

MLP_as_tp

February 20, 2025

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[2]: import numpy as np
import matplotlib.pyplot as plt
from tensorflow.keras.datasets import mnist

def init_params(nx, nh, ny):
    np.random.seed(42)
    params = {
        'W1': np.random.normal(0, 0.3, (nh, nx)),
        'b1': np.zeros((nh, 1)),
        'W2': np.random.normal(0, 0.3, (ny, nh)),
        'b2': np.zeros((ny, 1))
    }
    return params

def softmax(Z):
    expZ = np.exp(Z - np.max(Z, axis=0, keepdims=True))
    return expZ / np.sum(expZ, axis=0, keepdims=True)

def forward(params, X):
    Z1 = np.dot(params['W1'], X) + params['b1']
    A1 = np.tanh(Z1)
    Z2 = np.dot(params['W2'], A1) + params['b2']
    A2 = softmax(Z2)
    return A2, {'Z1': Z1, 'A1': A1, 'Z2': Z2, 'A2': A2}

def loss_accuracy(Yhat, Y):
    m = Y.shape[1]
    loss = -np.sum(Y * np.log(Yhat + 1e-8)) / m
    predictions = np.argmax(Yhat, axis=0)
    labels = np.argmax(Y, axis=0)
    accuracy = np.mean(predictions == labels)
    return loss, accuracy

def backward(X, params, outputs, Y):
    m = X.shape[1]
    dZ2 = outputs['A2'] - Y
    dW2 = np.dot(dZ2, outputs['A1'].T) / m
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db2 = np.sum(dZ2, axis=1, keepdims=True) / m
dA1 = np.dot(params['W2'].T, dZ2)
dZ1 = dA1 * (1 - np.tanh(outputs['Z1'])) ** 2)
dW1 = np.dot(dZ1, X.T) / m
db1 = np.sum(dZ1, axis=1, keepdims=True) / m
grads = {'dW1': dW1, 'db1': db1, 'dW2': dW2, 'db2': db2}
return grads

def sgd(params, grads, eta):
    for key in params.keys():
        params[key] -= eta * grads['d' + key]

# Step 6: Training Loop
def train_mlp(X_train, Y_train, X_val, Y_val, nx, nh, ny, epochs, batch_size,
eta):
    params = init_params(nx, nh, ny)
    losses = []
    accuracies = []
    for epoch in range(epochs):
        permutation = np.random.permutation(X_train.shape[1])
        X_train = X_train[:, permutation]
        Y_train = Y_train[:, permutation]

        for i in range(0, X_train.shape[1], batch_size):
            X_batch = X_train[:, i:i + batch_size]
            Y_batch = Y_train[:, i:i + batch_size]
            Yhat, outputs = forward(params, X_batch)
            loss, _ = loss_accuracy(Yhat, Y_batch)
            grads = backward(X_batch, params, outputs, Y_batch)
            sgd(params, grads, eta)

        Yhat_val, _ = forward(params, X_val)
        val_loss, val_accuracy = loss_accuracy(Yhat_val, Y_val)
        losses.append(val_loss)
        accuracies.append(val_accuracy)
        print(f"Epoch {epoch + 1}/{epochs}, Loss: {val_loss:.4f}, Accuracy:
{val_accuracy:.4f}")

    plt.plot(losses, label="Loss")
    plt.plot(accuracies, label="Accuracy")
    plt.xlabel("Epochs")
    plt.ylabel("Value")
    plt.legend()
    plt.show()

# Step 7: Load MNIST data and train the MLP
(X_train, Y_train), (X_test, Y_test) = mnist.load_data()

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X_train = X_train.reshape(X_train.shape[0], -1).T / 255.0
X_test = X_test.reshape(X_test.shape[0], -1).T / 255.0
Y_train = np.eye(10)[Y_train].T
Y_test = np.eye(10)[Y_test].T

train_mlp(X_train, Y_train, X_test, Y_test, nx=784, nh=128, ny=10, epochs=500,
↳batch_size=128, eta=0.1)

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Epoch 1/500, Loss: 0.3877, Accuracy: 0.8855
Epoch 2/500, Loss: 0.3206, Accuracy: 0.9036
Epoch 3/500, Loss: 0.2817, Accuracy: 0.9165
Epoch 4/500, Loss: 0.2587, Accuracy: 0.9248
Epoch 5/500, Loss: 0.2440, Accuracy: 0.9273
Epoch 6/500, Loss: 0.2290, Accuracy: 0.9354
Epoch 7/500, Loss: 0.2179, Accuracy: 0.9374
Epoch 8/500, Loss: 0.2095, Accuracy: 0.9390
Epoch 9/500, Loss: 0.2010, Accuracy: 0.9426
Epoch 10/500, Loss: 0.1939, Accuracy: 0.9440
Epoch 11/500, Loss: 0.1871, Accuracy: 0.9458
Epoch 12/500, Loss: 0.1817, Accuracy: 0.9469
Epoch 13/500, Loss: 0.1767, Accuracy: 0.9499
Epoch 14/500, Loss: 0.1729, Accuracy: 0.9495
Epoch 15/500, Loss: 0.1679, Accuracy: 0.9512
Epoch 16/500, Loss: 0.1651, Accuracy: 0.9517
Epoch 17/500, Loss: 0.1611, Accuracy: 0.9534
Epoch 18/500, Loss: 0.1590, Accuracy: 0.9534
Epoch 19/500, Loss: 0.1560, Accuracy: 0.9546
Epoch 20/500, Loss: 0.1531, Accuracy: 0.9538
Epoch 21/500, Loss: 0.1505, Accuracy: 0.9555
Epoch 22/500, Loss: 0.1488, Accuracy: 0.9562
Epoch 23/500, Loss: 0.1469, Accuracy: 0.9551
Epoch 24/500, Loss: 0.1453, Accuracy: 0.9550
Epoch 25/500, Loss: 0.1432, Accuracy: 0.9574
Epoch 26/500, Loss: 0.1409, Accuracy: 0.9573
Epoch 27/500, Loss: 0.1398, Accuracy: 0.9572
Epoch 28/500, Loss: 0.1377, Accuracy: 0.9574
Epoch 29/500, Loss: 0.1360, Accuracy: 0.9585
Epoch 30/500, Loss: 0.1362, Accuracy: 0.9580
Epoch 31/500, Loss: 0.1340, Accuracy: 0.9586
Epoch 32/500, Loss: 0.1338, Accuracy: 0.9582
Epoch 33/500, Loss: 0.1329, Accuracy: 0.9577
Epoch 34/500, Loss: 0.1313, Accuracy: 0.9595
Epoch 35/500, Loss: 0.1313, Accuracy: 0.9597
Epoch 36/500, Loss: 0.1298, Accuracy: 0.9591
Epoch 37/500, Loss: 0.1290, Accuracy: 0.9595
Epoch 38/500, Loss: 0.1278, Accuracy: 0.9607
Epoch 39/500, Loss: 0.1273, Accuracy: 0.9605
Epoch 40/500, Loss: 0.1269, Accuracy: 0.9603

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Epoch 41/500, Loss: 0.1273, Accuracy: 0.9600
Epoch 42/500, Loss: 0.1257, Accuracy: 0.9608
Epoch 43/500, Loss: 0.1247, Accuracy: 0.9611
Epoch 44/500, Loss: 0.1251, Accuracy: 0.9602
Epoch 45/500, Loss: 0.1240, Accuracy: 0.9613
Epoch 46/500, Loss: 0.1244, Accuracy: 0.9617
Epoch 47/500, Loss: 0.1232, Accuracy: 0.9624
Epoch 48/500, Loss: 0.1234, Accuracy: 0.9621
Epoch 49/500, Loss: 0.1234, Accuracy: 0.9611
Epoch 50/500, Loss: 0.1222, Accuracy: 0.9624
Epoch 51/500, Loss: 0.1222, Accuracy: 0.9618
Epoch 52/500, Loss: 0.1226, Accuracy: 0.9608
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Epoch 54/500, Loss: 0.1214, Accuracy: 0.9621
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Epoch 56/500, Loss: 0.1209, Accuracy: 0.9624
Epoch 57/500, Loss: 0.1209, Accuracy: 0.9617
Epoch 58/500, Loss: 0.1205, Accuracy: 0.9616
Epoch 59/500, Loss: 0.1196, Accuracy: 0.9626
Epoch 60/500, Loss: 0.1205, Accuracy: 0.9621
Epoch 61/500, Loss: 0.1212, Accuracy: 0.9614
Epoch 62/500, Loss: 0.1190, Accuracy: 0.9623
Epoch 63/500, Loss: 0.1193, Accuracy: 0.9630
Epoch 64/500, Loss: 0.1193, Accuracy: 0.9628
Epoch 65/500, Loss: 0.1190, Accuracy: 0.9630
Epoch 66/500, Loss: 0.1189, Accuracy: 0.9628
Epoch 67/500, Loss: 0.1186, Accuracy: 0.9624
Epoch 68/500, Loss: 0.1190, Accuracy: 0.9625
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Epoch 73/500, Loss: 0.1189, Accuracy: 0.9630
Epoch 74/500, Loss: 0.1191, Accuracy: 0.9634
Epoch 75/500, Loss: 0.1185, Accuracy: 0.9641
Epoch 76/500, Loss: 0.1185, Accuracy: 0.9639
Epoch 77/500, Loss: 0.1188, Accuracy: 0.9629
Epoch 78/500, Loss: 0.1186, Accuracy: 0.9635
Epoch 79/500, Loss: 0.1187, Accuracy: 0.9643
Epoch 80/500, Loss: 0.1188, Accuracy: 0.9637
Epoch 81/500, Loss: 0.1191, Accuracy: 0.9641
Epoch 82/500, Loss: 0.1184, Accuracy: 0.9638
Epoch 83/500, Loss: 0.1192, Accuracy: 0.9638
Epoch 84/500, Loss: 0.1193, Accuracy: 0.9637
Epoch 85/500, Loss: 0.1184, Accuracy: 0.9642
Epoch 86/500, Loss: 0.1183, Accuracy: 0.9649
Epoch 87/500, Loss: 0.1186, Accuracy: 0.9645
Epoch 88/500, Loss: 0.1191, Accuracy: 0.9635

Epoch 89/500, Loss: 0.1182, Accuracy: 0.9641
Epoch 90/500, Loss: 0.1191, Accuracy: 0.9644
Epoch 91/500, Loss: 0.1185, Accuracy: 0.9646
Epoch 92/500, Loss: 0.1184, Accuracy: 0.9646
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Epoch 94/500, Loss: 0.1192, Accuracy: 0.9648
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Epoch 109/500, Loss: 0.1196, Accuracy: 0.9647
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Epoch 253/500, Loss: 0.1321, Accuracy: 0.9658
Epoch 254/500, Loss: 0.1322, Accuracy: 0.9662
Epoch 255/500, Loss: 0.1323, Accuracy: 0.9660
Epoch 256/500, Loss: 0.1323, Accuracy: 0.9660
Epoch 257/500, Loss: 0.1323, Accuracy: 0.9660
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Epoch 262/500, Loss: 0.1325, Accuracy: 0.9661
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Epoch 264/500, Loss: 0.1326, Accuracy: 0.9661
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Epoch 267/500, Loss: 0.1329, Accuracy: 0.9661
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Epoch 273/500, Loss: 0.1332, Accuracy: 0.9661
Epoch 274/500, Loss: 0.1333, Accuracy: 0.9662
Epoch 275/500, Loss: 0.1335, Accuracy: 0.9659
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Epoch 277/500, Loss: 0.1335, Accuracy: 0.9662
Epoch 278/500, Loss: 0.1335, Accuracy: 0.9661
Epoch 279/500, Loss: 0.1336, Accuracy: 0.9661
Epoch 280/500, Loss: 0.1336, Accuracy: 0.9660

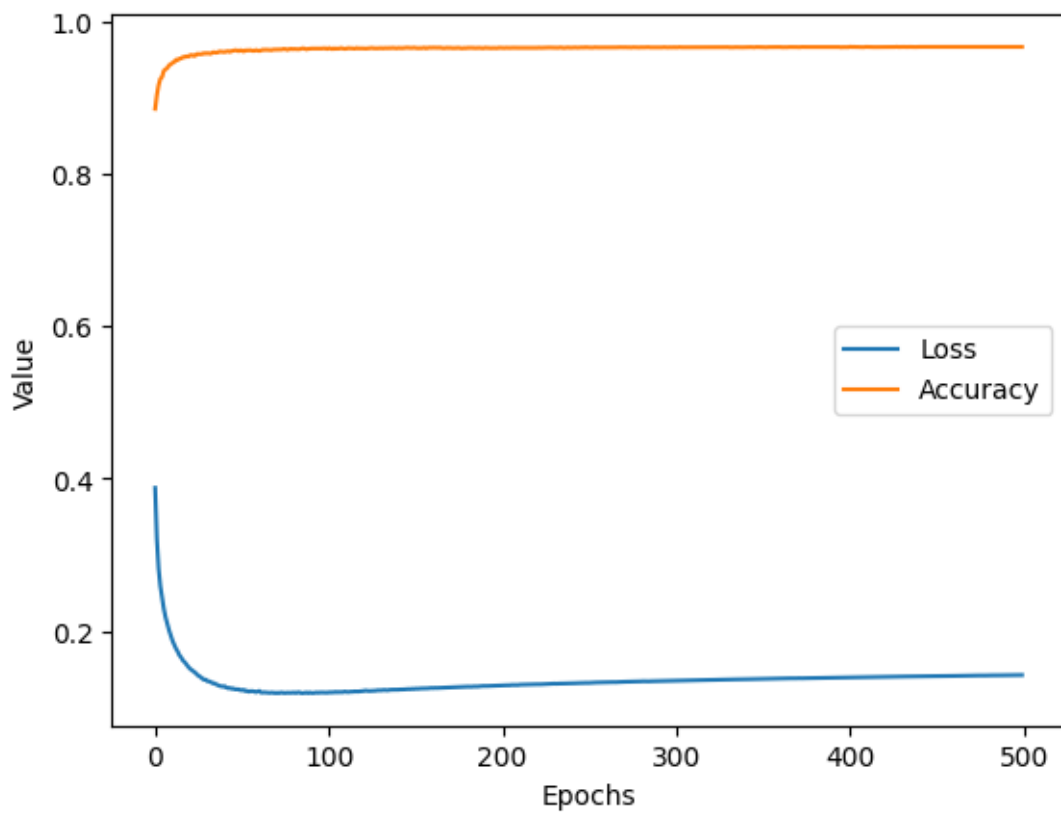
Epoch 281/500, Loss: 0.1337, Accuracy: 0.9663
Epoch 282/500, Loss: 0.1339, Accuracy: 0.9661
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Epoch 284/500, Loss: 0.1339, Accuracy: 0.9662
Epoch 285/500, Loss: 0.1337, Accuracy: 0.9664
Epoch 286/500, Loss: 0.1339, Accuracy: 0.9661
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Epoch 289/500, Loss: 0.1340, Accuracy: 0.9663
Epoch 290/500, Loss: 0.1342, Accuracy: 0.9662
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Epoch 292/500, Loss: 0.1342, Accuracy: 0.9663
Epoch 293/500, Loss: 0.1345, Accuracy: 0.9661
Epoch 294/500, Loss: 0.1342, Accuracy: 0.9664
Epoch 295/500, Loss: 0.1343, Accuracy: 0.9661
Epoch 296/500, Loss: 0.1345, Accuracy: 0.9660
Epoch 297/500, Loss: 0.1345, Accuracy: 0.9662
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Epoch 300/500, Loss: 0.1346, Accuracy: 0.9664
Epoch 301/500, Loss: 0.1348, Accuracy: 0.9660
Epoch 302/500, Loss: 0.1347, Accuracy: 0.9662
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Epoch 304/500, Loss: 0.1348, Accuracy: 0.9662
Epoch 305/500, Loss: 0.1348, Accuracy: 0.9662
Epoch 306/500, Loss: 0.1350, Accuracy: 0.9663
Epoch 307/500, Loss: 0.1350, Accuracy: 0.9662
Epoch 308/500, Loss: 0.1351, Accuracy: 0.9664
Epoch 309/500, Loss: 0.1350, Accuracy: 0.9664
Epoch 310/500, Loss: 0.1351, Accuracy: 0.9663
Epoch 311/500, Loss: 0.1353, Accuracy: 0.9663
Epoch 312/500, Loss: 0.1353, Accuracy: 0.9664
Epoch 313/500, Loss: 0.1353, Accuracy: 0.9663
Epoch 314/500, Loss: 0.1353, Accuracy: 0.9662
Epoch 315/500, Loss: 0.1354, Accuracy: 0.9661
Epoch 316/500, Loss: 0.1354, Accuracy: 0.9664
Epoch 317/500, Loss: 0.1355, Accuracy: 0.9662
Epoch 318/500, Loss: 0.1355, Accuracy: 0.9662
Epoch 319/500, Loss: 0.1356, Accuracy: 0.9663
Epoch 320/500, Loss: 0.1356, Accuracy: 0.9662
Epoch 321/500, Loss: 0.1356, Accuracy: 0.9664
Epoch 322/500, Loss: 0.1357, Accuracy: 0.9664
Epoch 323/500, Loss: 0.1357, Accuracy: 0.9663
Epoch 324/500, Loss: 0.1358, Accuracy: 0.9663
Epoch 325/500, Loss: 0.1358, Accuracy: 0.9662
Epoch 326/500, Loss: 0.1359, Accuracy: 0.9662
Epoch 327/500, Loss: 0.1360, Accuracy: 0.9663
Epoch 328/500, Loss: 0.1359, Accuracy: 0.9664

Epoch 329/500, Loss: 0.1360, Accuracy: 0.9663
Epoch 330/500, Loss: 0.1361, Accuracy: 0.9664
Epoch 331/500, Loss: 0.1361, Accuracy: 0.9665
Epoch 332/500, Loss: 0.1362, Accuracy: 0.9660
Epoch 333/500, Loss: 0.1362, Accuracy: 0.9663
Epoch 334/500, Loss: 0.1363, Accuracy: 0.9661
Epoch 335/500, Loss: 0.1363, Accuracy: 0.9664
Epoch 336/500, Loss: 0.1364, Accuracy: 0.9663
Epoch 337/500, Loss: 0.1363, Accuracy: 0.9664
Epoch 338/500, Loss: 0.1365, Accuracy: 0.9661
Epoch 339/500, Loss: 0.1364, Accuracy: 0.9662
Epoch 340/500, Loss: 0.1365, Accuracy: 0.9663
Epoch 341/500, Loss: 0.1365, Accuracy: 0.9664
Epoch 342/500, Loss: 0.1366, Accuracy: 0.9663
Epoch 343/500, Loss: 0.1366, Accuracy: 0.9664
Epoch 344/500, Loss: 0.1367, Accuracy: 0.9665
Epoch 345/500, Loss: 0.1367, Accuracy: 0.9664
Epoch 346/500, Loss: 0.1367, Accuracy: 0.9662
Epoch 347/500, Loss: 0.1368, Accuracy: 0.9666
Epoch 348/500, Loss: 0.1367, Accuracy: 0.9666
Epoch 349/500, Loss: 0.1369, Accuracy: 0.9665
Epoch 350/500, Loss: 0.1370, Accuracy: 0.9664
Epoch 351/500, Loss: 0.1370, Accuracy: 0.9664
Epoch 352/500, Loss: 0.1370, Accuracy: 0.9663
Epoch 353/500, Loss: 0.1371, Accuracy: 0.9662
Epoch 354/500, Loss: 0.1372, Accuracy: 0.9665
Epoch 355/500, Loss: 0.1371, Accuracy: 0.9664
Epoch 356/500, Loss: 0.1371, Accuracy: 0.9665
Epoch 357/500, Loss: 0.1373, Accuracy: 0.9665
Epoch 358/500, Loss: 0.1373, Accuracy: 0.9664
Epoch 359/500, Loss: 0.1374, Accuracy: 0.9664
Epoch 360/500, Loss: 0.1373, Accuracy: 0.9665
Epoch 361/500, Loss: 0.1374, Accuracy: 0.9666
Epoch 362/500, Loss: 0.1374, Accuracy: 0.9662
Epoch 363/500, Loss: 0.1374, Accuracy: 0.9664
Epoch 364/500, Loss: 0.1377, Accuracy: 0.9663
Epoch 365/500, Loss: 0.1376, Accuracy: 0.9663
Epoch 366/500, Loss: 0.1376, Accuracy: 0.9666
Epoch 367/500, Loss: 0.1377, Accuracy: 0.9666
Epoch 368/500, Loss: 0.1377, Accuracy: 0.9664
Epoch 369/500, Loss: 0.1377, Accuracy: 0.9664
Epoch 370/500, Loss: 0.1377, Accuracy: 0.9664
Epoch 371/500, Loss: 0.1379, Accuracy: 0.9665
Epoch 372/500, Loss: 0.1379, Accuracy: 0.9663
Epoch 373/500, Loss: 0.1378, Accuracy: 0.9667
Epoch 374/500, Loss: 0.1379, Accuracy: 0.9666
Epoch 375/500, Loss: 0.1379, Accuracy: 0.9667
Epoch 376/500, Loss: 0.1379, Accuracy: 0.9666

Epoch 377/500, Loss: 0.1381, Accuracy: 0.9666
Epoch 378/500, Loss: 0.1381, Accuracy: 0.9666
Epoch 379/500, Loss: 0.1382, Accuracy: 0.9665
Epoch 380/500, Loss: 0.1381, Accuracy: 0.9667
Epoch 381/500, Loss: 0.1382, Accuracy: 0.9664
Epoch 382/500, Loss: 0.1382, Accuracy: 0.9668
Epoch 383/500, Loss: 0.1383, Accuracy: 0.9664
Epoch 384/500, Loss: 0.1383, Accuracy: 0.9667
Epoch 385/500, Loss: 0.1384, Accuracy: 0.9664
Epoch 386/500, Loss: 0.1384, Accuracy: 0.9666
Epoch 387/500, Loss: 0.1385, Accuracy: 0.9665
Epoch 388/500, Loss: 0.1386, Accuracy: 0.9667
Epoch 389/500, Loss: 0.1386, Accuracy: 0.9666
Epoch 390/500, Loss: 0.1385, Accuracy: 0.9666
Epoch 391/500, Loss: 0.1386, Accuracy: 0.9665
Epoch 392/500, Loss: 0.1386, Accuracy: 0.9666
Epoch 393/500, Loss: 0.1386, Accuracy: 0.9666
Epoch 394/500, Loss: 0.1388, Accuracy: 0.9665
Epoch 395/500, Loss: 0.1388, Accuracy: 0.9666
Epoch 396/500, Loss: 0.1389, Accuracy: 0.9662
Epoch 397/500, Loss: 0.1388, Accuracy: 0.9665
Epoch 398/500, Loss: 0.1388, Accuracy: 0.9665
Epoch 399/500, Loss: 0.1388, Accuracy: 0.9666
Epoch 400/500, Loss: 0.1389, Accuracy: 0.9664
Epoch 401/500, Loss: 0.1389, Accuracy: 0.9670
Epoch 402/500, Loss: 0.1390, Accuracy: 0.9666
Epoch 403/500, Loss: 0.1390, Accuracy: 0.9669
Epoch 404/500, Loss: 0.1390, Accuracy: 0.9666
Epoch 405/500, Loss: 0.1391, Accuracy: 0.9667
Epoch 406/500, Loss: 0.1390, Accuracy: 0.9665
Epoch 407/500, Loss: 0.1392, Accuracy: 0.9665
Epoch 408/500, Loss: 0.1392, Accuracy: 0.9665
Epoch 409/500, Loss: 0.1393, Accuracy: 0.9664
Epoch 410/500, Loss: 0.1391, Accuracy: 0.9668
Epoch 411/500, Loss: 0.1393, Accuracy: 0.9667
Epoch 412/500, Loss: 0.1394, Accuracy: 0.9668
Epoch 413/500, Loss: 0.1394, Accuracy: 0.9667
Epoch 414/500, Loss: 0.1394, Accuracy: 0.9666
Epoch 415/500, Loss: 0.1394, Accuracy: 0.9665
Epoch 416/500, Loss: 0.1395, Accuracy: 0.9665
Epoch 417/500, Loss: 0.1395, Accuracy: 0.9664
Epoch 418/500, Loss: 0.1394, Accuracy: 0.9665
Epoch 419/500, Loss: 0.1396, Accuracy: 0.9666
Epoch 420/500, Loss: 0.1397, Accuracy: 0.9664
Epoch 421/500, Loss: 0.1396, Accuracy: 0.9667
Epoch 422/500, Loss: 0.1397, Accuracy: 0.9666
Epoch 423/500, Loss: 0.1398, Accuracy: 0.9666
Epoch 424/500, Loss: 0.1399, Accuracy: 0.9664

Epoch 425/500, Loss: 0.1398, Accuracy: 0.9666
Epoch 426/500, Loss: 0.1398, Accuracy: 0.9666
Epoch 427/500, Loss: 0.1399, Accuracy: 0.9667
Epoch 428/500, Loss: 0.1398, Accuracy: 0.9669
Epoch 429/500, Loss: 0.1399, Accuracy: 0.9666
Epoch 430/500, Loss: 0.1400, Accuracy: 0.9667
Epoch 431/500, Loss: 0.1400, Accuracy: 0.9668
Epoch 432/500, Loss: 0.1399, Accuracy: 0.9668
Epoch 433/500, Loss: 0.1401, Accuracy: 0.9667
Epoch 434/500, Loss: 0.1401, Accuracy: 0.9666
Epoch 435/500, Loss: 0.1402, Accuracy: 0.9668
Epoch 436/500, Loss: 0.1401, Accuracy: 0.9667
Epoch 437/500, Loss: 0.1402, Accuracy: 0.9667
Epoch 438/500, Loss: 0.1403, Accuracy: 0.9667
Epoch 439/500, Loss: 0.1402, Accuracy: 0.9666
Epoch 440/500, Loss: 0.1402, Accuracy: 0.9668
Epoch 441/500, Loss: 0.1403, Accuracy: 0.9668
Epoch 442/500, Loss: 0.1403, Accuracy: 0.9668
Epoch 443/500, Loss: 0.1404, Accuracy: 0.9667
Epoch 444/500, Loss: 0.1404, Accuracy: 0.9668
Epoch 445/500, Loss: 0.1405, Accuracy: 0.9667
Epoch 446/500, Loss: 0.1406, Accuracy: 0.9667
Epoch 447/500, Loss: 0.1406, Accuracy: 0.9667
Epoch 448/500, Loss: 0.1406, Accuracy: 0.9668
Epoch 449/500, Loss: 0.1406, Accuracy: 0.9667
Epoch 450/500, Loss: 0.1407, Accuracy: 0.9667
Epoch 451/500, Loss: 0.1406, Accuracy: 0.9668
Epoch 452/500, Loss: 0.1408, Accuracy: 0.9667
Epoch 453/500, Loss: 0.1407, Accuracy: 0.9667
Epoch 454/500, Loss: 0.1407, Accuracy: 0.9667
Epoch 455/500, Loss: 0.1408, Accuracy: 0.9666
Epoch 456/500, Loss: 0.1408, Accuracy: 0.9667
Epoch 457/500, Loss: 0.1408, Accuracy: 0.9668
Epoch 458/500, Loss: 0.1408, Accuracy: 0.9667
Epoch 459/500, Loss: 0.1409, Accuracy: 0.9666
Epoch 460/500, Loss: 0.1409, Accuracy: 0.9667
Epoch 461/500, Loss: 0.1409, Accuracy: 0.9668
Epoch 462/500, Loss: 0.1410, Accuracy: 0.9667
Epoch 463/500, Loss: 0.1410, Accuracy: 0.9667
Epoch 464/500, Loss: 0.1411, Accuracy: 0.9667
Epoch 465/500, Loss: 0.1411, Accuracy: 0.9668
Epoch 466/500, Loss: 0.1411, Accuracy: 0.9667
Epoch 467/500, Loss: 0.1411, Accuracy: 0.9667
Epoch 468/500, Loss: 0.1411, Accuracy: 0.9667
Epoch 469/500, Loss: 0.1413, Accuracy: 0.9668
Epoch 470/500, Loss: 0.1413, Accuracy: 0.9666
Epoch 471/500, Loss: 0.1413, Accuracy: 0.9667
Epoch 472/500, Loss: 0.1413, Accuracy: 0.9666

Epoch 473/500, Loss: 0.1413, Accuracy: 0.9668
Epoch 474/500, Loss: 0.1414, Accuracy: 0.9667
Epoch 475/500, Loss: 0.1414, Accuracy: 0.9666
Epoch 476/500, Loss: 0.1415, Accuracy: 0.9667
Epoch 477/500, Loss: 0.1414, Accuracy: 0.9668
Epoch 478/500, Loss: 0.1414, Accuracy: 0.9666
Epoch 479/500, Loss: 0.1415, Accuracy: 0.9668
Epoch 480/500, Loss: 0.1416, Accuracy: 0.9667
Epoch 481/500, Loss: 0.1416, Accuracy: 0.9666
Epoch 482/500, Loss: 0.1416, Accuracy: 0.9667
Epoch 483/500, Loss: 0.1417, Accuracy: 0.9667
Epoch 484/500, Loss: 0.1416, Accuracy: 0.9668
Epoch 485/500, Loss: 0.1418, Accuracy: 0.9666
Epoch 486/500, Loss: 0.1417, Accuracy: 0.9667
Epoch 487/500, Loss: 0.1417, Accuracy: 0.9668
Epoch 488/500, Loss: 0.1418, Accuracy: 0.9667
Epoch 489/500, Loss: 0.1418, Accuracy: 0.9668
Epoch 490/500, Loss: 0.1418, Accuracy: 0.9667
Epoch 491/500, Loss: 0.1418, Accuracy: 0.9667
Epoch 492/500, Loss: 0.1419, Accuracy: 0.9666
Epoch 493/500, Loss: 0.1419, Accuracy: 0.9668
Epoch 494/500, Loss: 0.1420, Accuracy: 0.9666
Epoch 495/500, Loss: 0.1420, Accuracy: 0.9667
Epoch 496/500, Loss: 0.1420, Accuracy: 0.9667
Epoch 497/500, Loss: 0.1420, Accuracy: 0.9667
Epoch 498/500, Loss: 0.1421, Accuracy: 0.9668
Epoch 499/500, Loss: 0.1421, Accuracy: 0.9667
Epoch 500/500, Loss: 0.1421, Accuracy: 0.9668



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