. Train Loss: 0.24986957013607025. Validation Accuracy: 50.42613636363637

Epoch: 47. Train Loss: 0.25024768710136414. Validation Accuracy: 46.875

Epoch: 48. Train Loss: 0.24996376037597656. Validation Accuracy: 48.72159090909091

Epoch: 49. Train Loss: 0.24985596537590027. Validation Accuracy: 48.15340909090909

Epoch: 50. Train Loss: 0.24981707334518433. Validation Accuracy: 51.5625

Epoch: 51. Train Loss: 0.24975807964801788. Validation Accuracy: 49.43181818181818

Epoch: 52. Train Loss: 0.2505432367324829. Validation Accuracy: 50.85227272727273

Epoch: 53. Train Loss: 0.2504380941390991. Validation Accuracy: 51.13636363636363

Epoch: 54. Train Loss: 0.2500186562538147. Validation Accuracy: 52.13068181818182

Epoch: 55. Train Loss: 0.2506580352783203. Validation Accuracy: 48.15340909090909

Epoch: 56. Train Loss: 0.2501249313354492. Validation Accuracy: 48.29545454545455

Epoch: 57. Train Loss: 0.25090837478637695. Validation Accuracy: 51.98863636363637
Epoch: 58. Train Loss: 0.250034898519516. Validation Accuracy: 51.5625
Epoch: 59. Train Loss: 0.24989423155784607. Validation Accuracy: 50.14204545454545
Epoch: 60. Train Loss: 0.24937818944454193. Validation Accuracy: 52.41477272727273
Epoch: 61. Train Loss: 0.24954970180988312. Validation Accuracy: 53.69318181818182
Epoch: 62. Train Loss: 0.25107041001319885. Validation Accuracy: 50.14204545454545
Epoch: 63. Train Loss: 0.24984782934188843. Validation Accuracy: 53.125
Epoch: 64. Train Loss: 0.24955299496650696. Validation Accuracy: 47.86931818181818
Epoch: 65. Train Loss: 0.2501087188720703. Validation Accuracy: 49.43181818181818
Epoch: 66. Train Loss: 0.24983975291252136. Validation Accuracy: 49.71590909090909
Epoch: 67. Train Loss: 0.25022175908088684. Validation Accuracy: 49.14772727272727
Epoch: 68. Train Loss: 0.24990099668502808. Validation Accuracy: 49.28977272727273
Epoch: 69. Train Loss: 0.2500048279762268. Validation Accuracy: 48.01136363636363
Epoch: 70. Train Loss: 0.24956630170345306. Validation Accuracy: 50.42613636363637
Epoch: 71. Train Loss: 0.24976709485054016. Validation Accuracy: 50.28409090909091
Epoch: 72. Train Loss: 0.2500678598880768. Validation Accuracy: 51.27840909090909
Epoch: 73. Train Loss: 0.2502891719341278. Validation Accuracy: 51.13636363636363
Epoch: 74. Train Loss: 0.24988214671611786. Validation Accuracy: 49.14772727272727
Epoch: 75. Train Loss: 0.25057485699653625. Validation Accuracy: 50.99431818181818
Epoch: 76. Train Loss: 0.2500675618648529. Validation Accuracy: 45.59659090909091
Epoch: 77. Train Loss: 0.25023153424263. Validation Accuracy: 51.13636363636363
Epoch: 78. Train Loss: 0.24963930249214172. Validation Accuracy: 52.55681818181818
Epoch: 79. Train Loss: 0.25067630410194397. Validation Accuracy: 50.42613636363637
Epoch: 80. Train Loss: 0.25033825635910034. Validation Accuracy: 50.42613636363637
Epoch: 81. Train Loss: 0.24970325827598572. Validation Accuracy: 50.28409090909091
Epoch: 82. Train Loss: 0.2502087950706482. Validation Accuracy:

49.85795454545455
Epoch: 83. Train Loss: 0.25122079253196716. Validation Accuracy:
49.57386363636363
Epoch: 84. Train Loss: 0.2494087666273117. Validation Accuracy:
51.13636363636363
Epoch: 85. Train Loss: 0.24980923533439636. Validation Accuracy: 50.0
Epoch: 86. Train Loss: 0.2503003478050232. Validation Accuracy:
50.99431818181818
Epoch: 87. Train Loss: 0.25082507729530334. Validation Accuracy:
51.84659090909091
Epoch: 88. Train Loss: 0.25007638335227966. Validation Accuracy:
48.72159090909091
Epoch: 89. Train Loss: 0.25005602836608887. Validation Accuracy:
53.40909090909091
Epoch: 90. Train Loss: 0.2499609738588333. Validation Accuracy:
49.28977272727273
Epoch: 91. Train Loss: 0.25032731890678406. Validation Accuracy:
49.71590909090909
Epoch: 92. Train Loss: 0.2500030994415283. Validation Accuracy:
47.15909090909091
Epoch: 93. Train Loss: 0.2501305639743805. Validation Accuracy:
51.13636363636363
Epoch: 94. Train Loss: 0.250460684299469. Validation Accuracy: 48.4375
Epoch: 95. Train Loss: 0.25050854682922363. Validation Accuracy:
52.69886363636363
Epoch: 96. Train Loss: 0.2502106726169586. Validation Accuracy:
49.43181818181818
Epoch: 97. Train Loss: 0.25023651123046875. Validation Accuracy: 48.4375
Epoch: 98. Train Loss: 0.2503310739994049. Validation Accuracy:
50.14204545454545
Epoch: 99. Train Loss: 0.25033822655677795. Validation Accuracy:
49.14772727272727
Epoch: 100. Train Loss: 0.2500845789909363. Validation Accuracy:
48.15340909090909
Epoch: 101. Train Loss: 0.25016552209854126. Validation Accuracy:
51.84659090909091
Epoch: 102. Train Loss: 0.2502051889896393. Validation Accuracy:
48.15340909090909
Epoch: 103. Train Loss: 0.25006914138793945. Validation Accuracy: 46.875
Epoch: 104. Train Loss: 0.25008416175842285. Validation Accuracy:
48.57954545454545
Epoch: 105. Train Loss: 0.24997954070568085. Validation Accuracy:
47.01704545454545
Epoch: 106. Train Loss: 0.24997104704380035. Validation Accuracy:
50.85227272727273
Epoch: 107. Train Loss: 0.2500540316104889. Validation Accuracy:
50.14204545454545
Epoch: 108. Train Loss: 0.24999083578586578. Validation Accuracy:

50.99431818181818

Epoch: 109. Train Loss: 0.25037169456481934. Validation Accuracy: 49.85795454545455

Epoch: 110. Train Loss: 0.24998582899570465. Validation Accuracy: 49.28977272727273

Epoch: 111. Train Loss: 0.2500191330909729. Validation Accuracy: 49.00568181818182

Epoch: 112. Train Loss: 0.2497752457857132. Validation Accuracy: 51.98863636363637

Epoch: 113. Train Loss: 0.2503126561641693. Validation Accuracy: 49.85795454545455

Epoch: 114. Train Loss: 0.2501813471317291. Validation Accuracy: 47.72727272727273

Epoch: 115. Train Loss: 0.25002336502075195. Validation Accuracy: 48.72159090909091

Epoch: 116. Train Loss: 0.2500190734863281. Validation Accuracy: 50.14204545454545

Epoch: 117. Train Loss: 0.24980537593364716. Validation Accuracy: 46.44886363636363

Epoch: 118. Train Loss: 0.25053301453590393. Validation Accuracy: 51.84659090909091

Epoch: 119. Train Loss: 0.2502053380012512. Validation Accuracy: 50.56818181818182

Epoch: 120. Train Loss: 0.2498607337474823. Validation Accuracy: 47.30113636363637

Epoch: 121. Train Loss: 0.25015494227409363. Validation Accuracy: 47.58522727272727

Epoch: 122. Train Loss: 0.24957731366157532. Validation Accuracy: 48.86363636363637

Epoch: 123. Train Loss: 0.24992473423480988. Validation Accuracy: 49.14772727272727

Epoch: 124. Train Loss: 0.24966353178024292. Validation Accuracy: 51.13636363636363

Epoch: 125. Train Loss: 0.2501407861709595. Validation Accuracy: 50.14204545454545

Epoch: 126. Train Loss: 0.25012174248695374. Validation Accuracy: 49.28977272727273

Epoch: 127. Train Loss: 0.24945902824401855. Validation Accuracy: 50.85227272727273

Epoch: 128. Train Loss: 0.24991945922374725. Validation Accuracy: 48.01136363636363

Epoch: 129. Train Loss: 0.24991334974765778. Validation Accuracy: 53.125

Epoch: 130. Train Loss: 0.2504446506500244. Validation Accuracy: 51.98863636363637

Epoch: 131. Train Loss: 0.25018563866615295. Validation Accuracy: 51.42045454545455

Epoch: 132. Train Loss: 0.2499515414237976. Validation Accuracy: 52.27272727272727

Epoch: 133. Train Loss: 0.25018206238746643. Validation Accuracy: 50.85227272727273
Epoch: 134. Train Loss: 0.2500554621219635. Validation Accuracy: 50.28409090909091
Epoch: 135. Train Loss: 0.24982360005378723. Validation Accuracy: 47.44318181818182
Epoch: 136. Train Loss: 0.2498820573091507. Validation Accuracy: 48.4375
Epoch: 137. Train Loss: 0.2501397430896759. Validation Accuracy: 49.28977272727273
Epoch: 138. Train Loss: 0.24988767504692078. Validation Accuracy: 53.83522727272727
Epoch: 139. Train Loss: 0.24973304569721222. Validation Accuracy: 51.27840909090909
Epoch: 140. Train Loss: 0.2500001788139343. Validation Accuracy: 49.28977272727273
Epoch: 141. Train Loss: 0.2502205967903137. Validation Accuracy: 51.98863636363637
Epoch: 142. Train Loss: 0.2500882148742676. Validation Accuracy: 48.15340909090909
Epoch: 143. Train Loss: 0.2501664161682129. Validation Accuracy: 49.28977272727273
Epoch: 144. Train Loss: 0.2500154972076416. Validation Accuracy: 50.71022727272727
Epoch: 145. Train Loss: 0.25014635920524597. Validation Accuracy: 48.86363636363637
Epoch: 146. Train Loss: 0.25050798058509827. Validation Accuracy: 49.14772727272727
Epoch: 147. Train Loss: 0.2500641942024231. Validation Accuracy: 47.86931818181818
Epoch: 148. Train Loss: 0.24984006583690643. Validation Accuracy: 49.28977272727273
Epoch: 149. Train Loss: 0.2498159259557724. Validation Accuracy: 48.86363636363637
Epoch: 150. Train Loss: 0.2503850758075714. Validation Accuracy: 49.85795454545455
Epoch: 151. Train Loss: 0.24994854629039764. Validation Accuracy: 49.43181818181818
Epoch: 152. Train Loss: 0.25002485513687134. Validation Accuracy: 49.71590909090909
Epoch: 153. Train Loss: 0.25017544627189636. Validation Accuracy: 50.0
Epoch: 154. Train Loss: 0.25005829334259033. Validation Accuracy: 48.57954545454545
Epoch: 155. Train Loss: 0.2503211498260498. Validation Accuracy: 49.57386363636363
Epoch: 156. Train Loss: 0.25015896558761597. Validation Accuracy: 47.72727272727273
Epoch: 157. Train Loss: 0.25014814734458923. Validation Accuracy: 50.28409090909091

Epoch: 158. Train Loss: 0.24986056983470917. Validation Accuracy: 51.5625
Epoch: 159. Train Loss: 0.24997083842754364. Validation Accuracy:
50.42613636363637
Epoch: 160. Train Loss: 0.25016871094703674. Validation Accuracy:
50.14204545454545
Epoch: 161. Train Loss: 0.24996055662631989. Validation Accuracy:
49.14772727272727
Epoch: 162. Train Loss: 0.2499820590019226. Validation Accuracy:
51.13636363636363
Epoch: 163. Train Loss: 0.2497801035642624. Validation Accuracy:
49.57386363636363
Epoch: 164. Train Loss: 0.2500188946723938. Validation Accuracy: 48.4375
Epoch: 165. Train Loss: 0.2500282824039459. Validation Accuracy:
50.85227272727273
Epoch: 166. Train Loss: 0.2500016689300537. Validation Accuracy:
51.42045454545455
Epoch: 167. Train Loss: 0.2501095235347748. Validation Accuracy:
49.14772727272727
Epoch: 168. Train Loss: 0.25005367398262024. Validation Accuracy: 50.0
Epoch: 169. Train Loss: 0.2501641809940338. Validation Accuracy:
50.71022727272727
Epoch: 170. Train Loss: 0.2500702440738678. Validation Accuracy:
45.73863636363637
Epoch: 171. Train Loss: 0.2501501142978668. Validation Accuracy:
47.72727272727273
Epoch: 172. Train Loss: 0.24997679889202118. Validation Accuracy:
52.55681818181818
Epoch: 173. Train Loss: 0.25028955936431885. Validation Accuracy:
51.84659090909091
Epoch: 174. Train Loss: 0.2502833306789398. Validation Accuracy:
48.15340909090909
Epoch: 175. Train Loss: 0.24994434416294098. Validation Accuracy:
47.30113636363637
Epoch: 176. Train Loss: 0.2503707706928253. Validation Accuracy:
46.73295454545455
Epoch: 177. Train Loss: 0.250143826007843. Validation Accuracy:
50.28409090909091
Epoch: 178. Train Loss: 0.2496880441904068. Validation Accuracy:
47.15909090909091
Epoch: 179. Train Loss: 0.25020286440849304. Validation Accuracy:
52.27272727272727
Epoch: 180. Train Loss: 0.2501567602157593. Validation Accuracy:
52.27272727272727
Epoch: 181. Train Loss: 0.25023117661476135. Validation Accuracy:
49.85795454545455
Epoch: 182. Train Loss: 0.2501080334186554. Validation Accuracy:
51.13636363636363
Epoch: 183. Train Loss: 0.2501992881298065. Validation Accuracy:

49.00568181818182
Epoch: 184. Train Loss: 0.2497628629207611. Validation Accuracy: 52.98295454545455
Epoch: 185. Train Loss: 0.24997486174106598. Validation Accuracy: 52.13068181818182
Epoch: 186. Train Loss: 0.2497909516096115. Validation Accuracy: 49.57386363636363
Epoch: 187. Train Loss: 0.2502158582210541. Validation Accuracy: 48.72159090909091
Epoch: 188. Train Loss: 0.24993938207626343. Validation Accuracy: 49.00568181818182
Epoch: 189. Train Loss: 0.24988014996051788. Validation Accuracy: 52.13068181818182
Epoch: 190. Train Loss: 0.2500547468662262. Validation Accuracy: 49.57386363636363
Epoch: 191. Train Loss: 0.24957606196403503. Validation Accuracy: 48.29545454545455
Epoch: 192. Train Loss: 0.2500974237918854. Validation Accuracy: 48.57954545454545
Epoch: 193. Train Loss: 0.25011393427848816. Validation Accuracy: 50.71022727272727
Epoch: 194. Train Loss: 0.2503921687602997. Validation Accuracy: 49.14772727272727
Epoch: 195. Train Loss: 0.2499544471502304. Validation Accuracy: 47.86931818181818
Epoch: 196. Train Loss: 0.24982599914073944. Validation Accuracy: 50.71022727272727
Epoch: 197. Train Loss: 0.25004151463508606. Validation Accuracy: 49.71590909090909
Epoch: 198. Train Loss: 0.25023695826530457. Validation Accuracy: 48.57954545454545
Epoch: 199. Train Loss: 0.24985453486442566. Validation Accuracy: 48.01136363636363
Epoch: 200. Train Loss: 0.24986442923545837. Validation Accuracy: 47.30113636363637
Epoch: 201. Train Loss: 0.25035521388053894. Validation Accuracy: 50.0
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Epoch: 205. Train Loss: 0.24980291724205017. Validation Accuracy: 52.69886363636363
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Epoch: 207. Train Loss: 0.2501632869243622. Validation Accuracy: 50.99431818181818
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Epoch: 452. Train Loss: 0.24961160123348236. Validation Accuracy: 47.86931818181818
Epoch: 453. Train Loss: 0.24958819150924683. Validation Accuracy: 49.28977272727273
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Epoch: 456. Train Loss: 0.24975736439228058. Validation Accuracy: 50.85227272727273
Epoch: 457. Train Loss: 0.24987363815307617. Validation Accuracy: 53.69318181818182
Epoch: 458. Train Loss: 0.24981121718883514. Validation Accuracy: 49.43181818181818
Epoch: 459. Train Loss: 0.2498466968536377. Validation Accuracy: 48.4375
Epoch: 460. Train Loss: 0.24972784519195557. Validation Accuracy: 50.71022727272727
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51.27840909090909

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Epoch: 468. Train Loss: 0.25021326541900635. Validation Accuracy: 49.00568181818182

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Epoch: 470. Train Loss: 0.2511928379535675. Validation Accuracy: 48.29545454545455

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Epoch: 474. Train Loss: 0.24957245588302612. Validation Accuracy: 50.14204545454545

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Epoch: 477. Train Loss: 0.25020623207092285. Validation Accuracy: 49.14772727272727

Epoch: 478. Train Loss: 0.25033438205718994. Validation Accuracy: 51.27840909090909

Epoch: 479. Train Loss: 0.24987578392028809. Validation Accuracy: 50.14204545454545

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Epoch: 481. Train Loss: 0.24990463256835938. Validation Accuracy: 49.00568181818182

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47.86931818181818
Epoch: 941. Train Loss: 0.24995578825473785. Validation Accuracy:
48.72159090909091
Epoch: 942. Train Loss: 0.2499924600124359. Validation Accuracy:
48.01136363636363

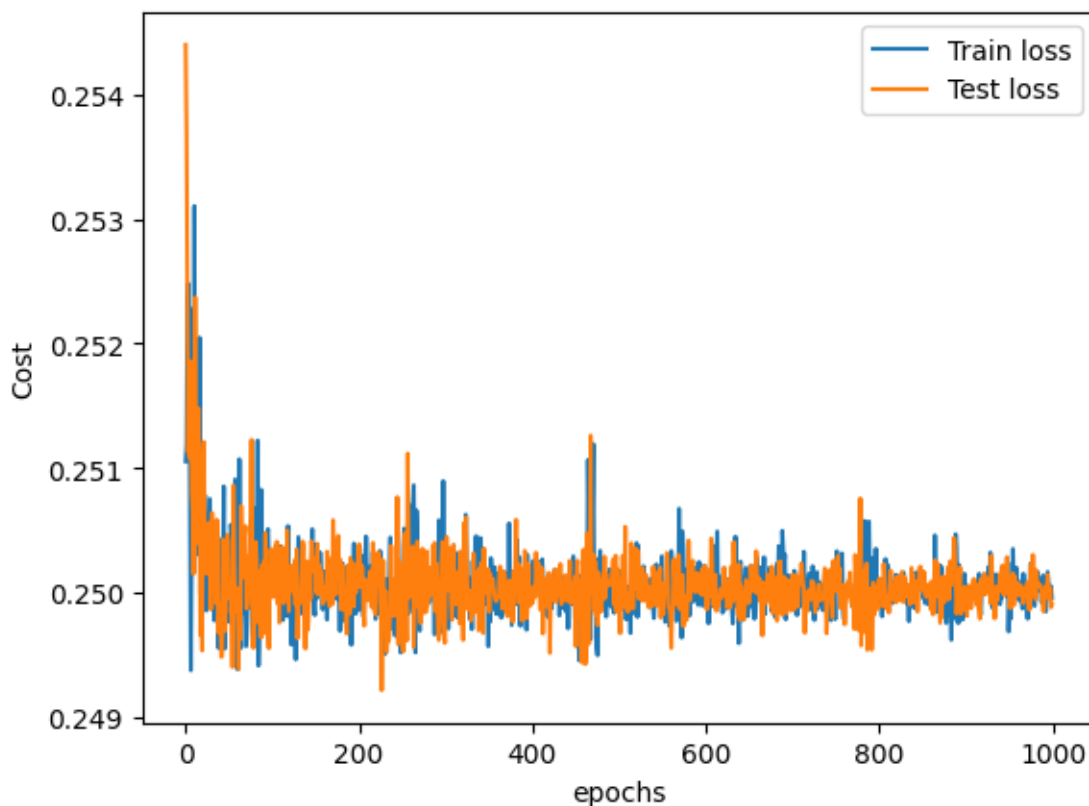
Epoch: 943. Train Loss: 0.24998995661735535. Validation Accuracy: 51.42045454545455
Epoch: 944. Train Loss: 0.2500845789909363. Validation Accuracy: 50.85227272727273
Epoch: 945. Train Loss: 0.2500119209289551. Validation Accuracy: 50.14204545454545
Epoch: 946. Train Loss: 0.25013118982315063. Validation Accuracy: 49.14772727272727
Epoch: 947. Train Loss: 0.24997317790985107. Validation Accuracy: 46.73295454545455
Epoch: 948. Train Loss: 0.25024116039276123. Validation Accuracy: 48.15340909090909
Epoch: 949. Train Loss: 0.24968403577804565. Validation Accuracy: 49.71590909090909
Epoch: 950. Train Loss: 0.24991175532341003. Validation Accuracy: 52.55681818181818
Epoch: 951. Train Loss: 0.24978283047676086. Validation Accuracy: 51.98863636363637
Epoch: 952. Train Loss: 0.25006604194641113. Validation Accuracy: 48.57954545454545
Epoch: 953. Train Loss: 0.24996082484722137. Validation Accuracy: 50.14204545454545
Epoch: 954. Train Loss: 0.2503489553928375. Validation Accuracy: 50.0
Epoch: 955. Train Loss: 0.25004464387893677. Validation Accuracy: 51.13636363636363
Epoch: 956. Train Loss: 0.2500247061252594. Validation Accuracy: 47.86931818181818
Epoch: 957. Train Loss: 0.2500147819519043. Validation Accuracy: 51.13636363636363
Epoch: 958. Train Loss: 0.2501976788043976. Validation Accuracy: 50.0
Epoch: 959. Train Loss: 0.2500778138637543. Validation Accuracy: 49.43181818181818
Epoch: 960. Train Loss: 0.25009167194366455. Validation Accuracy: 51.84659090909091
Epoch: 961. Train Loss: 0.24995431303977966. Validation Accuracy: 50.14204545454545
Epoch: 962. Train Loss: 0.24992969632148743. Validation Accuracy: 48.15340909090909
Epoch: 963. Train Loss: 0.250024676322937. Validation Accuracy: 50.56818181818182
Epoch: 964. Train Loss: 0.25001707673072815. Validation Accuracy: 49.43181818181818
Epoch: 965. Train Loss: 0.24986791610717773. Validation Accuracy: 46.59090909090909
Epoch: 966. Train Loss: 0.2501499056816101. Validation Accuracy: 52.27272727272727
Epoch: 967. Train Loss: 0.2500484883785248. Validation Accuracy: 50.85227272727273

Epoch: 968. Train Loss: 0.2499886453151703. Validation Accuracy: 51.42045454545455
Epoch: 969. Train Loss: 0.2499818056821823. Validation Accuracy: 49.14772727272727
Epoch: 970. Train Loss: 0.24996060132980347. Validation Accuracy: 50.85227272727273
Epoch: 971. Train Loss: 0.24978721141815186. Validation Accuracy: 49.00568181818182
Epoch: 972. Train Loss: 0.24997036159038544. Validation Accuracy: 50.0
Epoch: 973. Train Loss: 0.24990923702716827. Validation Accuracy: 51.84659090909091
Epoch: 974. Train Loss: 0.25022783875465393. Validation Accuracy: 50.28409090909091
Epoch: 975. Train Loss: 0.2501877248287201. Validation Accuracy: 47.72727272727273
Epoch: 976. Train Loss: 0.2499905824661255. Validation Accuracy: 50.42613636363637
Epoch: 977. Train Loss: 0.25000128149986267. Validation Accuracy: 46.44886363636363
Epoch: 978. Train Loss: 0.24991361796855927. Validation Accuracy: 50.42613636363637
Epoch: 979. Train Loss: 0.24988879263401031. Validation Accuracy: 49.85795454545455
Epoch: 980. Train Loss: 0.25011053681373596. Validation Accuracy: 50.14204545454545
Epoch: 981. Train Loss: 0.24999397993087769. Validation Accuracy: 47.72727272727273
Epoch: 982. Train Loss: 0.25016671419143677. Validation Accuracy: 49.85795454545455
Epoch: 983. Train Loss: 0.25002264976501465. Validation Accuracy: 48.86363636363637
Epoch: 984. Train Loss: 0.25002381205558777. Validation Accuracy: 49.00568181818182
Epoch: 985. Train Loss: 0.2500306963920593. Validation Accuracy: 50.14204545454545
Epoch: 986. Train Loss: 0.250081866979599. Validation Accuracy: 49.85795454545455
Epoch: 987. Train Loss: 0.2499193400144577. Validation Accuracy: 50.99431818181818
Epoch: 988. Train Loss: 0.25011229515075684. Validation Accuracy: 51.5625
Epoch: 989. Train Loss: 0.2501366436481476. Validation Accuracy: 53.69318181818182
Epoch: 990. Train Loss: 0.2499692440032959. Validation Accuracy: 51.98863636363637
Epoch: 991. Train Loss: 0.250070184469223. Validation Accuracy: 49.71590909090909
Epoch: 992. Train Loss: 0.24984391033649445. Validation Accuracy: 49.85795454545455

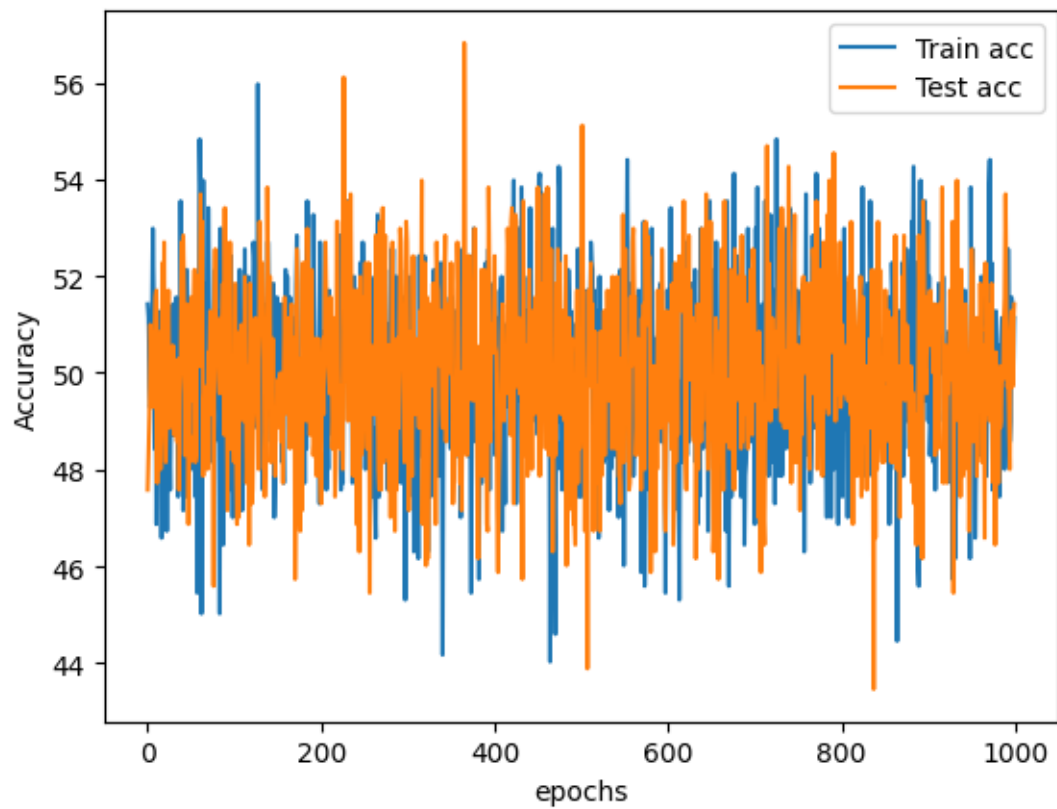
Epoch: 993. Train Loss: 0.24995875358581543. Validation Accuracy:
49.00568181818182
Epoch: 994. Train Loss: 0.25016361474990845. Validation Accuracy:
48.01136363636363
Epoch: 995. Train Loss: 0.2500653862953186. Validation Accuracy:
50.85227272727273
Epoch: 996. Train Loss: 0.25000035762786865. Validation Accuracy:
51.27840909090909
Epoch: 997. Train Loss: 0.25002485513687134. Validation Accuracy:
49.71590909090909
Epoch: 998. Train Loss: 0.25004860758781433. Validation Accuracy:
50.99431818181818
Epoch: 999. Train Loss: 0.24995453655719757. Validation Accuracy:
51.42045454545455

Train and test plots

```
[51]: plot_curves(train_costs, train_acc, val_costs, val_acc)
```



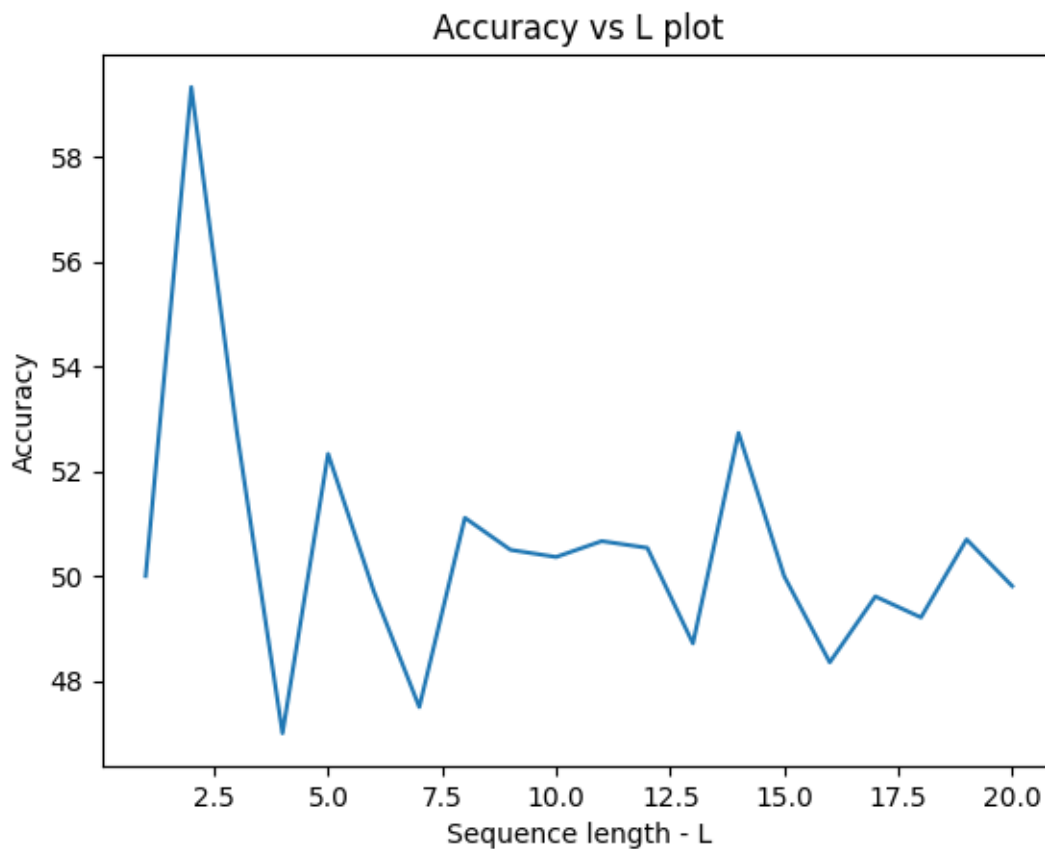
Train loss value after 1000 epochs: 0.24995453655719757
Vaildation loss value after 1000 epochs: 0.24990099668502808



Best Test Accuracy: 56.81818181818182%

Bitwise Accuracy vs Length

```
[52]: plot_accuracy_vs_length(model)
```



9.10.4 Summary

| Train Seq Length | Accuracy (MSE) | Accuracy (Cross Entropy) |
|------------------|----------------|--------------------------|
| 3 | 84.375% | 86.71875% |
| 5 | 77.34375% | 76.56% |
| 10 | 56.8181% | 66.4772% |

- Loss values observed with MSE are lower than those with cross entropy. This is expected because the Cross entropy loss function is known to penalize misclassifications more strictly.
- The performance of the model with the 2 loss functions is similar when trained on small sequences but it drops drastically and almost acts like it is random guessing when it is trained on longer strings.